# *THE SPATIAL DIMENSION OF URBAN METABOLISM*

*Resource flows, public space, and vulnerable communities.*

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*Resource flows, public space, and vulnerable communities.*

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# *Abstract*

Urban metabolism (UM) studies offer critical insights for enhancing resource efficiency in cities. Over recent years, these studies have adopted an interdisciplinary and multiscale perspective, with a growing focus on the socioeconomic contexts, power dynamics among stakeholders, and the ecological connectivity of urban areas. Localizing and quantifying urban flows and stocks are particularly valuable for identifying infrastructure deficiencies and disparities in resource accessibility, especially among vulnerable communities. However, only a limited number of such studies include spatially explicit data to inform design practitioners effectively. This research examines the spatial dimension of UM as applied to urban planning and design across diverse social and geographical contexts and at varying scales of resource infrastructure. In particular, by applying spatially explicit UM analysis as a diagnostic tool, including geographic and socio-ecological inputs, to understand how can public space design contribute to the resource efficiency and community involvement in urban environments. To this end, the study comprises three research projects, each employing distinct methodologies, case studies, and intervention scales: (*i*) mapping of resource efficiency hotspots at the city scale, (*ii*) illustrating and analyzing socio-ecological dynamics at the community scale, and (*iii*) developing a spatially explicit catalogue of resource-sensitive urban archetypes and design tools. These projects are supported by an extensive literature review, collection of primary spatial data, analysis of existing datasets, field visits, and interviews with main stakeholders. The findings highlight the potential to integrate resource use management across multiple scales, from localized urban systems to broader regional networks. This research advances a combined top-down and bottom-up analytical approach, merging conceptual frameworks with practical tools to enhance the applicability of UM studies for design practitioners. This dual perspective aims to bridge the gap between theoretical insights and the pragmatic demands of urban planning and design.

# *Résumé*

Les études sur le métabolisme urbain (MU) offrent des perspectives essentielles pour améliorer l'efficacité des ressources dans les villes. Ces dernières années, ces recherches ont adopté une approche interdisciplinaire et multi-échelle, mettant de plus en plus l'accent sur les contextes socio-économiques, les dynamiques de pouvoir entre les parties prenantes et la connectivité écologique des espaces urbains. La localisation et la quantification des flux et stocks urbains sont particulièrement précieuses pour identifier les carences infrastructurelles et les disparités en matière d'accès aux ressources, notamment au sein des communautés vulnérables. Toutefois, un nombre limité de ces études intègre des données spatialement explicites permettant d'orienter efficacement les professionnels de la conception urbaine. Cette recherche explore la dimension spatiale du MU appliquée à la planification et à la conception urbaines, en tenant compte de divers contextes sociaux et géographiques ainsi que des différentes échelles d'infrastructure des ressources. Plus spécifiquement, elle mobilise une analyse spatialement explicite du MU comme outil diagnostique, intégrant des données géographiques et socio-écologiques, afin d'examiner comment la conception de l'espace public peut contribuer à l'efficacité des ressources et à l'implication des communautés dans les environnements urbains. Pour ce faire, l'étude s'appuie sur trois projets de recherche, chacun adoptant des méthodologies, des études de cas et des échelles d'intervention distinctes: (*i*) cartographie des *hotspots* d'efficacité des ressources à l'échelle de la ville, (*ii*) illustration et analyse des dynamiques socio-écologiques à l'échelle communautaire, et (*iii*) élaboration d'un catalogue spatialement explicite d'archétypes urbains et d'outils de conception sensibles aux ressources. Ces projets reposent sur une revue de littérature approfondie, la collecte de données spatiales primaires, l'analyse de bases de données existantes, des visites de terrain et des entretiens avec les principaux acteurs concernés. Les résultats soulignent le potentiel d'une intégration de la gestion des ressources à différentes échelles, allant des systèmes urbains locaux aux réseaux régionaux plus vastes. Cette recherche propose une approche analytique combinant les approches *top-down* et *bottom-up*, fusionnant les cadres conceptuels et les outils pratiques afin d'améliorer l'applicabilité des études MU pour les praticiens de la conception. Cette double approche vise à réduire l'écart entre les analyses théoriques et les exigences pragmatiques de la planification et de la conception urbaines.

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# *Preface*

*Figure 0.1: People gathered to collect water released through a sewage drain that feeds into the Guaire River in Caracas, which carries most of the city's wastewater. Photo: REUTERS/ García Rawlins. (2019, March 13). https://www.reuters.com/news/picture/desperate-venezuelans-search-for-water-idUSRTX6R0LV/.*

In 2019, Venezuela experienced a nationwide electrical blackout that lasted approximately two weeks, primarily attributed to failures in the hydroelectric system. These failures stemmed from a combination of inadequate maintenance practices, administrative negligence, and the effects of a prolonged dry season. During this period, most urban areas suffered disruptions in essential services, including the drinking water pumping and distribution systems. In Caracas, inhabitants of the *San Agustin del Sur* informal settlements faced acute water scarcity, compelling them to gather water from natural streams that ultimately flowed into the *Guaire River*, the main watercourse traversing the city, which also serves as the collector of non-industrial wastewater disposal (see *Figure 0.1*). This crisis underscored the fragility and precariousness of access to essential resources for a significant portion of the population, who contend with deficiencies in basic services and substandard living conditions. Simultaneously, however, it exposed an unexpected potential within the urban landscape. This event brought to light the leveraging of existing urban spaces that are commonly neglected or underused, such as the river basin infrastructures and their access slopes, alongside favorable climatic conditions and rich spontaneous tropical vegetation, to temporarily transform these areas into resource management public open spaces for the local community. This adaptability within constrained urban settings invites broader considerations relevant not only to Latin American cities but also to several European urban centers that encounter similar challenges in resource infrastructure and spatial dynamics. Consequently, this PhD research explores critical questions about the complex relationships between resource flows, public space, and vulnerable communities within urbanized environments from an urban planning and design perspective.

*Fog, nature, and power lines in Caracas, Venezuela. Photo by author, 2016.*

## *1 Introduction*

*Motivation and relevance, research questions and objectives, structure and methods.*

# *1 Introduction*

## *1.1 Motivation and relevance*

As noted in the preface, the recent blackout in Venezuela exposed critical deficiencies in urban infrastructure. Triggered by failures in the hydroelectric system, the crisis severely affected essential services across the country. In Caracas, informal settlements experienced acute water shortages, forcing residents to collect water from hillside streams that flowed into the polluted main watercourse. Beyond highlighting the fragility of basic infrastructure, this event revealed the latent potential of neglected or underdeveloped urban spaces, such as hillsides, riverbanks, and patches of natural vegetation, which were temporarily repurposed by communities as gathering points for water collection. These improvised responses invite reflection on the intersections between decentralized management of resource flows, public space, and vulnerable communities' resilience within the context of urban planning and design. In this context, this PhD research examines the spatial dimension of urban metabolism (UM) as applied to urban planning and design across diverse social and geographical contexts and at varying scales of resource infrastructure. In particular, it investigates how can public space design, informed by spatially explicit UM assessments, including geographic and socio-ecological data, enhance the resource efficiency and community involvement in urban environments.

There is growing evidence that urban environments, with their high resource consumption and waste generation rates, face increased vulnerability to future resource scarcity resulting from the combined pressures of climate change and global population growth (Dodman et al., 2023; Grimm et al., 2008; Parish et al., 2012). Currently, more than 50% of the world's population lives in urban regions. This figure is projected to rise to 70% by 2050, which will intensify the strain on critical systems due to even higher demand for energy, water, and material resources and increased waste generation (Agudelo-Vera et al., 2012; Currie & Musango, 2017). As a result of uncontrolled urban sprawl and migration movements driven by climate change, many cities will struggle to keep pace with rapid urbanization, leading to severe deficits in housing, resource infrastructure, public space, and preservation of green spaces and ecosystems for expanding populations (UN DESA, 2024). Moreover, without adequate governance and planning mechanisms, this trend may further accelerate the growth of informal settlements and neighborhoods with poor sanitary conditions in both the Global South and the Global North.

It is estimated that over one-fifth of the global population lives in informal settlements, while nearly half of the world's population lives in poverty (UN HABITAT, 2019, 2022). In Latin America, nearly a third of the population lives in poverty, with cities such as Mexico City and Caracas experiencing poverty rates approaching half of their populations (ECLAC, 2023). In Europe, approximately one fifth of the population is estimated to be at risk of poverty, defined as having a monthly income insufficient to cover basic needs, with cities such as Brussels exhibiting poverty rates of one-third of the population (EUROSTAT, 2023). Urban planning and design, shaped by geographic conditions, construction practices and material use, can significantly influence the resource efficiency of a more sustainable urban fabric (Davoudi & Sturzaker, 2017; Kennedy et al., 2011; Pincetl et al., 2016). Unplanned urban expansion, in both the Global South and Global North, will present complex scenarios where vulnerable communities may intersect with emerging resource infrastructure needs, alongside the imperative to preserve existing open spaces (Pauchard & Barbosa, 2013). These conditions present new opportunities for urban planning and design to intervene by developing public space that integrates resource infrastructure that provide the dual benefits of meeting essential needs in resource generation, storage, and distribution while promoting community involvement within vulnerable communities.

Urban metabolism (UM) has become a key interdisciplinary and multiscale approach for analyzing resource flows and socio-ecological dynamics in urban systems (Broto et al., 2012; Pincetl et al., 2012; Wang et al., 2021). Drawing from fields such as industrial ecology, urban ecology, and political ecology, UM encompasses the technical and socio-economic processes associated with resource production, distribution, and consumption in cities (Kennedy et al., 2007; Newell & Cousins, 2015). UM research offers valuable insights to create more resource-efficient cities by using holistic urban assessment models, which help understand the impact of human activities on the environment (Perrotti, 2020). Recent studies highlight UM's potential to inform strategies that reduce resource consumption, optimize resource flows, and enhance urban sustainability through solutions like rainwater harvesting and urban waste valorization into renewable energy, which can significantly improve self-sufficiency and reduce carbon emissions. (Chaker et al., 2021; Cui, 2018; Islam, 2017; Marteleira et al., 2014). Such strategies could potentially address critical urban challenges associated with climate change, population growth, and scarce resource availability. However, challenges remain in transferring these scientific findings to urban planners, designers, and policymakers due to the complexity of methodologies, data limitations, and theoretical frameworks (Perrotti, 2019). Despite its theoretical advancements, the practical application of UM in urban planning and design is still limited. The use of UM frameworks in urban planning and design offers valuable tools for decision-makers to understand and evaluate socio-technical processes related to resource collection and management in cities (Kennedy et al., 2011; Perrotti & Stremke, 2018). By providing methodologies to analyze the scale and dynamics of resource flows, a metabolic perspective supports more resource-efficient urban planning and design, the development of effective waste minimization strategies, and the identification of deficiencies in existing infrastructure (Dijst et al., 2018; Zhang et al., 2015). This approach also enables the recognition of opportunities within urban spaces to address resource-related vulnerabilities and enhance local resource harvesting through spatial design strategies (Agudelo-Vera et al., 2012; Leduc & Van Kann, 2013; Wielemaker et al., 2020), ultimately promoting sustainable and resilient urban environments.

There is increasing emphasis on the integration of spatially explicit UM, i.e., geo-referenced analyses of resource flows and stocks, into urban planning and design, as a means to enhance resource efficiency and provide deeper insights into the human impact on natural systems (Dijst et al., 2018; John et al., 2019). In their bibliometric study on the spatial dimension of UM, Bahers et al. (2022) identified five research themes linked to key systemic challenges, including power relations between stakeholders, organizational economics of supply chains, society-nature interactions, infrastructure governance and planning, and spatially explicit modeling approaches. The analysis points to a potential spatial turn in UM research and underscores the value of cross-thematic approaches, advocating for a new research agenda to explore hybrid concepts and emerging trends further as a means to improve decision-making processes in urban planning and design. The spatial dimension of UM in this research refers to considering urban public space (e.g. streets, squares, gardens, parks, nature reserves, riverbanks) as an asset to minimize resource consumption and waste generation through urban planning and design strategies while preserving and enhancing existing socio-ecological activities and practices (i.e., organized and sustained interactions between the community involved and publicly available spaces). For example, these strategies may involve incorporating nature-based solutions into utility infrastructure to increase urban green spaces, fostering synergies among various urban functions to enhance mutual benefits for resource recycling, and decentralizing resource management to contribute to the expansion and resilience of the resource supply system, among other strategies considering the spatial dimension of UM.

Furthermore, many studies lack geographic information systems (GIS)-based data integration, which is relevant for practical application by practitioners in urban planning and design (Geremicca & Bilec, 2024; Li & Kwan, 2018). Recent spatially explicit UM research has illustrated spatiotemporal dynamics of materials and resource flows and infrastructure at multiple scales, power dynamics between stakeholder relations, and integrated the spatial dimension of environmental and socio economic datasets (Camacho-Caballero et al., 2024; Caputo et al., 2019; Currie et al., 2017; Doussard et al., 2024; Guibrunet et al., 2017; Juwet & Ryckewaert, 2018; Lanau & Liu, 2020; Marin & De Meulder, 2021; Soto et al., 2024; Tsui et al., 2022; Yeow & Cheah, 2019).

Some of these studies have focused directly on urban planning and design applications. For instance, Soto et al. (2024),  mapped four urban systems in Glasgow, Scotland (building and property assets, socio-productive networks, energy and mobility, and natural and ecological systems), alongside policies, plans, and projects impacting these systems, arguing that this integrated mapping could support policymakers in creating cohesive and efficient urban policies that bridge economic and spatial planning, fostering inclusivity, collaboration, and active stakeholder engagement. Taking another approach with direct involvement of urban designers and architects, Doussard et al. (2024) analyzed the resource flow impact of the *Champs-Élysées* renovation project in Paris. Their study revealed that while projects of this scale can yield perceivable impacts, those with higher metabolic activity and typical design typologies, such as service infrastructure and public space, require further attention to evaluate and replicate outcomes effectively. These studies underscore the need for continued research to develop accessible design tools that address resource-related vulnerabilities and advance sustainable urban planning.

Since the 1990s, the theory and practice of landscape integration as a means of urban intervention has been widely examined by scholars and practitioners in landscape architecture and urban planning and design (Waldheim, 2006, 2016). Rooted in this theoretical foundation, this *landscape urbanism* approach, urban systems are seen as ecological processes shaped by time and space, with landscapes redefined as functional resource infrastructures that emphasize process over form, promoting innovative and multi-scale perspectives that incorporate time, space, imagination, and cartographic experimentation, reshaping traditional methods and representations for a more dynamic urban understanding of open spaces (Corner, 2006). While projects and academic studies have largely investigated the complexities of large-scale resource infrastructure systems primarily in the Global North, the integration of green open spaces has also proven valuable in managing resources and mitigating climate change impacts in informal settlements in the Global South, where vulnerabilities to resource scarcity and environmental risks are heightened (Vera & Sordi, 2020; Waldheim, 2016).

In 2014, landscape architect and theorist James Corner (*Field Operations*) and urban design practice *FABRICations*, conducted one of the first urban planning and design projects integrating a UM framework during the *International Architecture Biennale Rotterdam* (Tillie et al., 2014). Engaging key stakeholders in workshops, they mapped nine critical flows within the Rhine catchment and Rotterdam region and proposed four circular design strategies: reclaiming raw materials from waste and food, creating biotopes to enhance urban environmental quality, using by-products from the energy sector, and encouraging re-industrialization within the port area. This practitioner-based initiative not only provided a tangible example of the applicability of UM concepts but also inspired similar multidisciplinary studies across Europe and Asia (Brugmans et al., 2015; FABRICations, 2024). Many of these studies successfully assessed and mapped resource flows and infrastructure at regional and territorial scales, highlighting the scalability and versatility of UM frameworks in diverse geographic contexts. However, many of these studies faced challenges in translating their findings into context-specific urban planning and design strategies, as their feasibility was often constrained by the diversity of stakeholder interests and the complexity of specific local geographies.

Based on the foregoing, this PhD research aims to investigate the spatial dimension of UM as applied to urban planning and design across various socio-economic and geographical contexts. The study explores the integration of UM at multiple scales of resource infrastructure, from localized urban systems to broader regional networks, focusing on three key resource flows: water, energy, and solid waste. These resources are not only essential for the functioning and development of urban areas but are also interdependent, forming a critical resource nexus central to UM approaches for addressing resource scarcity (Bristow & Kennedy, 2013; Chen & Chen, 2015; Derrible et al., 2021; Fan et al., 2019). Specifically, it seeks to develop a combined top-down and bottom-up analytical approach that bridges conceptual frameworks with practical tools to enhance the applicability of UM by design practitioners, i.e., urban planners and designers, architects, researchers and activists, among others. This dual perspective will address gaps between theoretical insights and practical needs in urban planning and design.

In the following sections, the research first outlines its guiding framework by presenting research questions and objectives derived from the identified research gaps and opportunities to contribute to and expand the scientific literature. Next, the structure and methods of the research are detailed, emphasizing its interdisciplinary and multi-scale approach. Subsequent chapters elaborate on the main concepts central to the research, providing a comprehensive review of theoretical underpinnings and their relevance to practical applications. In each chapter also findings are discussed by focusing on the implications of the spatial dimension of UM across different scales and contexts. Finally, the concluding chapter synthesizes the key insights and implications of the research for future studies and practical applications.

### *1.2 Research questions and objectives*

Although each urban metabolism (UM) study is unique in its scope and ambition, the spatialization of resource flows and their infrastructures to inform urban planning and design remains limited. The lack of a robust spatially explicit UM literature, including mapping representations, quantitative and qualitative analyses of spatially explicit fine-grained data, and resource-sensitive public space design, presents a gap that this research seeks to address. Based on this premise, the main research question, sub-questions, and corresponding objectives are presented below, along with references to the manuscript chapters in which they are addressed.

Main research question addressed in all *Chapters*:

***RQ:*** *How can public space design, informed by spatially explicit UM assessments including geographic and socio-ecological data, enhance resource efficiency and community involvement in urban environments?*

*Main objectives*
. Integrate UM frameworks into different phases of urban planning and design to develop strategies that enhance the efficiency of urban resource flows while addressing the needs of vulnerable communities.
. Combine geographical information system (GIS) mapping, 3D modeling techniques, and qualitative and quantitative socio-ecological data inputs to provide a combined top-down and bottom-up analytical approach to improve UM application by design practitioners.
. Develop practical design tools and methodological frameworks that can be adapted to various geographic and socio-economic contexts, supporting design practitioners in improving resource efficiency and community involvement.
. Implement and validate the methodological frameworks through case studies conducted in both the Global South and Global North, exploring applications at multiple scales of urban systems and resource infrastructure.

Resource efficiency: GIS-based data, mapping representation, and open space networks.
Research sub-question addressed in *Chapter 3*:

***RSQ1:*** *To what extent GIS-explicit data can improve the applicability of UM studies in the planning and management of open space networks?*

*Sub-question objectives*
. Perform a spatially explicit UM assessment of Mexico City, Mexico, considering socio-ecologic datasets (open space networks and vulnerable communities).
. Identify and classify available types of spatially explicit datasets that could enhance UM assessment and inform urban planning and design.
. Develop a methodological approach for identifying and mapping hotspots at the city scale based on resource efficiency, open space networks, and vulnerable communities' characteristics.
. Formulate planning and design strategies for the effective management of open space networks to increase resource ef
ficiency in cities.

Community involvement: alternative resource governance systems and fine-grained data.
Research sub-questions addressed in *Chapter 4*:

***RSQ2:*** *Which spatially explicit socio-ecological activities and practices within alternative resource governance systems (ARGS) can be identified as drivers to enhance the applicability of resource-sensitive and community led urban design strategies?*

***RSQ3:*** *What kind of finer-grain spatially explicit data could be collected to enhance a context- and community-specific UM analysis?*

*Sub-question objectives*
. Perform a spatially explicit UM assessment of Brussels, Belgium, considering socio-ecologic datasets (open space networks and vulnerable communities) and ARGS.
. Collect and analyze finer-grain spatially explicit data from ARGS, focusing on identifying and classifying their main characteristics.
. Develop a methodological framework for identifying and spatializing socio-ecological practices and activities at the local scale that enhance sense of belonging, participation, inclusion, and legitimacy within a community.
. Assess the impact of ARGS on increasing publicly accessible spaces and improving resource management at various scales.
Urban Archetypes: Methods and tools to enhance UM applicability by design practitioners.
Research sub-question addressed in *Chapter 5*:

***RSQ4:*** *How can design strategies for publicly accessible urban spaces be developed taking into consideration the most common spatial characteristics of ARGS in both the Global South and North? ?*

*Sub-question objectives*
. Identify and classify an inventory of alternative resource governance systems from diverse regions across the Global South and Global North.
. Propose resource-sensitive and community-inclusive urban archetypes that synthetize the spatial and functional characteristics of ARGS, ensuring adaptability to various geographic and socio-economic contexts.
. Test the proposed urban archetypes through a case study in Caracas, Venezuela, evaluating their effectiveness in resource management and spatial adaptability within a vulnerable community.
. Develop practical design tools and methodologies grounded in UM principles to enhance their applicability and utility for design practitioners.
. Contribute to the practical application of UM in urban design.

### *1.3 Structure and methods*

This research is structured into six chapters, as depicted in the methodological conceptual diagram (Figure 1.1). *Chapter 1* introduces the research topic, identifies the knowledge gaps, formulates the research questions and objectives, and outlines the framework and structure of the dissertation. *Chapter 2* covers the cross-sectional and non-linear phase of the research, where the theoretical foundation is established through a literature review of fundamental concepts informing both the main research question and its sub-questions. The literature review began with a systematic analysis of the main subjects addressed in the main research question, followed by a narrative literature review tailored to each research sub-question, as detailed in the respective sections. These concepts underpin the subsequent chapters, which focus on the spatial dimension of urban metabolism (UM) to enhance the practical application of UM frameworks by design practitioners. This chapter builds on the knowledge gaps in the existing literature and emphasizes the relevance of the research regarding spatializing resource efficiency patterns through mapping, capturing and modeling fine-grained spatial data, assessing the spatial quality of existing resource management practices, and developing tools for designing resource-sensitive and community-inclusive spaces.

The research questions outlined in *Chapter 1* are systematically addressed in *Chapters 3*, *4*, and *5*. To effectively answer these questions, the research employs three distinct methodological approaches, each designed to explore the spatial dimension of UM through various case studies, scales of intervention, and complementary geographic and socioeconomic contexts. Each chapter focuses on a specific case study that presents particular challenges related to poverty, population density, and resource infrastructure, offering a valuable opportunity to apply and compare UM methodologies across both Global South and Global North settings. Case study selection was guided by the availability of relevant datasets and the presence of complex interrelations between resource infrastructure and vulnerable communities (Mexico City); the variety of citizen-led resource management initiatives (Brussels); and the opportunity to engage directly with a vulnerable community through an urban planning workshop (Caracas). Following an article-based thesis model, these chapters are presented as scientific publications, forming the main body of the dissertation. *Chapters 3* is a published peer-reviewed scientific article, *Chapter 4* is a manuscript currently under submission to an international peer-reviewed journal, while Chapter 5 is a manuscript organized to be submitted to an international peer-reviewed journal. Each chapter presents its primary topics, research question, applied methods, results, and key conclusions.

*Chapter 3* focuses on the spatial dimension of UM at the city scale, encompassing region, city, and municipal levels. In particular, it explores to what extent GIS-explicit data can improve the applicability of UM studies in the planning and management of open space networks. This chapter builds on the concept that integrating spatially explicit UM data into urban planning and design can enhance resource-efficient development and the management of open spaces. To explore this premise, a GIS-based UM assessment of Mexico City is conducted at the city-region scale, incorporating data on vulnerable communities and open space networks. Following the mapping of selected GIS layers, a detailed hotspot resource efficiency analysis is carried out through the compilation of a *Borough Pattern Scan*, which quantifies resource use, the total area of resource infrastructure, and public open spaces. The objective of this top-down, multi-scale, spatially explicit analysis is to provide a methodological approach for understanding metabolic profiles, which can inform and support the development of more resource-efficient open space networks in urban settings.

After developing a methodological approach at the city scale, *Chapter 4* shifts the focus to the spatial dimension of UM at the neighborhood scale, encompassing municipal, neighborhood, and building levels. This chapter emphasizes the relevance of capturing and modeling fine-grained data and assessing the spatial quality of existing resource management practices led by citizens to enhance a context-based and community-sensitive UM analysis. Specifically, it explores which spatially explicit socio-ecological activities and practices within ARGS can be identified as drivers to enhance the applicability of resource-sensitive and community led urban design strategies; and what kind of finer-grain spatially explicit data could be collected to enhance a context- and community-specific UM analysis. A UM assessment is applied in the Brussels Capital Region, combining in-depth fieldwork data, including GIS mapping, 3D spatial modeling, and semi-structured interviews with key stakeholders. The objective of this bottom-up approach is to provide a more detailed understanding of ARGS operating at the neighborhood scale and to explore the opportunities and barriers design practitioners face when developing potential publicly accessible urban spaces.

*Chapter 5* builds on the premise of leveraging the spatial dimension of UM to develop tools for designing resource-sensitive spaces, with the aim of enhancing their applicability in urban design. The study explores how can design strategies for publicly accessible urban spaces be developed taking into consideration the most common spatial characteristics of ARGS in both the Global South and Global North. This chapter introduces nine resource-sensitive urban archetypes drawn from the spatial characteristics of an inventory of ARGS. Additionally, the design tools employed in these projects are identified to provide practitioners with a tangible set of options that can be tailored to meet the specific spatial and programmatic needs of future developments focused on resource efficiency and community involvement. This chapter also presents an evaluation of three urban archetypes through a case study in Caracas, Venezuela, highlighting their resource efficiency and flexibility in creating functional gathering and workspaces within a real-world vulnerable community setting. The objective of this chapter is to contribute to the growing interest in the spatial dimension of UM and its practical application in designing publicly accessible spaces, reinforcing community involvement and improving resource efficiency.

*Chapter 6* provides a summary of the findings from the previous chapters, offering a general discussion and concluding the work conducted throughout the thesis concerning the spatial dimension of UM. This chapter also highlights the relevance of the research for both academia and society, discusses the limitations encountered, and presents potential directions for future research.

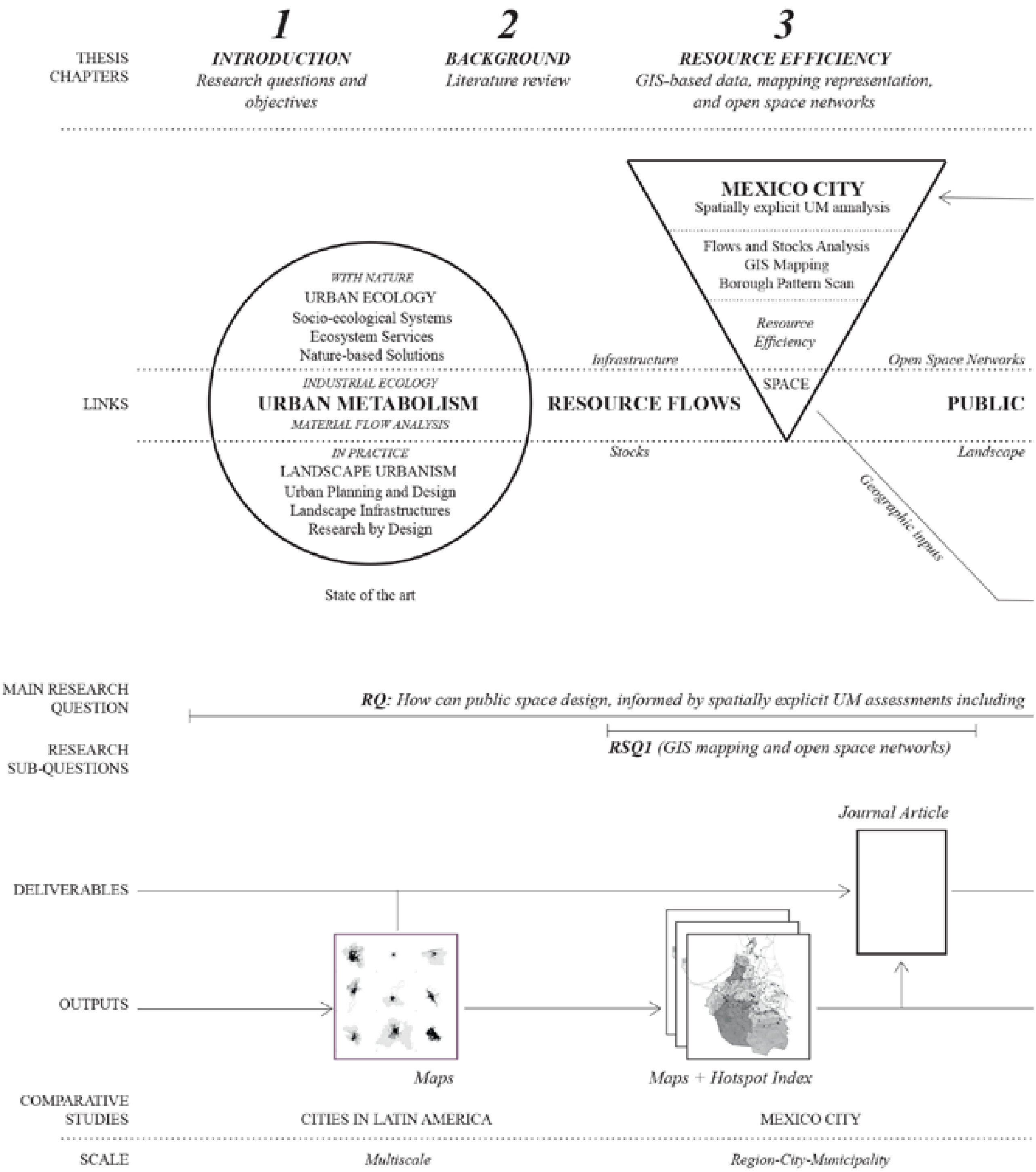
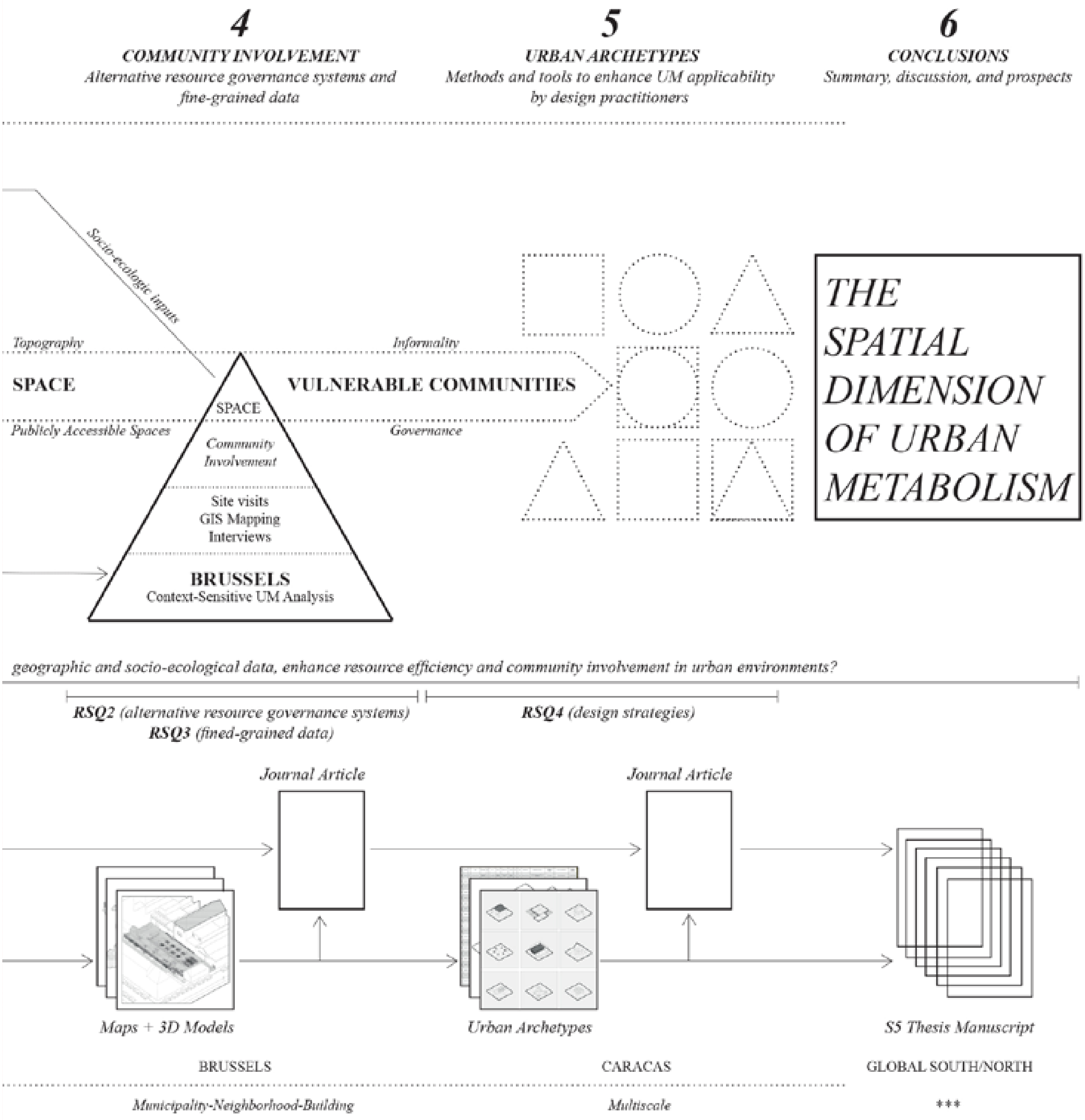



*Figure 1.1: PhD methodological conceptual diagram.*



4
COMMUNITY INVOLVEMENT
Alternative resource governance systems and fine-grained data
5
URBAN ARCHETYPES
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6
CONCLUSIONS
Summary, discussion, and prospects
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Journal Article
Maps + 3D Models
Urban Archetypes
S5 Thesis Manuscript
BRUSSELS
CARACAS
GLOBAL SOUTH/NORTH
Municipality-Neighborhood-Building
Multiscale
***


*Community compost in Brussels, Belgium. Photo by author, 2022.*

## ***2 Background***

*Literature Review*

## *2 Background*

### *2.1 Urban Metabolism: Resource flows, stocks, and infrastructure in cities*

Urban metabolism (UM) studies provide an essential framework for analyzing the complex flows of materials and energy within urban environments, capturing the processes by which cities consume resources and produce waste (Broto et al., 2012; Kennedy et al., 2011; Pincetl et al., 2012). Defined within the field of industrial ecology as the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste (Kennedy et al., 2007), UM has advanced as an interdisciplinary framework, integrating concepts from industrial ecology, territorial ecology, political ecology, and urban ecology (Barles, 2010; Newell & Cousins, 2015). By incorporating geographic and socio-ecological data, these perspectives allow UM studies to evaluate urban systems at multiple scales and account for both natural and social dimensions, including material and energy flows, resource efficiency and accessibility, and power dynamics among stakeholders (Dijst et al., 2018; Perrotti, 2020a; Zhang et al., 2015). Additionally, the use of case studies has demonstrated the potential of UM methods to optimize urban systems by examining sociotechnical processes in the design of resilient cities (Agudelo-Vera et al., 2012; Chelleri et al., 2015; Perrotti, 2022), addressing resource-related vulnerabilities based on the current balance of flows (Athanassiadis et al., 2017; Barles, 2009; Cárdenas-Mamani & Perrotti, 2024), revealing greenhouse gas emissions and resource flows across multiple urban areas in the context of global climate change (Delgado-Ramos, 2013; Kennedy et al., 2009; Kennedy et al., 2015; Mohareb & Perrotti, 2024), and promoting local sustainability through evidence-based planning (Baccini & Brunner, 2012; Chrysoulakis et al., 2013; Currie et al., 2017; Galan & Perrotti, 2019).

One of the earliest references to the concept of metabolism was made by Karl Marx in the 1860s, when he identified a *metabolic rift* between nature and society in the context of agricultural exploitation (Fischer-Kowalski, 2002; Foster, 1999). Marx argued that capitalist production disrupted the vital relationship between people and the soil, exploiting both natural resources and human labor to the point of depletion and degradation, while disregarding the long-term environmental and social consequences of such unsustainable practices. Later, the integration of energy and material accounting from an environmental perspective found its foundation in the works of Patrick Geddes in 1884, who emphasized the importance of linking cities to their hinterlands and watersheds (Barles, 2020). However, it was not until several decades later, with the establishment of ecology as a formal science and the application of the ecosystem concept to urban environments (Odum, 1953, 1975), that interest in the metabolism of cities experienced a resurgence.

UM studies trace their origins to Abel Wolman's foundational study in 1965, which provided a detailed model of resource inflows and outflows in a typical American city of one million inhabitants (Wolman, 1965). By quantifying these flows, Wolman was able to draw comparisons with resource management practices in other American cities and through various infrastructure construction scenarios, his study explored strategies for maximizing resource efficiency by minimizing resource imports, encouraging local production, and facilitating the simultaneous recycling of waste within city limits. This approach demonstrated the role of urban planning in resource efficiency, as localized recycling strategies could reduce transportation costs and energy consumption, fostering greater sustainability. After Wolman's pioneering work, the following decades saw the development of several UM studies by researchers across various disciplines that further developed interpretations, methods, and extensions of the UM concept. Systems ecologists, led largely by Howard T. Odum, advanced the UM studies by focusing on representing resource flows through the concept of solar energy equivalents, which they termed *emergy* in reference to the embodied energy (Odum, 1983; Stanhill, 1976; Zucchetto, 1975). Also, during the same decade, Duvigneaud and Denayer-De Smet (1977) presented their seminal work on the Brussels city-region where they illustrated resource consumption and emissions on a regional scale, including the natural energy balance, through spatially explicit territorial cross-sections. Girardet (1992) identified the key links of UM with the sustainable development of cities through its approach to reducing urban footprint and achieving a circular metabolism of resources.

Many researchers have applied material flow analysis (MFA) in UM research across different cities, making it one of the most widely used methods and helping to establish a common methodological framework in disciplines like industrial ecology (Kennedy et al., 2011). Most of these studies analyzed resource flows and stocks by focusing on the socioeconomic systems, either treating them as complex organisms or considering their relationship with the broader environment as an ecosystem (Fischer-Kowalski & Hüttler, 1998). MFA is an analytical tool to quantify flows and stocks of materials, substances or products in a well-defined system in time and space, i.e. industries, sectors or ecosystems (Escobar & Laibach, 2021). According to the first law of thermodynamics, the inputs (elements entering the system) must equal the outputs (elements leaving the system), with any elements remaining within the system classified as stocks. In MFA, processes are often treated as *black box* processes, meaning the internal workings of these processes are not considered in the analysis. Since the 2000s, the emergence of case studies on diverse UM frameworks has introduced numerous strategies and tools to address resource management deficiencies through urban planning and design (Beloin-Saint-Pierre et al., 2017; Kennedy et al., 2011; Wang et al., 2021). The integration of socio-ecological data into these analyses has enhanced the connection between the metabolic frameworks and urban planning and design. By understanding the social dimensions of resource use, such as unequal access to resources, these frameworks could inform policies aimed at promoting community involvement, allowing more comprehensive planning approaches that address both environmental sustainability and social equity, making urban systems more resilient and inclusive.

UM serves as a critical analytical framework for rethinking resource use in urban environments. For example, previous research has examined greenhouse gas emissions and carbon fluxes in existing and proposed solid waste management infrastructure (Islam, 2017), analyzed water flows from conventional supply and wastewater treatment systems to develop a global set of indicators for small-scale comparisons (Marteleira et al., 2014), and illustrated the spatiotemporal dynamics of energy and water urban-harvesting scenarios (Agudelo-Vera et al., 2012). By integrating insights from various disciplines, UM frameworks enable cities to pursue sustainable planning and design, mitigate climate change impacts, and address the challenges of urbanization. This approach fosters the development of resilient, resource-efficient urban systems better equipped to adapt to changing environmental conditions. Many UM studies focus on quantifying resource flows and stocks, their circulation, and their location within urban systems, as well as the power relations between stakeholders, without considering the use of urban space as a means to improve resource efficiency and accessibility, thus opening and modeling the *black box* processes. In this context, resource efficiency is commonly defined as the ratio of useful material output to the total material input over a product’s life cycle or alternatively, as the monetary value of goods and services produced per unit of material input, aiming to reduce environmental impacts while supporting sustainable economic performance (Dahlström & Ekins, 2005; Haas et al., 2015; UN ENVIRONMENT, 2016; UNEP, 2011). In this research, a broader definition of resource efficiency has been used, which is intended to be an optimal combination of low resource use (resource consumption and generation of waste) and high resource access (resource infrastructure and open space networks).

Despite the growing interest in the spatial dimension of UM, as highlighted by Bahers et al. (2022), only a limited number of UM research are spatially explicit studies that can effectively inform urban planning and design. Addressing this gap is essential for design practitioners, (i.e., urban planners and designers, architects, researchers and activists, among others) aiming to create resource-efficient cities that foster community involvement. In this context, community involvement refers to the process of working collaboratively to strengthen the sense of belonging, participation, inclusion, recognition, and legitimacy within a community. Understanding the spatial organization of cities and their infrastructure can uncover untapped opportunities for more equitable resource distribution. Based on this premise, this research examines the potential of public space design, driven by spatially explicit UM assessments that integrate geographic and socio-ecological data, to enhance resource efficiency and community involvement in urban environments. For instance, identifying and localizing deficiencies in service infrastructure could better inform planning and design strategies for resource management, storage, and distribution, offering more spatially informed opportunities to enhance the overall system. Moreover, most of the case studies used in UM research are located in cities within developed economies (John et al., 2019; Musango et al., 2017), neglecting urban regions with large populations and high rates of poverty and informality.

### *2.2 Resource Efficiency: GIS-based data, mapping representation, and open space networks*

In this research, the spatial dimension of UM refers to a geo-referenced visual representation of a spatial analysis encompassing the flows and stocks of resources, their associated infrastructure, and the socio-ecological context within a defined area under study. Recent studies analyzing the state of the art in UM research have emphasized the growing interest in integrating spatial analyses of resource flows and stocks to provide more valuable and accurate information for developing strategies aimed at enhancing resource efficiency in cities, while also offering a better understanding of the impact of human activities on natural environments (Bahers et al., 2022; Dijst et al., 2018; Geremicca & Bilec, 2024; John et al., 2019). However, many studies lack explicit geographic information systems (GIS)-based data integration, which is critical for making UM analyses more applicable to practical urban planning and design, particularly in managing open spaces. While spatial analysis of UM is growing, this approach has not yet become a major area of research focus (Li & Kwan, 2018; Wang et al., 2021), highlighting the need for enhanced GIS-explicit methods.

The growing focus on the spatial dimensions of metabolic phenomena in research was underscored by a bibliometric analysis conducted by Bahers et al. (2022) on the spatialization of UM. The study identified five major spatially oriented themes: power relations between stakeholders, organizational economics of supply chains, society-nature interactions, infrastructure governance and planning, and spatially explicit modeling approaches. The authors highlighted that urban planners and designers primarily concentrate on site-level flow management, often without fully examining the interdependencies between supply flows or the critical decision-making role of local actors. Furthermore, the power dynamics between cities and resource-producing areas are seldom addressed, despite their importance in understanding spatially explicit UM and its environmental impacts. The analysis points to a potential spatial turn in UM research and underscores the value of cross-thematic approaches, proposing a new research agenda to explore hybrid concepts and emerging trends further. For example, studies aimed at informing urban planning and design have used geo-referenced visualization methods, such as GIS mapping, satellite imagery, and digital twin technologies, to facilitate analyses and provide valuable insights for practitioners, regardless of their level of technical expertise (Geremicca & Bilec, 2024).

Previous spatially explicit UM studies have developed maps of resource consumption, access, stocks, and infrastructure at multiple scales and integrating spatial data from socio-ecological systems (Currie et al., 2017; Federico K. et al., 2023; Soto et al., 2024), assessed the metabolic effects of neighborhood-scale renovation projects (Doussard et al., 2024), mapped drinking water and sewer networks to identify potential disease exposures (Rusca et al., 2022), investigated ways to enhance the transition to a circular economy by clustering waste management infrastructure and involving stakeholders (Furlan et al., 2024; Furlan et al., 2022; Garzilli et al., 2022; Tsui et al., 2022), visualized food system infrastructure and its environmental impacts (Camacho-Caballero et al., 2024; Pianegonda et al., 2022), evaluated the effects of landscape pattern changes and infrastructure arrangement optimization (Liu et al., 2017), and illustrated design scenarios to activated regional wood flows, landscapes, and infrastructures (Marin & De Meulder, 2021). Significant research has focused on quantifying energy consumption and production infrastructure from global to urban scales (Clark & Chester, 2017; Duval & Bahers, 2023; Nalini, 2017; Pincetl et al., 2016; Tanguy et al., 2020), examined carbon metabolism in relation to emissions from energy production (González et al., 2013; Xia et al., 2018; Xia et al., 2022; Xia et al., 2019), calculated the carbon sequestration potential of trees (Bhaskaran et al., 2023; Younan et al., 2023), and proposed models for the spatial arrangement of land use in cities to decrease carbon emissions (Penazzi et al., 2019). Additionally, other researchers have located building material stocks, considering the temporal dimension of building lifetimes (Lanau & Liu, 2020; Mao et al., 2020; Mao et al., 2022), and identified material replacement clusters through the flow of building materials (Kolkwitz et al., 2022).

Although most of these studies set out to inform urban planning and design, only a limited number have produced spatially explicit tools that are readily applicable for use by design practitioners. This gap highlights the need for more GIS-based applications in UM research that directly support urban planning and design. Examples include the creation of synthesis maps that compile spatially explicit overlapping information on UM and other socio-ecological systems in cities (Federico K. et al., 2023; Marin & De Meulder, 2021; Soto et al., 2024; Tsui et al., 2022), the development of design scenarios for the testing of urban design schemes (Camacho-Caballero et al., 2024; Penazzi et al., 2019; Xia et al., 2022), and the UM impact assessment of urban design projects (Doussard et al., 2024; González et al., 2013).

Building on recent discussions around urban circularity in urban planning and design, Soto et al. (2024) conducted a cartographic analysis of Glasgow, Scotland, overlaying thematic maps of four urban systems: natural-ecological systems, energy and mobility systems, socio-productive systems, and built environment and property systems. One of the outcomes is a map of the city highlighting circularity potential hotspots at the neighborhood scale, along with a diagram outlining possible design strategies for socio-spatial systems (e.g., building material stock and waste management through grassroots practices). The thematic mapping study enhances and localizes the evaluation of circular potential; however, the design strategies, being general and not site-specific, do not take into account key stakeholders and existing infrastructure that could significantly improve future decision-making processes. Marin and De Meulder (2021) developed a synthesis map that explores potential synergies between various stakeholders and infrastructures related to the wood industry in Leuven, Belgium, offering insights for urban decision-making through concrete design proposals. In another example, Penazzi et al. (2019) developed design scenarios that focus on transforming existing urban areas into self-sufficient, sustainable urban-rural ecosystems. These scenarios analyze building layouts and densities, renewable energy and crop yield potential, while evaluating the effects of building energy efficiency and per capita energy consumption on urban land use planning. Research exploring the potential of UM to enhance planners' understanding of resource flows and depletion within urban systems includes work by González et al. (2013). They developed a decision support system that systematically integrates UM components into impact assessment processes, enabling more accurate quantification of the potential effects of proposed planning interventions. In applying this methodology to five European cities, the researchers demonstrated improvements in both impact assessment and planning processes by anticipating the effects of urban changes. Their approach offered a spatially specific, systematic, and participatory framework for evaluating planning alternatives.

These studies demonstrate the value of visually representing spatially explicit UM data on critical flows and stocks at different scales to inform urban planning and design. They emphasize that GIS-explicit data can significantly enhance the practicality and applicability of UM studies, particularly for open spaces where spatial interdependencies play a key role in resource management. They also suggest the need for further research to strengthen spatially explicit data collection methods with GIS tools. Additionally, they highlight the importance of integrating socio-ecological data from urban systems to enhance analyses and better identify key stakeholders and available urban spaces for future projects. Moreover, considering open space networks and including vulnerable communities in sustaining the dynamics of metabolic flows could significantly contribute to a systematic approach to resource efficiency.

Considering the inclusion of open space networks (OSN) that support the dynamics of metabolic flows and stocks in UM studies can significantly enhance their applicability for urban planning and design practitioners (Perrotti, 2020a). Integrating GIS-explicit data in these studies provides a spatially detailed view of how these flows are produced within OSN, allowing for more precise planning and management strategies. Furthermore, it can highlight the roles of key metabolic components as agents, not only in the socio-technical configuration of metabolic assemblages but also in the production of urban space and culture (Perrotti, 2020b). OSN refer to all public and private interconnected systems of natural and semi-natural green and blue infrastructure areas and public space in an urban region. These spaces offer a range of socio-ecological benefits that are essential to the well-being of cities and the sustainable management of their resources (Perrotti & Iuorio, 2019; Perrotti & Stremke, 2018).

OSN improve air quality by filtering pollutants and acting as carbon sinks, helping to mitigate the effects of climate change (Bhaskaran et al., 2023; Xia et al., 2019). In terms of water management, permeable spaces allow stormwater to infiltrate into the ground, reducing the risk of flooding, improving water quality by filtering pollutants, and helping to maintain water balance by recharging aquifers, which is especially crucial in drought-prone areas (Fenner et al., 2019). From an energy perspective, OSN can reduce the urban heat island effect by providing shade and cooling the surrounding air, lowering the need for cooling in nearby buildings and consequently reducing urban energy consumption (Brown et al., 2015). Additionally, OSN can reduce food system energy demand and promote food security by supporting urban agriculture programs, providing access to fresh and healthy food, and encouraging healthier eating habits among city residents (Acevedo-De-los-Ríos & Perrotti, 2024; Mohareb et al., 2017). Also, open spaces (e.g., parks, gardens, crops, pastureland) and forests are key to urban biodiversity, offering habitats for various species and contributing to ecological connectivity (Nalumu et al., 2023).

From a social perspective, OSN enhance quality of life by providing recreational areas that promote physical activity, essential for residents' health and well being while fostering community involvement through spaces that encourage recreation, social gathering, and a sense of belonging (Aelbrecht & Stevens, 2019; Otero Peña et al., 2021). The inclusion of OSN in urban planning and design could have a particularly significant impact on vulnerable communities, as it offers multiple socio-ecological benefits and improves accessibility to resources. Vulnerable communities for this research are meant to be the urban and rural areas where the majority of the population lives under precarious social and economic conditions. Depending on the geographical context of the case study, these populations may reside in low-income and highly-dense neighborhoods or informal settlements. These areas, being built without or with minimum support from local authorities, lack reliable connections to municipal utility networks or experience frequent service disruptions due to economic hardship or infrastructure failures. Incorporating GIS-explicit data could help visualize gaps in infrastructure and resource access, providing essential information for more inclusive planning decisions. Moreover, involving vulnerable communities in the planning and management of resource infrastructure can enhance both resource efficiency and accessibility, ultimately contributing to improved living conditions.

Recent UM research has incorporated knowledge from the ecosystem services to enhance the OSN assessment to contribute to the development of more energy-efficient and low-carbon cities (Camacho-Caballero et al., 2024; Cárdenas-Mamani & Perrotti, 2024; Perrotti & Iuorio, 2019; Perrotti & Stremke, 2018), explored the permeability and connectivity of open spaces through a metabolic framework (Choe & Thorne, 2019), calculated the circularity of water and organic waste in local-scale urban agriculture projects (Grard et al., 2015; Jagadisan & Sen, 2023), analyzed the social benefits and improved resource accessibility associated with OSN (Chelleri et al., 2016), and integrated urban forests into industrial symbiosis processes to enhance circular metabolism (La Rosa & Ramakrishna, 2021). Ecosystem services are defined as the benefits people obtain from ecosystems and include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits (Millenium Ecosystem Assesment, 2005).

In this context, the study of Perrotti and Stremke (2018) proposed urban green infrastructure as a key driver of the flows and stocks of energy, materials, and substances (such as biomass and carbon), which contribute to the energy metabolism of urban systems. The authors indicated that growing concerns about climate change, alongside the need for a transition toward more energy-efficient and less carbon-intensive urban development models, have led to a significant increase in research on renewable energy provision and climate regulation services. The findings highlighted the provision, regulation, and maintenance services offered by urban ecosystems, along with their abiotic outputs, which have a direct impact on urban energy metabolism, particularly in optimizing renewable energy generation, reducing building energy demand, and lowering atmospheric carbon concentrations. Moving forward, the authors proposed an expanded Material Flow Analysis (MFA) that integrates the accounting of energy provision and climate regulation services provided by green infrastructure into energy-related inputs, outputs, and internal cycling. The integration of an UM and ecosystem services framework was recently tested in Lima, Peru, by Cárdenas-Mamani and Perrotti (2024), where they emphasized the relevance of analyzing cities through both socioeconomic and ecological lenses. By modeling spatiotemporal variations in resource flows and emissions up to 2050, the study revealed that the city's demand for the ecosystem service flows studied surpassed the local supply, with the exception of surface water supply and cane-mat for construction materials. The authors underscored the potential to implement green infrastructure in the urban region, emphasizing the need for a systematic assessment of metabolic requirements and the associated supply and demand of ecosystem services. Choe and Thorne (2019) conducted a connectivity modeling of open spaces in Seoul, Korea, to assess the ease with which resources, animals, and people could move through urban spaces, taking into account land use types, permeability, and resistance to movement. The researchers emphasized that open spaces must not only exist but also be connected. They argued that the permeability of these spaces (the ease with which resources and organisms can move through them) plays a crucial role in the functioning of a city, particularly in resource allocation and waste management. The study suggested that local governments could use permeability metrics to evaluate their urban spaces and collaborate with neighboring districts to improve overall connectivity, thereby enhancing resource flows and reducing urban fragmentation.

Despite the clear benefits of integrating OSN into UM frameworks for urban planning and design highlighted by these studies, as emphasized in existing studies, there is still a lack of applied case studies that spatially test its potential. there remains a notable lack of applied case studies that spatially assess this potential. In particular, there is a need for methodological approaches that incorporate spatially explicit datasets into UM assessments in ways that are accessible and actionable for design practitioners. A significant gap remains in the use of GIS-explicit data to spatially evaluate the role of OSNs within UM frameworks, especially in vulnerable urban areas where access to essential resources is limited. Addressing this gap is critical for the development of more inclusive, equitable, and resource-efficient strategies in urban planning and design.

### *2.3 Community Involvement:*
### *Alternative resource governance systems and fine-grained data*

The increasing interest in using UM frameworks for resource management in cities highlights ongoing challenges that limit their practical application by design practitioners. These challenges include the lack of standardized spatially explicit assessment approaches, methods, and fine-grained city-level data (Beloin-Saint-Pierre et al., 2017; Broto et al., 2012; Perrotti, 2020a; Shahrokni et al., 2015), particularly in cities in the Global South (Guibrunet & Castán Broto, 2015; Kaviti Musango et al., 2020). Kaviti Musango et al. (2020) advocate for shifting away from city-wide generalizations and top-down approaches aimed at global comparisons to UM frameworks that explicitly consider the unique spatio-temporal realities of cities. Much of their research has focused on applying UM to informal settlements, using various approaches such as community co-design and data capture with local stakeholders, societal metabolic analysis, and urban scaling methods based on national resource data. Their concept of community co-design emphasizes the importance of incorporating local knowledge and practices to develop context-specific indicators that reflect the realities of informal settings. This approach has enriched the understanding of UM, enhanced the relevance and applicability of indicators through community engagement (e.g., mapping and identifying informal settlement typologies in relation to infrastructure and population), and fostered community ownership in the monitoring, evaluation, and tracking of sustainability metrics.

Integrating spatially explicit and refined data from bottom-up, context-sensitive, and practice-based resource collection and management systems could provide valuable insights for local planning and design strategies. These alternative resource governance systems (ARGS) encompass publicly accessible spaces subject to a local-scale and community-led approach towards decentralized resource management, which in many cases, aim not only to increase community involvement but also to support the preservation of cultural heritage, local identity, and habitat. Publicly accessible spaces refer to all public spaces and include both public and private facilities and open areas that are accessible to the public during designated times at no cost. These spaces include libraries, community centers, municipal markets, sports facilities, gardens, and common areas. Focusing on ARGS would enhance understanding of spatial qualities and the quantity of resources managed locally, accounting for the stakeholders involved and the socio-ecological activities and practices observed, specifically, the organized and sustained interactions between the community involved and open space networks.

A UM approach advocating for holistic policies to decentralize resource and waste management, particularly for vulnerable communities, could enhance governance by fostering inclusiveness, transparency, and efficiency, ultimately promoting sustainable and equitable urban systems (Dijst et al., 2018). Numerous UM studies have assessed the environmental and social benefits of ARGS for enhancing resource efficiency and promoting community involvement in urban areas (Bahers & Giacchè, 2019; Berigüete et al., 2023; Chelleri et al., 2016; Espinosa-Aquino et al., 2023; Estrada et al., 2023; Guibrunet et al., 2017; Gutberlet et al., 2017; Jadeja et al., 2018; Kaviti Musango et al., 2020; Obersteg et al., 2020; Pietta & Tononi, 2021; Putri & Moulaert, 2017; Smit et al., 2019). Depending on their primary objectives, green spaces can be designed to emphasize environmental benefits (e.g., enclosed natural reserves for biodiversity conservation) which may offer limited social engagement and therefore have limited social benefits, or to prioritize social inclusion and recreation (e.g., parks and squares) which may provide limited ecosystem services. For instance, studies have highlighted the inclusion of organized groups of garbage collectors in metabolic studies and their importance to the local economy of cities in the Global South (Estrada et al., 2023; Guibrunet et al., 2017; Gutberlet et al., 2017).

Based on research on waste picker organizations in Buenos Aires, Argentina, and São Paulo, Brazil, Gutberlet et al. (2017) concluded that circular economy frameworks, often developed in the Global North, need to be adapted to suit the distinct political, social, and cultural contexts of cities in the Global South. They further emphasized that waste pickers are integral to the local economies of the Global South, and that additional resources are necessary to support their efforts in contributing to circular economy transitions. The study highlights the limitations of what unorganized and unsupported waste pickers can achieve within this framework, underscoring the need for institutional and financial backing to foster meaningful change. A similar focus on local engagement was demonstrated by a multidisciplinary project in India involving researchers, social workers, and rural villagers educated and trained local farmers to conduct geo-hydrological assessments of their areas to monitor aquifers and share findings with their communities (Jadeja et al., 2018). This initiative provided a scientific foundation for groundwater discussions at the village level, enabling communities and stakeholders to make better-informed decisions regarding groundwater use, crop selection, agronomy, recharge strategies, and other aspects of sustainable groundwater management. In a different context, Obersteg et al. (2020) found that the lack of public space in a dense neighborhood in Hamburg, Germany, has hindered the implementation of improved waste infrastructure, such as underfloor garbage bins, creating conflicts with other urban needs like parking and electric vehicle charging. This reliance on collection bags has led to issues such as littering, unpleasant odors, and aesthetic decline. This spatial conflict between waste infrastructure and urban planning is an example of where spatially explicit data on socio-ecological practices could improve the alignment of urban metabolic flows with urban design strategies. To address these challenges, co-creation workshops were organized, involving institutional stakeholders and local grassroots initiatives to reduce the use of collection bags and promote waste separation, particularly organic waste. These practices could be identified as drivers of resource-sensitive planning, where the socio-ecological activities of local communities actively influenced urban waste governance systems. The findings indicate that the success of collaborative economy strategies in waste management is highly dependent on urban structures and stakeholder interests, and that such strategies must be integrated into the local governance framework and spatial planning systems to be effective.

UM studies that incorporate case studies involving vulnerable communities datasets have gained increasing attention, primarily due to the significant concentration of urban populations experiencing precarious access to essential resources. A growing body of research highlights the central role of UM in understanding and addressing sustainability challenges within informal settlements. Researchers have explored resource flows and infrastructure gaps, particularly focusing on inefficiencies in water, waste, energy, and food management, and the socioeconomic impacts on vulnerable communities, especially in cities of the Global South (Acevedo-De-los-Ríos et al., 2024; Currie et al., 2017; Smit et al., 2019). A key area of focus has been food security and urban agriculture in informal settlements in Latin America, where researchers have emphasized the need for agro-food systems and circular economy strategies to enhance sustainability and resilience (Acevedo-De-los-Ríos & Perrotti, 2024; Shillington, 2013). Another study on water and sanitation systems in a peripheral neighborhood of Jakarta, Indonesia, examined the interplay between informal practices and formal infrastructure, proposing integrated solutions such as community-led water and wastewater management systems (Putri & Moulaert, 2017). In Mexico City, Guibrunet et al. (2017) analyzed the role of the informal sector in municipal solid waste collection and recycling in a low-income neighborhood, where local leaders provided basic waste management services in exchange for an informal tax. The study mapped waste flows to better understand the interdependence of formal and informal waste management systems. Similarly, the role of climate change adaptation and waste management has been explored by Allam (2018), who focused on how low-income cities, such as Port Louis in Mauritius, can pursue net-zero carbon targets through waste minimization and efficient resource use. Further research has highlighted the relationship between informality and socio-ecological practices in African cities. Authors such as Kaviti Musango et al. (2020) and Nalumu and Perrotti (2024) emphasized how vulnerable communities creatively manage resources through nature-based solutions and engage in informal economies to meet basic needs. Additionally, a study in Ethiopia employed a bottom-up approach using informal fine-grained data sources to quantify and map housing material flows in a rural town, emphasizing the environmental impacts of construction practices in low-income areas (Tola et al., 2019).

Collectively, these studies underscore the relevance of understanding citizen-led resource management practices in vulnerable communities and integrating spatially explicit, fine-grained data into broader sustainability frameworks. Such integration offers critical insights for addressing the complex challenges faced by communities in the Global South, where conventional planning often overlooks localized needs. The integration of fine-grain and spatially explicit data on ARGS could enhance the applicability of UM by urban planners and designers, enabling more nuanced, resource-sensitive strategies that align with local community practices. Despite this potential, the UM literature still lacks sufficient exploration of the socio-economic and cultural dimensions of vulnerable communities. This gap limits a comprehensive understanding of the socio-ecological activities and practices occurring within public spaces, as well as the feasibility of collecting and applying fine-grained data in these settings. ARGS not only improve resource efficiency by repurposing underused urban areas but also serve as communal assets that foster community involvement and contribute to healthier urban ecosystems, particularly when integrated with OSN through thoughtful planning and design.

### *2.4 Urban Archetypes: Methods and tools to enhance UM applicability by design practitioners*

Integrating urban metabolism (UM) into urban planning and design facilitates the optimization of resource use, reduction of waste and emissions, and enhancement of overall efficiency and accessibility (Pincetl et al., 2012; Pistoni & Bonin, 2017). A nuanced understanding of these resource flows enables the development of more sustainable infrastructure, the expansion of green spaces, and the promotion of circular economy principles that can be adapted to the distinct socio-ecological spatial characteristics between alternative resource governance systems (ARGS) in both the Global South and Global North (Amenta & Van Timmeren, 2018; Kaviti Musango et al., 2020; Perrotti & Stremke, 2018). By identifying common spatial characteristics between ARGS, design strategies for public spaces can be tailored to enhance sustainability across diverse contexts. Key applications, including sustainability reporting, urban greenhouse gas accounting, mathematical modeling for policy analysis, and urban design strategies, demonstrate how UM aids data-driven urban planning and design by offering insights that guide resource management, emissions reduction, and policy decisions to build sustainable, resilient cities (Kennedy et al., 2011). The application of UM frameworks in urban planning and design has been explored in case studies involving architectural and urban design academic studios, landscape and urban infrastructure theoretical projects, as well as initiatives focused on the reuse of local materials in architecture (Bortolotti et al., 2020; Perrotti, 2020b). However, the complexity of issues and methods discussed in scientific literature, along with the intricate nature of UM frameworks and the technical challenges of translating theory into actionable design strategies, often limits their practical applicability and poses a barrier to wider adoption in urban planning and design (Perrotti, 2019).

The application of UM frameworks in case studies within academic urban planning and design studios demonstrate that common spatial characteristics of ARGS, such as decentralized waste management systems, community-driven energy projects, and local material reuse, offer valuable lessons for publicly accessible space design strategies across both regions. For instance, Baccini and Oswald (2008) conducted two complementary experiments, one with urban design students and the other within community workshops, employing morphological and physiological tools to test urban design hypotheses. These hands-on projects analyzed urban settlements as networked systems composed of nodes and connections. The outcomes, evaluated by participants and reviewers, were ultimately published as the *Netzstadt Method: Designing the Urban*, providing a versatile framework that can be applied independently or alongside other approaches within urban design practices. *MIT* architecture students, guided by Professor John E. Fernández, used system dynamics to assess New Orleans' resource needs after *Hurricane Katrina* (Quinn, 2008). Viewing the city as a macrosystem of stocks, flows, and time delays, they analyzed feedback loops and interactions, leading to alternative recovery scenarios, each based on the system's dynamic interdependencies. Similarly, civil engineering students at the University of Toronto employed UM to guide sustainable design at the neighborhood scale, incorporating best practices in green building, sustainable transportation, and alternative energy systems to close loops in resource flows (Kennedy et al., 2011).

More recently, the inclusion of UM analytical frameworks within architectural and landscape design studios has been put into practice in many European universities (Baker-Brown & Brooker, 2024; Bortolotti et al., 2024; Grulois et al., 2018; Marin &

De Meulder, 2018). Many of these academic initiatives have successfully developed urban planning and design proposals by applying multi-scale analyses of resource and stock management tailored to specific contexts. Furthermore, these studies highlight the relevance of ARGS-based publicly accessible space designs, where community participation and localized resource flows are critical. For instance, Bortolotti et al. (2024) conducted a master in urban planning and design studio at the *University of Venice* that integrated macro-data analysis at the metropolitan scale, ground and visual surveys at the meso-scale, and project designs at the micro-scale, all within a circular UM framework. The professors overseeing the study evaluated the experience as satisfactory, noting that it achieved a high level of argumentation, along with well-developed readings, spatial visions, and project proposals. However, they critically observed a significant limitation based on the lack of engagement with local stakeholders, which would have provided deeper contextual insight and enriched the relevance and grounding of the students' proposals.

The discourse and practice of landscape as a means of urban intervention in social, cultural, economic, and ecological contexts has been extensively examined by scholars and professionals in landscape architecture and urban planning. (Waldheim, 2006, 2016). In his essay *Terra Fluxus*, Corner (2006) emphasizes the transformative potential of landscape to function across multiple scales, positioning urban fabric within broader regional and ecological contexts, and fostering connections between dynamic environmental processes and urban form. Moreover, he identifies four key themes central to *landscape urbanism* practice. The first theme addresses the processes occurring over time and space that shape urban systems, treating cities and resource infrastructures as ecological systems similar to natural environments. The second theme highlights the role of horizontal surfaces in landscapes, conceptualized as urban infrastructures. This approach shifts the focus from fixed design outcomes to operational processes, prioritizing the means over the ends and emphasizing functionality and performance over formal composition. The third and fourth themes revolve around rethinking traditional methods and representations, inviting for the exploration of multi-scale approaches that account for both time and space, along with a focus on imaginative possibilities and cartographic experimentation. Waldheim (2016) argues that while the practice of using landscape as a medium for planning has traditionally been significant in addressing the complexities at the intersection of large-scale ecological and resource infrastructural systems in the Global North, it has more recently proven valuable in exploring the role of green infrastructure within resource management in informal settlements in the Global South. This approach has become particularly relevant in responding to questions of risk, adaptation, and resilience, where landscape-based interventions can address vulnerabilities and enhance the capacity of these settlements to withstand environmental challenges. For example, Vera and Sordi (2020) identified and classified recent projects that employ nature-based solutions and green infrastructure strategies to mitigate the impacts of the climate crisis on vulnerable communities in Latin America. This perspective conceptualizes landscape as infrastructure, proposing a multi-scalar system that seamlessly integrates natural and constructed elements to deliver essential urban services (e.g., drinking water, wastewater management, waste disposal, transportation, and energy) while simultaneously embedding ecological processes (Bélanger, 2012); thus, achieving this vision requires a comprehensive approach that harmonizes artificial and natural ecologies (Perrotti, 2014). Landscape and infrastructure are increasingly viewed as a spectrum of the public realm (Shannon & Smets, 2016), with landscape practice expanding its scope to include the functional and logistical dimensions of urbanization (Bélanger, 2009). This shift marks a transformative moment in urban planning and design, positioning it as a model for practice that renews architecture's role in shaping the future infrastructure of cities (Allen, 1999). But more importantly, it highlights a relevant conceptual approach for identifying common spatial characteristics and interconnecting resource flows and stocks, open space networks, and vulnerable communities in both the Global South and North that can be used by practitioners and academics to enhance resource governance and community-led sustainability initiatives.

As part of the 2014 International Architecture Biennale Rotterdam, themed *Urban by Nature*, the American landscape architect James Corner (*Field Operations)* and the Dutch urban design practice *FABRICations* led a multidisciplinary research by design workshop to reorganize Rotterdam's metabolic flows (Tillie et al., 2014). This research examined and mapped nine key flows (including materials, people, waste, biota, energy, food, drinking water, air, sand, and clay) across the Rhine catchment area and the city-region of Rotterdam. Four thematic spatial strategies were then proposed, each addressing circular approaches: reclaiming raw materials from waste and food, creating biotopes to enhance urban environmental quality, using by-products from the energy sector, and stimulating re-industrialization within the port area. Inspired by this project, other spatially explicit case studies using UM frameworks have since emerged across Europe and Asia, led by multidisciplinary teams of practitioners, including *FABRICations*, alongside local stakeholders. Cities such as Brussels and Antwerp in Belgium, Amsterdam in the Netherlands, Almaty in Kazakhstan, and Izmir in Turkey, as well as countries including Albania and Laos, have implemented these approaches, integrating UM principles to support sustainable urban transformations (Brugmans et al., 2015; FABRICations, 2024). However, while many of these studies successfully assess and map resource flows and infrastructure at regional and territorial scales, much of their urban planning and design outcomes remain non-context-specific development strategies. This limitation often arises from the complexity of involving all relevant stakeholders and the challenge of delivering tailored responses that address the unique needs and conditions of each case.

In recent years, circular UM frameworks have increasingly been applied to produce new building materials by reusing construction waste materials and the reduction of transport distances of materials through the use of nearby resources. In Brussels, Belgium, two examples of architecture and design cooperatives illustrate this approach: *BC Materials* transforms excavated earth from construction sites into earth plasters, compressed earth blocks, and rammed earth; and *Rotor DC* specializes in collecting and reusing materials and construction elements from building demolitions. *Rotor DC*, a spin-off from the design practice *Rotor*, promotes the reuse of building materials to support a resource-efficient economy. By reclaiming, restoring, and selling dismantled building components, the cooperative significantly reduces demolition waste while offering high-quality reclaimed materials and offering their design services. In 2018 alone, *Rotor DC* recovered 160 tonnes of construction waste, a notable contribution given the estimated 600 tonnes of construction waste incinerated annually across Brussels (Verga & Khan, 2022). Additionally, in a renovation project for its Brussels headquarters, the socio-cultural organization *Zinneke* collaborated with architectural firm *Ouest* and design cooperative *Rotor* to repurpose the existing building using a strategic framework centered on material recovery, reuse, and adaptation (Stoffen, 2020). This approach treated the existing structure as a primary resource, emphasizing adaptable design, stakeholder co-creation, and the integration of local knowledge and craftsmanship. *BC Materials*, the product sales wing of *BC Architects*, advocates for the use of earth construction by capitalizing on the estimated 36 million tons of soil generated annually from construction sites through stakeholder workshops and activism in construction management protocols (De Cooman, 2020). These two architecture-scale initiatives illustrate the potential of design practices to create business opportunities that reduce environmental impact and encourage the sustainable use of resources in construction. Their approaches not only minimize construction waste but also foster environmentally friendly building practices, advancing a circular economy within the construction sector.

In sum, the literature underscores the relevance of integrating UM frameworks into urban planning and design, particularly in the development of publicly accessible spaces, to foster sustainable and equitable urban environments. UM studies are increasingly recognized as essential frameworks for understanding the environmental impacts and resource dynamics of cities. Particularly, studies that emphasize the spatial dimension of UM highlight the significance of configuring OSN and ensuring their accessibility to vulnerable communities, which are key factors in promoting resource efficiency and community involvement in urban spaces. These spatial considerations are vital in both the Global South and North, though the specific challenges and opportunities differ across regional contexts. Additionally, the literature identifies ARGS as promising case studies for addressing the limitations of conventional resource management, emphasizing decentralized and community-based approaches that enhance urban resilience by diversifying resource sources and promoting flexible and localized management strategies. This is particularly important for vulnerable communities that face higher risks related to resource scarcity and environmental degradation. Building on these insights, future research could focus on developing resource-sensitive urban design strategies within a UM analysis framework. These design explorations could serve as practical tools for urban planning and design practitioners, providing guidance for incorporating UM frameworks and ARGS characteristics into the early stages of urban projects. Such strategies would offer a foundation for creating adaptable, resource-efficient, and inclusive urban environments across diverse geographic contexts.

*Open space networks in Mexico City, Mexico. Photo by author, 2023.*

## *3 Resource Efficiency*
*GIS-based data, mapping representation, and open space networks.*

*Abstract*
Urban metabolism studies provide valuable insights that can improve resource efficiency at the city scale. However, only a limited number of such studies include spatially explicit data to inform planning practitioners. In this article, we argue that integrating spatially explicit urban metabolism data in urban planning can leverage resource-efficient development and management of open space networks. Based on this premise, our research presents a methodological strategy to investigate how the use of GIS data can improve the applicability of metabolic studies in urban planning and the management of open space networks in particular. A GIS-based urban metabolism assessment of Mexico City was performed at the city scale, including data on vulnerable communities, communal lands, and indigenous areas. After mapping selected GIS layers, a detailed resource-efficiency analysis was performed through the compilation of a *Borough Pattern Scan*, based on quantification of resource use, total areas of resource infrastructure, and public open spaces. The results of our multiscale spatially explicit analysis provide an improved understanding of borough metabolic profiles, which can leverage a more resource-efficient development of open space networks in Mexico City.

*Keywords*
Global South, green and blue infrastructure, industrial ecology, socio-ecological systems, urban and landscape planning, urban resource harvesting.

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### *3.1 Introduction*

#### *3.1.1 Urban metabolism and open space networks*

Growing evidence demonstrates that cities with high resource consumption and waste generation are more vulnerable to scenarios of future resource scarcity due to climate change and global population growth (Hanjra & Qureshi, 2010; Mannan et al., 2018; Parish et al., 2012). Urban planning defines urban forms and the types of infrastructure in a city depending on geographic characteristics and construction material preferences, thus determining an important part of the overall resource efficiency of the urban fabric (Deilmann, 2009; Pincetl et al., 2012; Yang et al., 2014). Urban metabolism (UM) research has evolved substantially in recent years by adopting an interdisciplinary and multiscale approach in the analysis of internal resources and social–ecological dynamics in urban systems, encompassing different lines of thinking as in industrial ecology, urban ecology, political ecology, and political–industrial ecology (Broto et al., 2012; Newell & Cousins, 2015; Newell et al., 2017). In industrial ecology, UM is defined as the sum total of all technical and socio-economic processes associated with the production, distribution, and consumption of resources that occur in cities, resulting in growth, production of energy, and elimination of waste (Kennedy et al., 2007). UM studies provide valuable insights to inform strategies for more resource-efficient cities by developing holistic frameworks for urban modeling (Barles, 2010; Kennedy et al., 2011), which can advance understanding of the impacts of human activities on the natural environment.

In this article, we argue that integrating spatially explicit UM data into urban planning can leverage the resource-efficient development and management of open space networks (OSN). OSN are interconnected systems of natural and seminatural green-blue infrastructure areas and public space in an urban region (Frazier & Bagchi-Sen, 2015; Linehan et al., 1995). From a UM perspective, OSN planning strategies can help generate or recycle resources as well as reduce resource demand through optimized, multiscale, and qualitative use of urban space (Agudelo-Vera et al., 2012; Kennedy et al., 2011; Leduc & Van Kann, 2013). In other words, OSN can be used as an asset to minimize resource extraction, energy consumption, and waste generation, while preserving urban ecological dynamics.

Previous spatially explicit UM studies have illustrated spatiotemporal dynamics of materials and resource flows and infrastructure at multiple scales (Clark & Chester, 2017; Guibrunet et al., 2017; Smit et al., 2019; Yeow & Cheah, 2019), building stocks (He et al., 2020; Lanau & Liu, 2020; Mao et al., 2020; Miatto et al., 2019), energy and water urban-harvesting scenarios (Agudelo-Vera et al., 2012) and integrated the spatial dimension of environmental and socio-economic information (Caputo et al., 2019; Choe & Thorne, 2019; González et al., 2013; Juwet & Ryckewaert, 2018; Leduc & Van Kann, 2013). However, these studies mainly focused on the quantification of resource flows/stocks, their circulation and location in urban systems, and the relations of power among stakeholders, without considering the use of space as a means to improve the resource efficiency of the system being studied. A growing number of works highlight the benefits of integrating spatially explicit accounts of UM flows/stocks for informing policy-making and resource-management strategies at the city level. For example, mapping the distribution of energy demand by a district in Bengaluru, India, allowed Nalini (2017) to understand the local water–energy nexus and the spatial dimension of UM flows and resource infrastructure. By overlapping spatially explicit water and energy datasets, researchers were able to relate the location of inefficient sections of the drinking water distribution network and pumping facilities with high energy consumption districts and geographic features of the city. Wielemaker et al. (2020) used geographic boundaries, socio-demographic data, and geographic information system (GIS)-based information on urine and feces at the neighborhood and building levels in Amsterdam to produce a spatially explicit inventory of nutrient hotspots in several areas of the city. The spatially explicit data at the local level allowed to identify clusters of buildings with a high nutrient load and, through this, to better inform the planning of future sanitary systems. These studies demonstrate the value of spatially explicit UM data on critical flows/stocks (energy, construction materials, and nutrients) at different scales (regional, urban, and building) and suggest further research to consolidate spatially explicit data-harvesting methods. However, they did not focus on applicability of results in practice or the identification of opportunities to enhance the incorporation of UM results into urban planning and design strategies (Perrotti, 2019). Consideration of urban spatial structures (i.e., open spaces) underpinning metabolic flow/stock dynamics can favor the uptake of UM studies by planning practitioners and, consequently, significantly contribute to the development of a systemic approach to resource efficiency in urban systems (Perrotti, 2020).

Reinforcing and preserving existing OSN in urban areas can increase urban populations' exposure to natural environments, enhance biodiversity, increase soil water infiltration and reduce the concentrations of atmospheric pollutants (Cohen et al., 2014; Tratalos et al., 2007), while providing opportunities for recreation and physical activity, promoting community identity and a sense of well-being (Perrotti & Iuorio, 2019), and increasing economic benefits (Zhang et al., 2012), among other social-ecological benefits (Perrotti et al., 2020). Previous research on OSN has, for example, focused on land-use regulations to preserve existing ecological networks (Arendt, 2004; Weber & Wolf, 2000), applied landscape ecology models to integrate future vacant lots in shrinking cities (Frazier & Bagchi-Sen, 2015), investigated energy and resource requirements for scaling-up urban agriculture (Mohareb et al., 2017), and designed scenarios to reframe circular economy questions through urban and landscape planning strategies (Amenta & Van Timmeren, 2018; Marin & De Meulder, 2018). Another prolific line of research focused on assessing the loss of connectivity among fragmented green patches caused by uncontrolled urban form and urban sprawl (Toger et al., 2016; Yacamán Ochoa et al., 2020). It demonstrated that enhancing connectivity can provide higher social-ecological values in urban environments (Frazier & Bagchi-Sen, 2015).

Despite the increased focus on the social-ecological values of OSN over the last decades, only a limited number of studies have related the spatial configuration of open spaces with resource accessibility; this represents a critical frontier in UM research. Spatially explicit studies on resource consumption and the availability and accessibility of utility networks and infrastructure can help urban and landscape planners identify opportunities in the urban space for mitigating resource-related vulnerabilities (e.g., neighborhoods with high energy demand and/or significant solid waste generation) and enhancing the harvesting of local resources through spatial design strategies. Based on this premise, this article will present a methodological strategy to investigate how the use of GIS-explicit data can improve the applicability of UM studies in the planning and management of OSN. Addressing this question can provide novel insights into using OSN to achieve more efficient distribution and concentration of UM flows and infrastructure in urban systems.

### *3.1.2 Case study: Mexico City*

Mexico City is located on a plateau at 2,240 meters above sea level, surrounded by volcanic mountains in the *Valley of Mexico* with a total area of 1,480 $km^2$ and approximately 8.9 million inhabitants. An estimated 3.4 million live below the poverty line and are in a situation of social and economic vulnerability (CONEVAL, 2018). This population is mainly located in low-income neighborhoods on the urban-rural edge and some areas of the city center; they have deficiencies of access to education, healthcare, basic services, public space, housing quality conditions, and property titling (Aguilar & Mateos, 2011; Bayón & Saraví, 2013; Ziccardi, 2016). The large urbanized region within which Mexico City is located is known as the *Metropolitan Zone of the Mexico Valley* and has a total population of approximately 21 million, including 60 other municipalities in the states of *Hidalgo* and *Mexico* (see *Figure 3.1*). Mexico City is managed by a city government (*Gobierno de la Ciudad de México*) and includes 16 independent boroughs (*alcaldías*) with diverse geographic and socio-economic characteristics. The boroughs are subdivided into neighborhoods (*colonias*); for statistical analysis, these are divided into rural and urban "basic geostatistical areas" (*AGEB, Área Geo-Estadística Básica*), which constitute the smallest units of the national census.

Approximately 59% of Mexico City's land area is classified as *Conservation Land* (*Suelo de Conservación*) due to unique climatic, topographic, and soil characteristics, and includes a variety of agricultural and natural ecosystems such as forests, grasslands and wetlands. About 12% of the *Conservation Land* is urbanized (SEDEMA, 2016) and 3% is covered by informal settlements (*asentamientos humanos irregulares*), i.e. residential areas where inhabitants lack legal ownership of the land and basic services are limited due to irregular land occupation, precarious dwelling construction, or for being located in hazardous areas of high ecological value (Aguilar & López Guerrero, 2013; UN HABITAT, 2015). Moreover, being built without the support of local authorities, they are not always connected to the municipal utility networks and, in some cases, basic needs (e.g., drinking water) are fulfilled through informal means such as water trucks, public hydrants, natural springs, rivers, and wells (Aguilar & López Guerrero, 2013). In 2010, it was estimated that more than 50,000 families lived in informal settlements in Mexico City and only 30% of all dwellings in the city were connected to all municipal utility networks: drinking water, electricity, and sewage (PAOT, 2010).

Vulnerable communities are defined as urban and rural areas with a majority of the population living with precarious access to basic services, public space, and housing quality conditions due to their socio-economic status or irregular land occupation. These areas can play a key role in future natural-system conservation strategies and the management and planning of new infrastructure and OSN in Mexico City (Wigle, 2010), considering that many of them are located on the urban-rural edge, at the intersection of nature reserves, communal lands, and indigenous areas (*pueblos originarios*). Communal lands are properties given to farmers after the Mexican Revolution (1910–1912), and are held by a community for agriculture use, residential settlement, and public use. This period of land reform ended in 1992, with a constitutional amendment that allowed privatization of communal lands (Jones & Ward, 1998; Lerner et al., 2018) and resulted in the conversion of green areas into new urban developments. Due to rapid urban growth over the last 30 years, communal lands were annexed to areas inhabited by indigenous people, which were historically urban and rural areas developed independently from Mexico City (Arach et al., 2018; Medina, 2009). These indigenous areas are territorial units preserving and reproducing totally or partially their own social, economic, cultural, and political institutions, establishing their political status with juridical personality, own

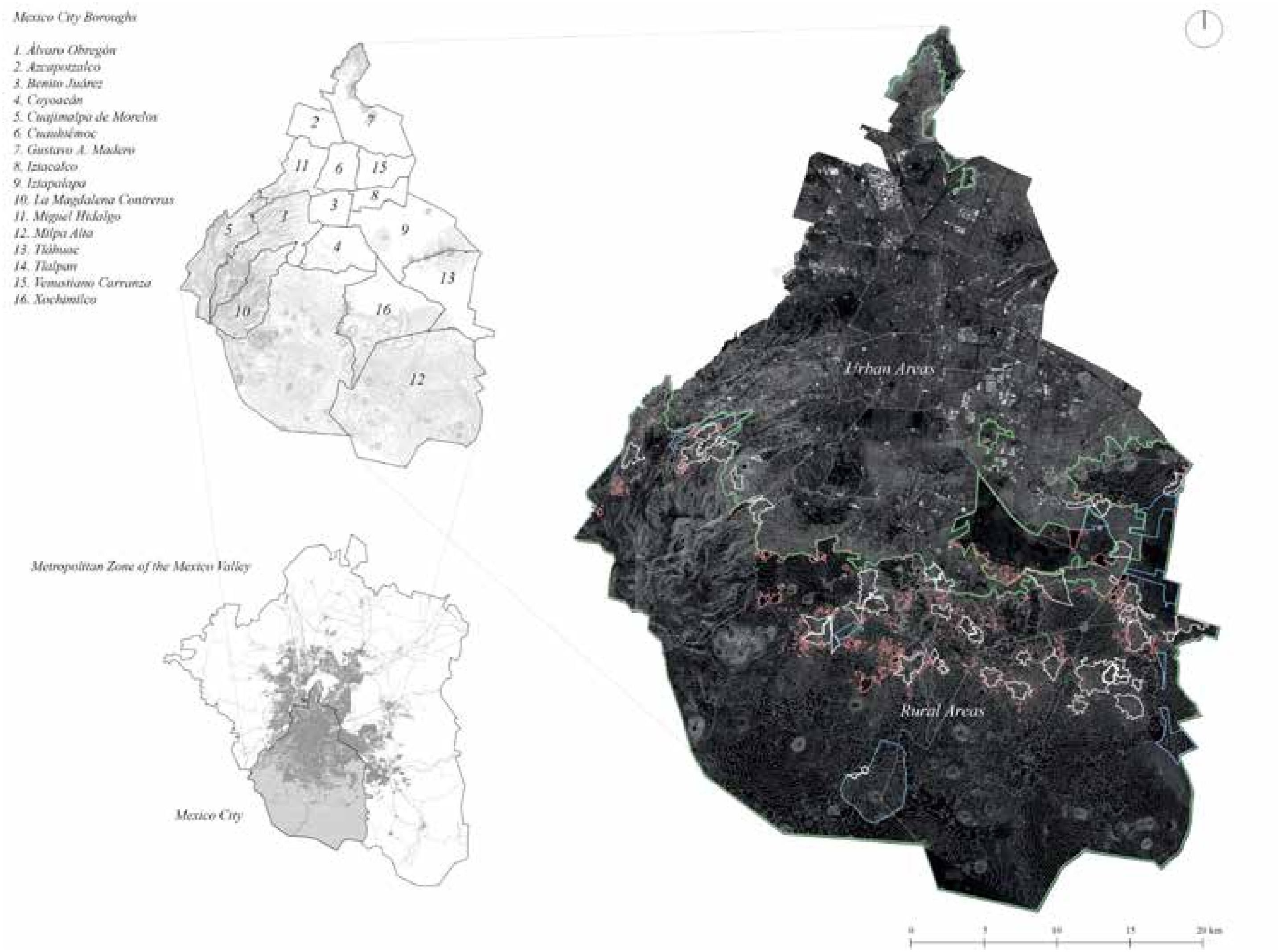



*Figure 3.1: The geographic location of Mexico City and its 16 boroughs subdivision. The Metropolitan Zone of the Mexico Valley including the states of Mexico and Hidalgo. Mexico City including topography, administrative boundaries, informal settlement areas (red contour lines), indigenous areas (white contour lines), and communal lands (blue contour lines). The Conservation Land (with green contour lines) delimits the urban and rural areas in the city.*

patrimony and right to self-determination (SEPI, 2019). All indigenous areas have leaders elected by their community, who have the responsibility to encourage collective works for common benefits, organize community work and social development projects, and establish agreements between neighbors to solve conflicts such as those associated with the distribution of resources and common lands (Ortega Olivares, 2010). Common to both communal lands and indigenous areas is the legal and spatial capacity (i.e. independent governance supported by local authorities and areas with public open spaces) to organize different communities with a local-scale and community-led approach to decentralized resource management while preserving their cultural heritage, identity, and habitat.

*Existing UM studies*

The use of a UM approach to study Mexico City is still limited to few research projects. Depending on the discipline and focus of the study, these vary with regard to the metabolic flows analyzed and scale of study (Delgado-Ramos, 2013, 2015a, 2015b, 2021; Guibrunet et al., 2017; Hoornweg et al., 2011; Huerta-Barrientos, 2018; Kennedy et al., 2015; Páez, 2010). However, the translation of these studies into spatially explicit accounts (e.g., GIS mapping) of resource flows/stocks and an understanding of the role of OSN in resource management in Mexico City are still limited to date. Researchers have used UM frameworks to study the configuration of waste management systems, drinking water consumption and water infrastructure (distribution system and sewer network) from an urban political ecology perspective (Delgado-Ramos, 2015b; Guibrunet et al., 2017). Other studies have focused on the impact of material flows on GHG emissions (Delgado-Ramos, 2015a; Hoornweg et al., 2011) and the assessment of a social-ecological metabolism (Huerta-Barrientos, 2018), included Mexico City in a comparative study of 27 megacities worldwide (Kennedy et al., 2015), and examined the potential benefits of urban energy transition (Páez, 2010). Guibrunet et al. (2017) studied the role of the informal sector in the collection and recycling of municipal solid waste (MSW) in areas of Mexico City where municipal waste collection services are not available. They focused on urban waste flows in the *Tepito* neighborhood (*Cuauhtémoc* borough), where, following the development of a parallel political structure by local leaders (*caciques*), basic services were provided in exchange for an informal tax paid to the local community. MSW flows were mapped to understand the available distribution and disposal infrastructures, to compare the public, private, and informal waste management systems, and study their interdependence. However, the approach proposed by Guibrunet et al. did not encompass a spatially explicit accounting of MSW flows (e.g., GIS map with solid waste generation by borough or AGEB). Delgado-Ramos (2015b) described the environmental and economic challenges arising from the development of the drinking water distribution system. In particular, he studied the inflow of bottled water (the most common solution for consuming drinking water in Mexico City), inequalities in the distribution and access to drinking water across high/low-income boroughs (which can have a difference of 3 to 1 in total per capita consumption), as well as the social movements for environmental justice related to water accessibility.

In conclusion, based on the results of our preliminary context analysis and previous UM studies, Mexico City provides a relevant case study for our research due to: *i*) its complex and energy-intensity infrastructure for water extraction, distribution and drainage, *ii*) a large population living in informal settlements and low-income neighborhoods that are more vulnerable to resource access and public space; *iii*) the high concentration of common lands, indigenous areas, resource infrastructure, and nature reserves in several areas of the city.

### *3.2 Methodology*

We performed a Geographic Information System (GIS)-based assessment of the metabolism of Mexico City at two urban scales: city administrative boundary (including the 16 boroughs) and borough scale. These scales were investigated through the compilation of primary GIS data (see supporting information) and the following available datasets: (1) resource flows, including drinking water consumption and wastewater outflows, electricity consumption, generation of organic and inorganic MSW, and construction solid waste (CSW); (2) location and capacity of utility infrastructure and resource management facilities; (3) geographic features of the city (e.g., topography and land-use cover areas), including OSN; (4) location of vulnerable communities; and (5) location of indigenous areas and communal lands and their administrative limits.

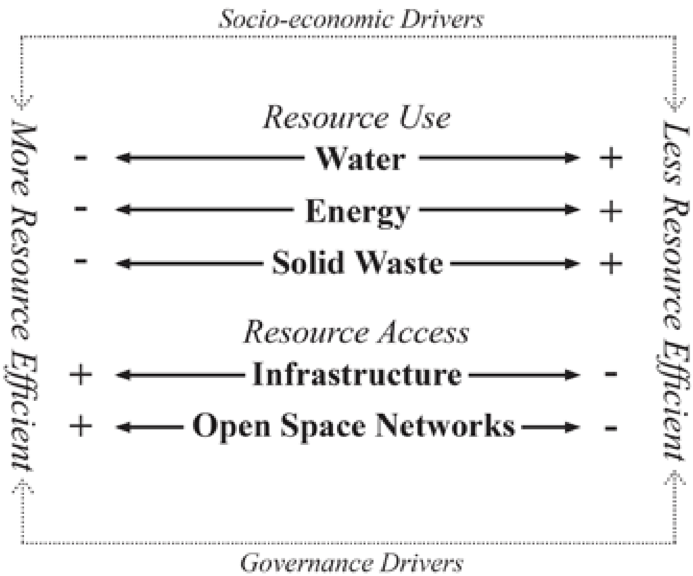
Resource infrastructure datasets include main generation, distribution, and storage facilities within the city administrative boundary (electrical power plants and substations, water distribution system and sewage network, recycling and compost plants). OSN datasets include public and private green spaces (parks and gardens), blue spaces (rivers, streams, channels, and lakes), gray spaces (squares and pedestrian walkways), and nature reserves.

Vulnerable communities' datasets include location data for informal settlements and areas with a high urban marginality index. The urban marginality index was presented in the *Mexico City Resilience Strategy* report (CDMX Resilience Office, 2016); we used it to assess the overall degree of deprivation for the population in each *AGEB* based on a set of socio-economic variables. These include percentage of children without access to education, population without access to health services and high death rate at birth, as well as population living in houses with dirt floors and not connected to the water and sewage system.

#### *3.2.1 Borough Pattern Scan*

After mapping the selected GIS layers, a detailed analysis of per capita data patterns was performed for each borough. The boroughs were classified according to their (high/low) resource efficiency. We intentionally use a broader definition of resource efficiency, which is intended to be an optimal combination of low resource use (UM flows) and high resource access (resource infrastructure and OSN). Boroughs were classified as more resource efficient if they had lower resource use (less resource consumption and waste generation than the city average) and higher resource access than the city average; inversely, boroughs with higher resource use and lower resource access were classified as less resource efficient (see *Figure 3.2*).

The criterion used to analyze resource use was the total per capita amount of resource consumption (for water and energy flows) or generation (for solid waste flows). For resource access, the criteria used were the location and capacity of resource infrastructure by type of flow, and the location of OSN. Each criterion is characterized by sub-criteria (see *Table S3.2* in the *Supporting Material*), which were defined using spatially explicit data. The *Borough Pattern Scan* allowed for the identification and classification of areas with high or low resource efficiency based on resource consumption/infrastructure and urban space availability (i.e., OSN). Spatially explicit socio-economic datasets were used to characterize resource efficiency by identifying communities affected by resource vulnerability (informal settlements and areas with high urban marginality index), and decentralized resource management structures (communal lands and indigenous areas).




To classify the boroughs, each sub-criterion was evaluated using a value index (see *Table S3.3* in the *Supporting Material* for details on calculations). A “1” score was assigned to the highest value of each sub-criterion and a “0” score in case of a null value. Then, the scores for the remaining sub-criteria were proportionally calculated based on comparison with the highest score. For example, *Cuauhtémoc* had the highest quantity of MSW generation per capita and was evaluated with a score of 1; *Iztapalapa* had half as much MSW generation per capita and was evaluated with a score of 0.5. The final score of each criterion corresponds to the mean of all scores assigned to its sub-criteria (e.g., the values assigned to solid waste flows of all boroughs were calculated as mean values of the sub-criteria MSW and CSW generation). Finally, to highlight high/low scores for each criterion, criteria with scores above the mean score were marked with a “+” symbol and those under the mean score with a “-” symbol.

*Figure 3.2: Resource efficiency framework diagram.*

### *3.3 Results*

*Table 3.1* illustrates the quantification and classification of all data used in the GIS analysis by criteria and for each of the 16 boroughs; sub-criteria with values 10% above the average are highlighted in red, while orange is used for average values, and gray for values 10% below the average. All values are on a unit-per-capita basis, except for the vulnerable communities, communal lands, and indigenous areas criteria, in which values are provided based on total square kilometers by borough.

The first set of maps refers to the spatial distribution of resource flows and utility infrastructure by borough (*Figures 3.3*, *3.4*, and 3.*5*), including total and per capita resource use, and the location of resource infrastructure, administrative/storage facilities, and main distribution network. The second set of maps includes the distribution of OSN (*Figure 3.6*), and the location of areas characterized by vulnerable communities, communal lands, and indigenous areas (*Figure 3.7*). Results of the Borough Pattern Scan are presented in *Figure 3.8*, including a set of tables (*Figure 3.8a*) and a synthesis map (*Figure 3.8b*), in which the spatial distribution of resource infrastructure, OSN, and vulnerable communities within communal lands and indigenous areas are overlaid to highlight in-boundary spatial relation dynamics (e.g., location, elevation, overlapping, type of boundaries, closeness). The synthesis map allows for identification of the OSN or their components; it can be used to mitigate context-specific resource-related vulnerabilities and enhance resource-efficient urban and landscape planning strategies.

#### *3.3.1 Resource use*

The result of our mapping highlights that boroughs in the city center (*Azcapotzalco*, *Benito Juárez*, *Cuauhtémoc*, *Miguel Hidalgo*, and *Venustiano Carranza*) have the highest resource use per capita compared to the per capita average for Mexico City as a whole. The lowest resource use is concentrated in two areas of the city: the northeastern boroughs with vulnerable communities (*Gustavo A. Madero*, *Iztacalco*, and *Iztapalapa*) and the southern rural boroughs with the highest surfaces of informal settlements (*Milpa Alta*, *Tlalpan*, *Tláhuac*, and *Xochimilco*). In Mexico City, average water consumption is 350 l/day/capita, and electricity consumption is 1,753 kWh/year/capita. Five out of the 16 boroughs generate more municipal solid waste per capita than the average (1.42 kg/day), of which all except *Xochimilco*, are located in the city center and encompass more than 50% of the illegal dumping sites.

#### *3.3.2 Resource infrastructure*

Southern boroughs with rural areas are best equipped with water supply infrastructure compared to all other boroughs, while northern boroughs concentrate most solid waste infrastructure in the city and a borough in the city center has the most energy infrastructure. Even though almost every borough has a MSW transfer station, the average pickup radius distance to the transfer station is between 5 km and 12 km, which increases transport distance and, therefore, the associated fossil fuel consumption. Southern rural areas are crossed by 90 km of the *Cutzamala-Lerma* aqueduct and the electrical power main distribution system. Almost 50% of all rural areas are not equipped with any MSW treatment facility, and the only compost plant in the city is located in the northern urban area of *Venustiano Carranza*, more than 30 km away from the agricultural areas.

In *Iztapalapa*, the *Cerro La Estrella* natural reserve areas concentrate 50% of all informal settlements. These areas are less than 9 km away from the *Bordo Poniente* compost plant and 4 km away from the *Central de Abastos* food-supply complex, which encompasses the two MSW treatment plants. *Gustavo A. Madero* contains the highest number of MSW facilities (including the only recycling plant in the city). The recycling plant is located at the eastern side of the borough and centralizes all such facilities, increasing the distance for transportation of MSW from other areas. The location and proximity of vulnerable communities to the MSW infrastructure and OSN is similar in the two boroughs. As we will see in the *Discussion* section, this points to a potential use of existing open spaces to enhance resource harvesting while improving its accessibility.

### *3.3.3 Open space networks*

The OSN map (*Figure 3.6*) shows the existing typologies of open spaces and highlights how urban areas contain almost 90% of all the public green-gray spaces. In comparison, rural areas contain more than 92% of the nature reserves, agricultural fields, and blue spaces. Results show that the average quantity of green-gray-blue open spaces available in Mexico City is 3.14 $m^2$/inhab. This is significantly lower than in other cities with similar population density, as for example Madrid, Spain, where it reaches 14 $m^2$/inhab. (ADB IDB, 2014). The highest quantities of public green spaces per capita in urban areas are found in central boroughs that concentrate low amounts of areas with high urban marginality index and informal settlements, such as *Miguel Hidalgo* and *Coyoacán*, where they reach 14 $m^2$/inhab. and 7 $m^2$/inhab., respectively. Three of the five boroughs with the lowest quantities of public green spaces (less than 1$m^2$/inhab.), *Iztapalapa*, *Gustavo A. Madero*, and *Xochimilco*, concentrate 38% of the total population of Mexico City and the largest amount of areas with informal settlements and a high urban marginality index (44 $km^2$ and 30 $km^2$ respectively), revealing the inequalities in the distribution of OSN between vulnerable communities and other neighborhoods. *Milpa Alta* has the largest land area, with 269 $km^2$, the lowest population (137,000 inhabitants), and the lowest electricity consumption (371 kWh/year/capita) in the city. Nature reserves extend over three quarters of the borough's total land area, and the only waste-to-energy plant is located in the northern zone, more than 20 km away from the southern agriculture areas.

*Table 3.1: Evaluation and classification of all criteria and subcriteria used in the analysis by borough. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| Administrative limit | Water (W) W flows | | W infrastructure capacity and total number of facilities | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Boroughs | Water consumption (l/day/cap) | Waste water discharge (l/day/cap) | Aqueducts capacity (l/day/cap) | Extraction wells (l/day/cap) | Treatment plants (l/day/cap) | Water pump facilities (l/day/cap) | Water tanks (l/day/cap) | Sewage treatment plants (l/day/cap) | Dams (l/day/cap) |
| Álvaro Obregón | 321 | 6 | 122 | 114 (33) | 0 (0) | 337 (14) | 454 (31) | 32 (1) | 3,994.76 (1) |
| Azcapotzalco | 404 | 16 | 0 | 220 (3) | 24 (2) | 0 (0) | 0 (0) | 5 (1) | 0 (0) |
| Benito Juárez | 406 | 14 | 0 | 145 (23) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Coyoacán | 355 | 7 | 0 | 324 (7) | 0 (0) | 236 (5) | 0 (0) | 114 (1) | 0 (0) |
| Cuajimalpa de Morelos | 293 | 7 | 655 | 26 (2) | 0 (0) | 1,011 (7) | 773 (18) | 0 (0) | 0.10 (1) |
| Cuauhtémoc | 332 | 25 | 0 | 34 (7) | 0 (0) | 0 (0) | 0 (0) | 4 (1) | 0 (0) |
| Gustavo A. Madero | 237 | 4 | 0 | 7 (3) | 20 (5) | 49 (2) | 160 (17) | 45 (2) | 0 (0) |
| Iztacalco | 219 | 5 | 0 | 66 (10) | 49 (1) | 74 (1) | 0 (0) | 54 (2) | 0 (0) |
| Iztapalapa | 235 | 4 | 0 | 87 (61) | 156 (27) | 236 (15) | 138 (23) | 142 (1) | 0 (0) |
| Magdalena Contreras | 554 | 3 | 563 | 21 (2) | 145 (2) | 1,062 (9) | 1,262 (20) | 18 (1) | 0 (0) |
| Miguel Hidalgo | 502 | 37 | 0 | 228 (12) | 0 (0) | 237 (3) | 211 (7) | 44 (2) | 0.77 (2) |
| Milpa Alta | 410 | 1 | 2,082 | 169 (9) | 0 (0) | 0 (0) | 2,471 (3) | 38 (1) | 0 (0) |
| Tláhuac | 210 | 2 | 0 | 79 (11) | 143 (2) | 398 (5) | 61 (2) | 128 (5) | 0 (0) |
| Tlalpan | 560 | 7 | 648 | 272 (13) | 0 (0) | 1,062 (23) | 1,153 (11) | 5 (4) | 0 (0) |
| Venustiano Carranza | 203 | 5 | 0 | 30 (5) | 16 (2) | 135 (2) | 26 (1) | 0 (0) | 0 (0) |
| Xochimilco | 374 | 3 | 150 | 505 (81) | 54 (8) | 415 (19) | 555 (21) | 37 (2) | 1.54 (1) |
| *Total* | - | - | - | - (460) | - (52) | - (94) | - (246) | - (25) | - (19) |
| *Average* | *351* | *9* | *263* | *145* (29) | *38* (3) | *341* (6) | *454* (15) | *42* (1) | *250* (1) |

| Administrative limit | Energy (E) E flows | E infrastructure capacity and total number of facilities | | | Solid Waste (SW) SW flows | | SW infrastructure capacity and total number of facilities | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Boroughs | Electricity consumption (kWh/day/cap) | Electrical power plant (kWh/day/cap) | Waste-to-energy electrical plant (kWh/day/cap) | Electrical substations (kVA/cap) | Municipal SW generation (kg/day/cap) | Construction SW generation (l/day/cap) | Transfer stations (kg/day/cap) | Compaction plants (kg/day/cap) | Recycling plants (kg/day/cap) | Compost plants (kg/day/cap) |
| Álvaro Obregón | 1,404 | 0 (0) | 0 (0) | 0.93 (4) | 0.91 | 0 | 12.93 (2) | 0 (0) | 0 (0) | 0.08 (1) |
| Azcapotzalco | 2,329 | 0 (0) | 0 (0) | 0.51 (1) | 1.30 | 0 | 20.32 (1) | 0 (0) | 0 (0) | 0 (0) |
| Benito Juárez | 2,767 | 0 (0) | 0 (0) | 0.82 (2) | 1.72 | 0.29 | 8.48 (1) | 0 (0) | 0 (0) | 0 (0) |
| Coyoacán | 1,726 | 0 (0) | 0 (0) | 1.47 (3) | 1.34 | 0.04 | 16.52 (1) | 0 (0) | 0 (0) | 0 (0) |
| Cuajimalpa de Morelos | 2,442 | 0 (0) | 0 (0) | 6.97 (1) | 0.94 | 0 | 0 (0) | 0 (0) | 0 (0) | 0.21 (1) |
| Cuauhtémoc | 3,740 | 1,070 (1) | 0 (0) | 2.70 (4) | 2.49 | 0 | 12.94 (1) | 0 (0) | 0 (0) | 0 (0) |
| Gustavo A. Madero | 1,088 | 0 (0) | 0 (0) | 0.44 (2) | 1.50 | 0 | 1.37 (1) | 2.04 (1) | 21.10 (1) | 0.05 (1) |
| Iztacalco | 1,215 | 0 (0) | 0 (0) | 1.59 (1) | 1.24 | 0.12 | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Iztapalapa | 1,063 | 0 (0) | 0 (0) | 1.04 (3) | 1.24 | 0 | 6.73 (2) | 3.80 (1) | 0 (0) | 0.01 (1) |
| Magdalena Contreras | 649 | 0 (0) | 0 (0) | 0.89 (1) | 1.08 | 0 | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Miguel Hidalgo | 4,672 | 0 (0) | 0 (0) | 0.94 (2) | 2.28 | 0 | 10.18 (1) | 0 (0) | 0 (0) | 0 (0) |
| Milpa Alta | 371 | 0 (0) | 0.46 (1) | 0 (0) | 0.88 | 0 | 4.13 (1) | 0 (0) | 0 (0) | 0.32 (2) |
| Tláhuac | 558 | 0 (0) | 0 (0) | 0 (0) | 1.00 | 0 | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Tlalpan | 1,275 | 0 (0) | 0 (0) | 0.20 (1) | 1.29 | 0 | 5.35 (1) | 0 (0) | 0 (0) | 0 (0) |
| Venustiano Carranza | 2,051 | 0 (0) | 0 (0) | 0.45 (1) | 2.02 | 0.63 | 11.28 (1) | 0 (0) | 0 (0) | 21,356.87 (1) |
| Xochimilco | 702 | 0 (0) | 0 (0) | 1.02 (2) | 2.24 | 0.31 | 8.39 (1) | 0 (0) | 0 (0) | 0.17 (1) |
| *Total* | - | - (1) | - (1) | - (20) | - | - | - (15) | - (2) | - (1) | - (5) |
| *Average* | *1,753* | *67* (0) | *0.03* (0) | *1.25* (2) | *1.47* | *0.09* | *7.41* (1) | *0.37* (0) | *1.32* (0) | *1,334.86* (1) |

| Administrative limit | Population Statistics | | Open Space Networks (OSN) | | | | | Vulnerable Communities | | Communal lands and Indigenous Areas | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Boroughs | Population (inhabitants) | Area (km²) | Public green spaces (m²/inhab) | Public blue spaces (m²/inhab) | Public gray spaces (m²/inhab) | Private green spaces (m²/inhab) | Nature reserves (m²/inhab) | Informal settlements (km²) | Areas with high urban marginality index (km²) | Communal lands (km²) | Indigenous areas (km²) |
| Álvaro Obregón | 749,982 | 97 | 2.67 | 0 | 0.02 | 8.51 | 38.04 | 0.18 | 2.10 | 0.92 | 2.32 |
| Azcapotzalco | 400,161 | 35 | 2.39 | 0 | 0.09 | 10.33 | 0 | 0 | 2.33 | 0 | 0 |
| Benito Juárez | 417,416 | 27 | 1.10 | 0 | 0.01 | 0.70 | 0 | 0 | 0 | 0 | 0 |
| Coyoacán | 608,479 | 54 | 7.04 | 0 | 0.20 | 8.70 | 0 | 0 | 0.29 | 0 | 0 |
| Cuajimalpa de Morelos | 199,224 | 81 | 2.81 | 0 | 0 | 25.75 | 213.54 | 2.61 | 8.05 | 2.25 | 4.14 |
| Cuauhtémoc | 532,553 | 32 | 1.03 | 0 | 0.37 | 2.77 | 0 | 0 | 0 | 0 | 0 |
| Gustavo A. Madero | 1,164,477 | 92 | 0.85 | 0.21 | 0.06 | 6.17 | 9.98 | 0.28 | 16.25 | 0 | 0 |
| Iztacalco | 390,348 | 22 | 0.24 | 0 | 0.08 | 7.96 | 0 | 0 | 0 | 0 | 0 |
| Iztapalapa | 1,827,868 | 106 | 1.68 | 0.18 | 0.01 | 8.55 | 2.58 | 0.24 | 28.16 | 0.47 | 0 |
| Magdalena Contreras | 243,886 | 62 | 0.27 | 0 | 0 | 4.02 | 187.11 | 0.24 | 3.79 | 0 | 2.76 |
| Miguel Hidalgo | 364,439 | 48 | 14.49 | 0 | 0.02 | 15.31 | 0 | 0 | 0 | 0 | 0 |
| Milpa Alta | 137,927 | 269 | 0.03 | 0 | 0.07 | 1.25 | 1,479.32 | 4.03 | 22.05 | 10.10 | 17.51 |
| Tláhuac | 361,593 | 85 | 2.17 | 8.31 | 0.03 | 10.08 | 42.18 | 4.28 | 7.79 | 8.40 | 8.96 |
| Tlalpan | 677,104 | 312 | 5.00 | 0 | 0.15 | 14.00 | 282.06 | 9.81 | 29.98 | 12.70 | 11.54 |
| Venustiano Carranza | 427,263 | 33 | 3.07 | 0.26 | 0.23 | 8.90 | 0 | 0 | 0 | 0 | 0 |
| Xochimilco | 415,933 | 125 | 0.53 | 5.56 | 0 | 5.90 | 72.99 | 5.71 | 24.89 | 0 | 9.74 |
| *Total* | *8,918,653* | *1,480* | - | - | - | - | - | - | - | - | - |
| *Average* | *557,416* | *92* | *2.84* | *0.91* | *0.08* | *8.69* | *145.49* | *1.71* | *9.10* | *2.18* | *3.36* |

*Water flows and infrastructure*

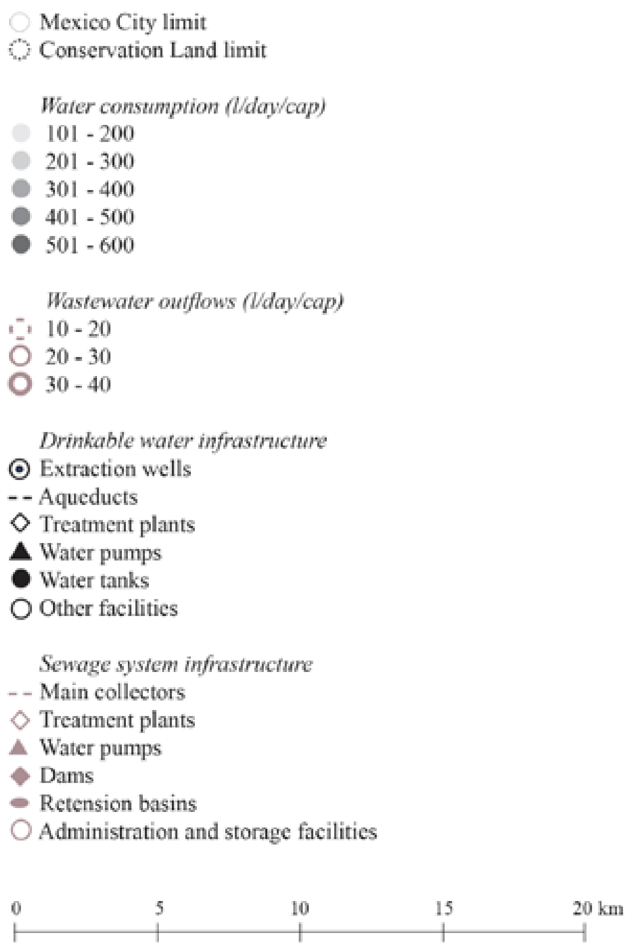
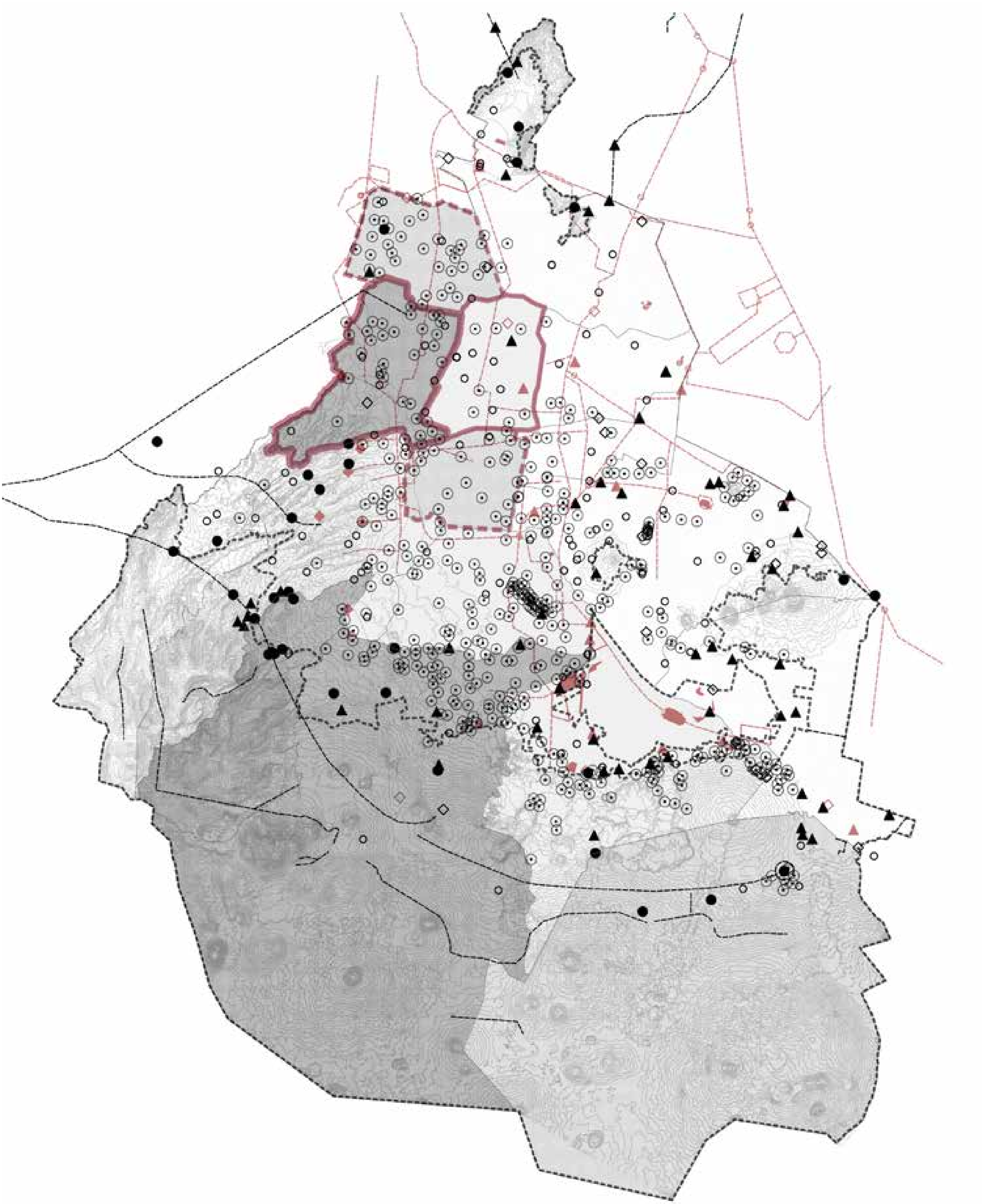



*Figure 3.3: Spatial distribution of drinking water and sewage system flows and infrastructure. Water consumption and wastewater outflows are quantified by borough. The location of infrastructure, resource management facilities, and main networks for drinking water and sewage system are highlighted with specific symbols and colors by type. Underlying data for this figure are available in Table S3.3 of the Supporting Material.*



*Energy flows and infrastructure*

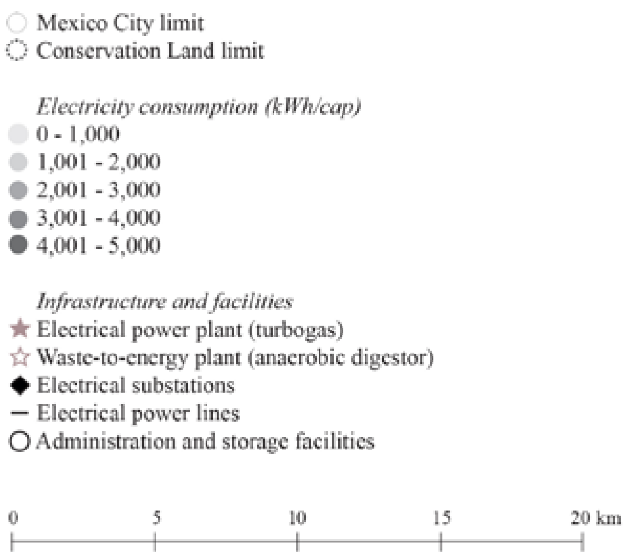
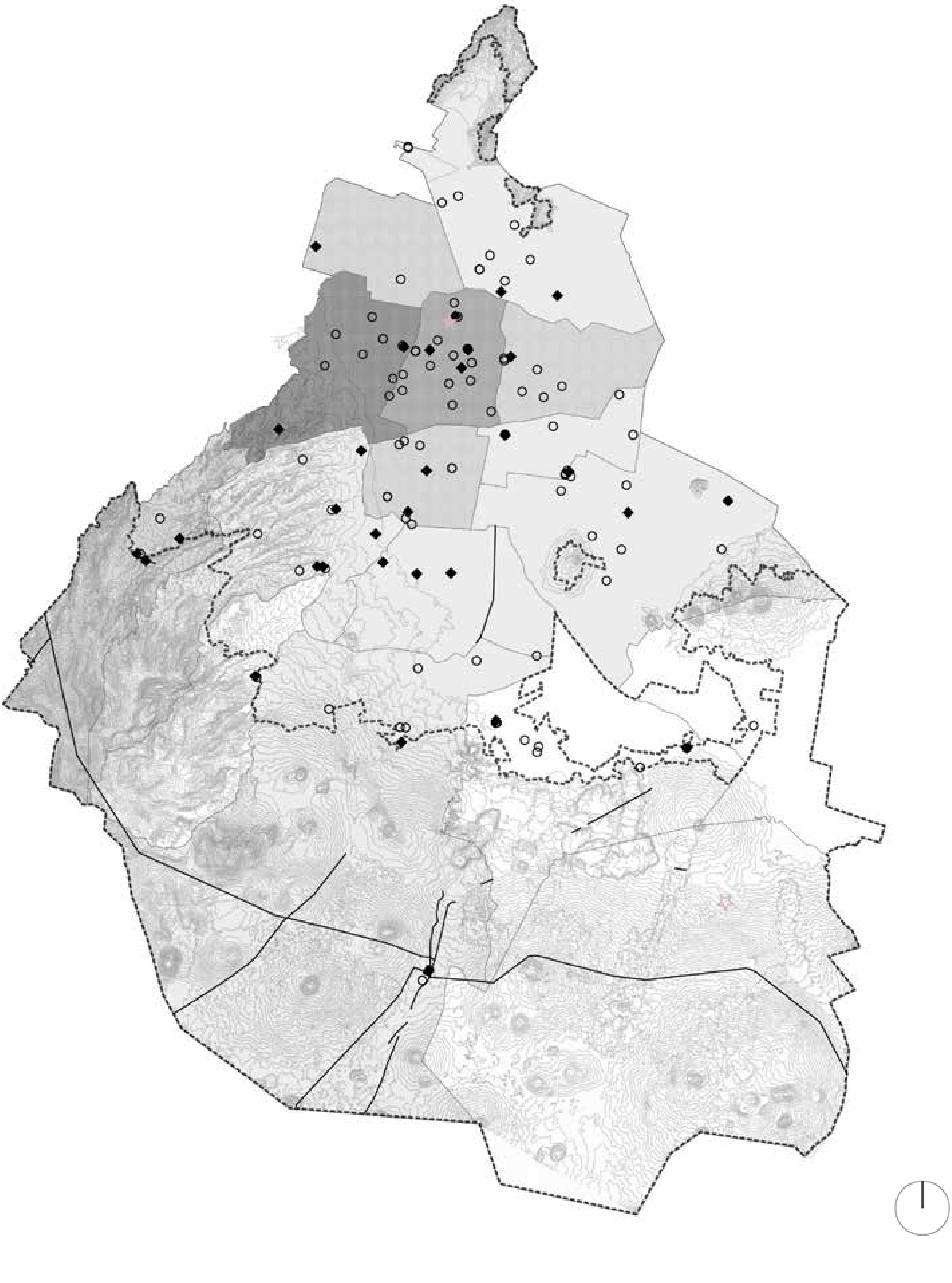



*Figure 3.4: Spatial distribution of electrical energy flows and infrastructure. Electricity consumption is quantified by borough. The locations of the infrastructure, resource management facilities, and main distribution network are highlighted with specific symbols and colors by type. Underlying data for this figure are available in Table S3.3 of the Supporting Material.*



Solid waste flows and infrastructure

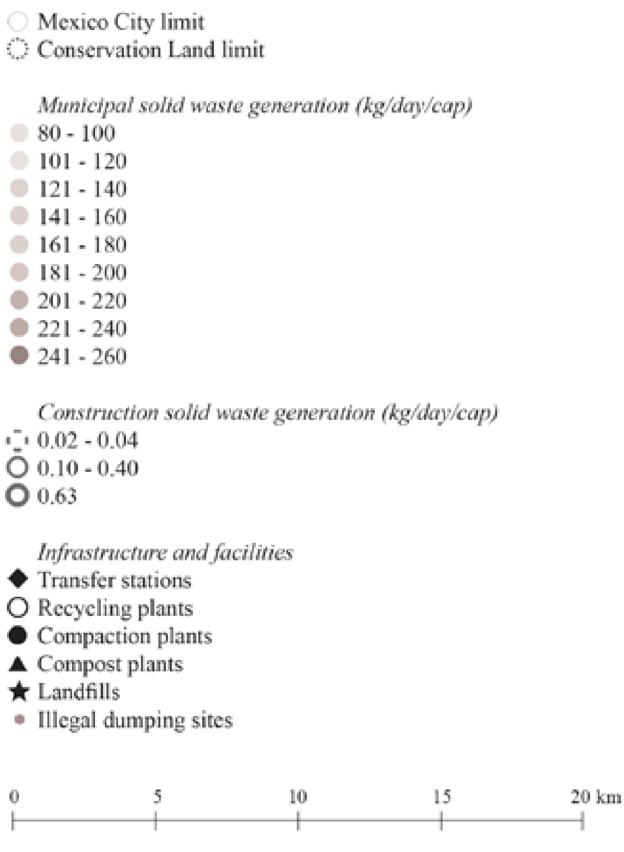
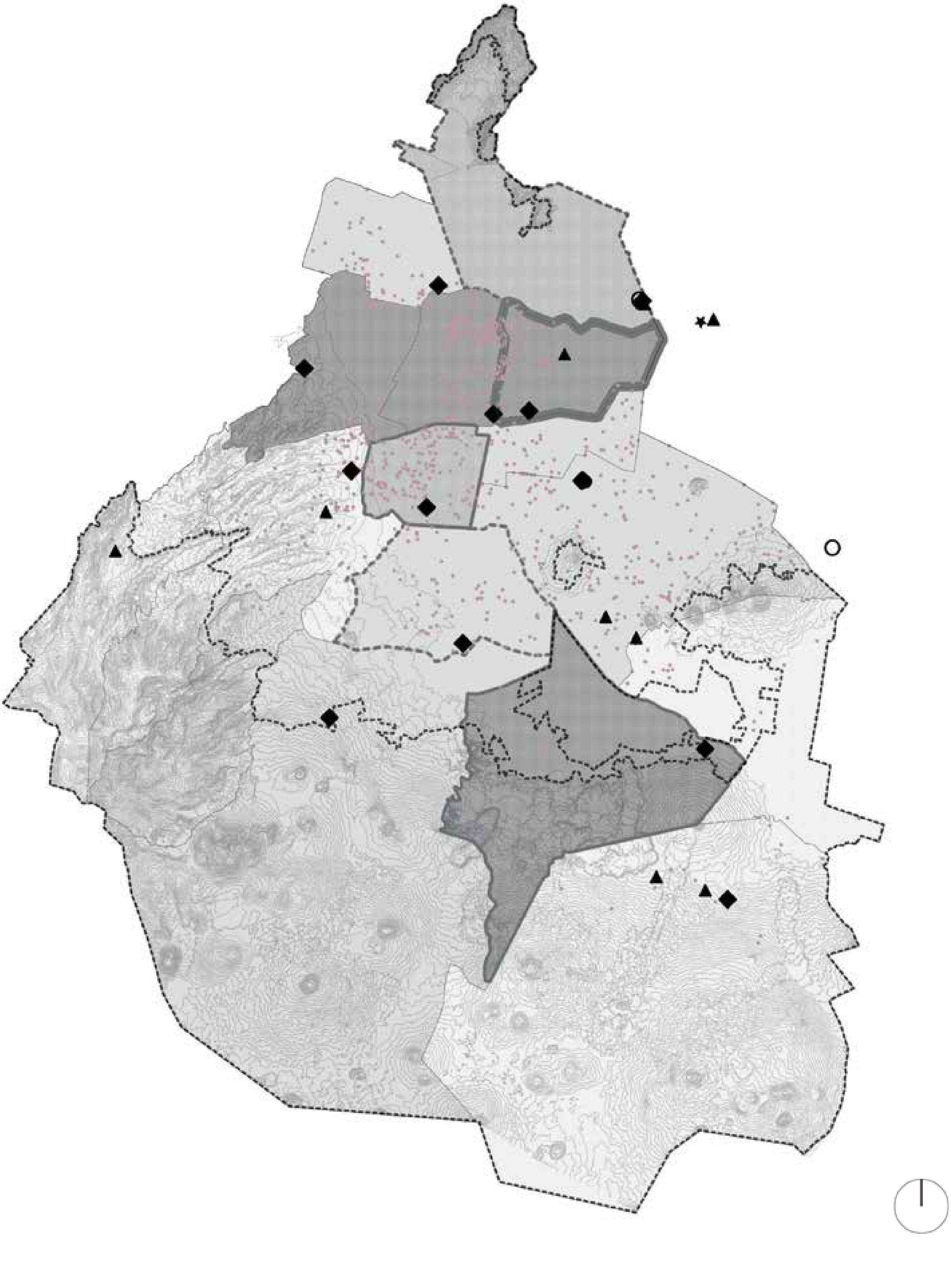



*Figure 3.5: Spatial distribution of solid waste flows and infrastructure. Municipal solid waste (MSW) and construction solid waste (CSW) are quantified by borough. Locations of the infrastructure and resource management facilities are highlighted with specific symbols and colors by type. Underlying data for this figure are available in Table S3.3 of the Supporting Material.*



*Open space networks*

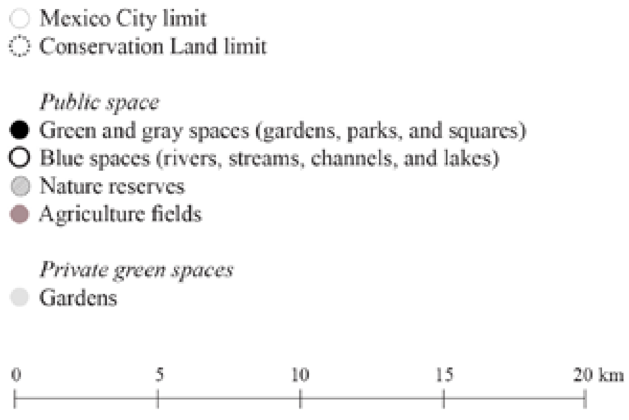
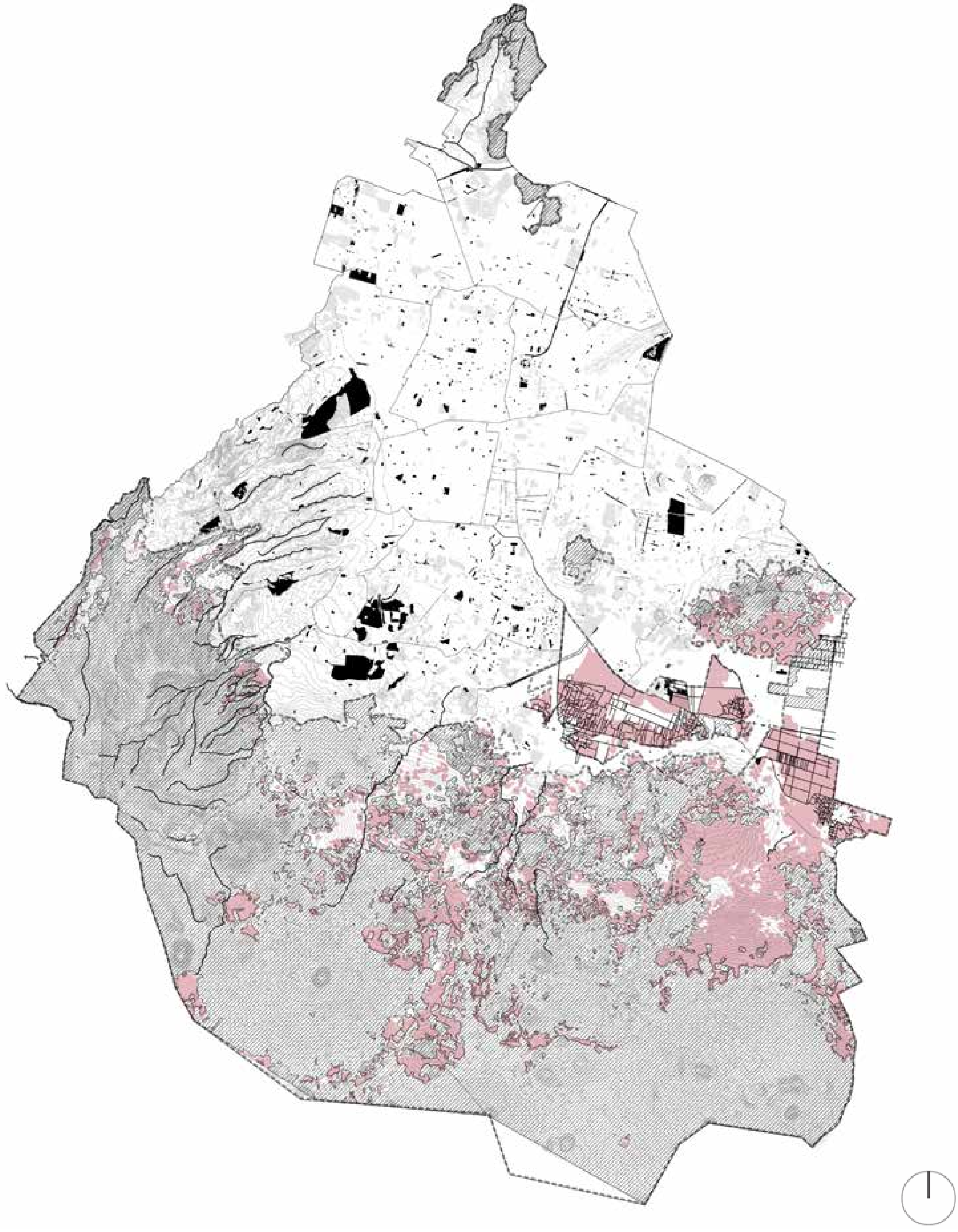



*Figure 3.6: Spatial distribution of the open space networks (OSN). Underlying data for this figure are available in Table S3.3 of the Supporting Material.*



*Vulnerable communities*

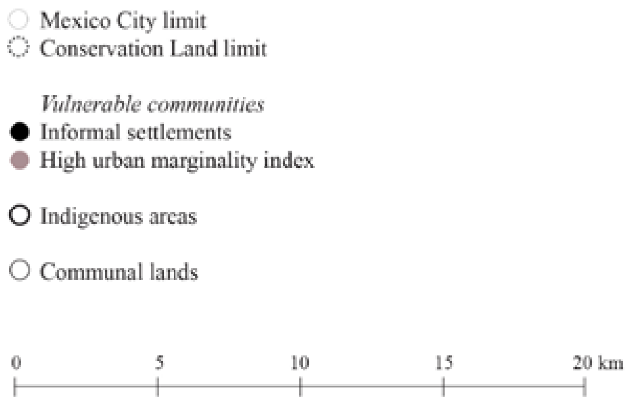
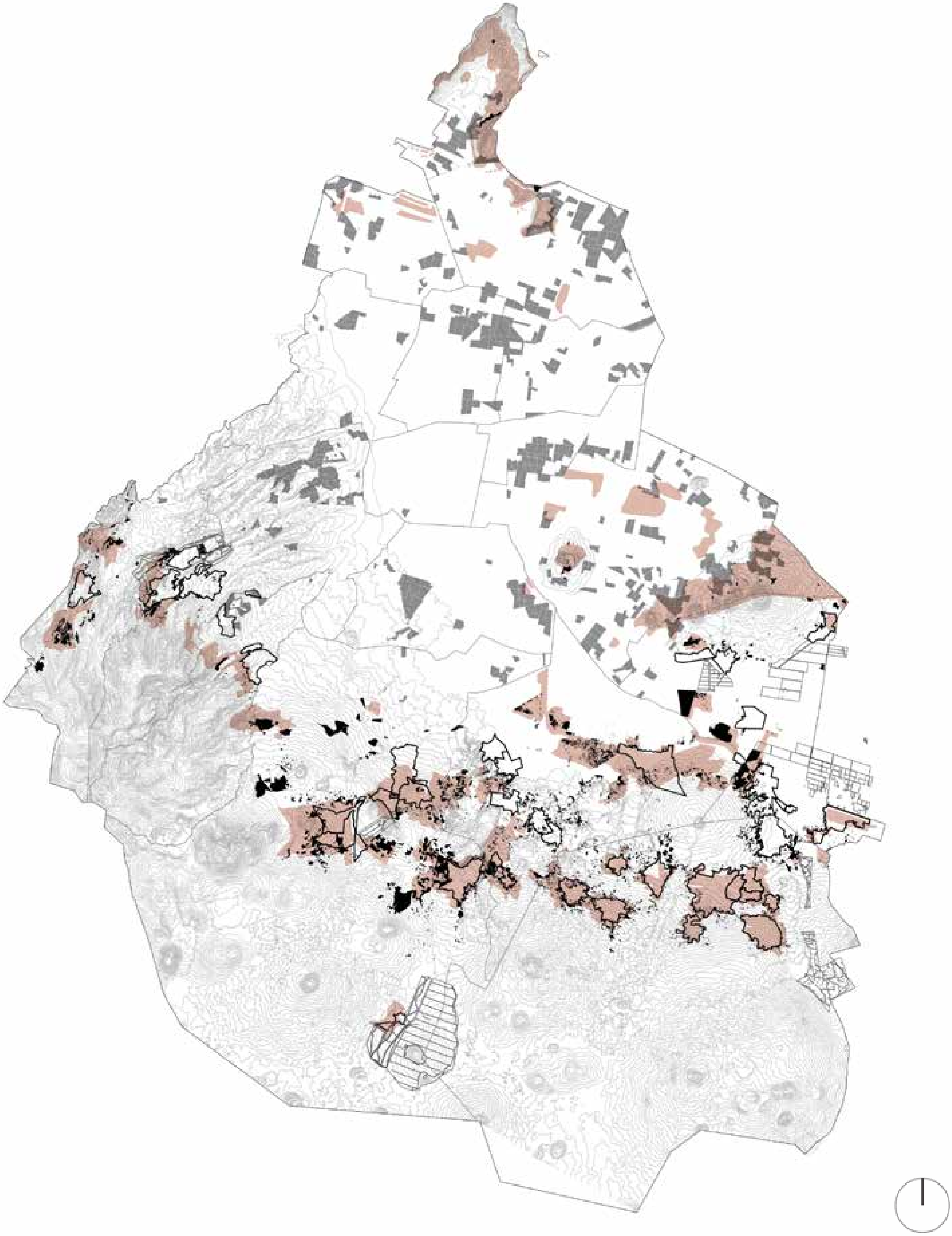



*Figure 3.7: Spatial distribution of the vulnerable communities, communal lands, and indigenous areas. Underlying data for this figure are available in Table S3.3 of the Supporting Material.*



## Borough Pattern Scan

### *a. Resource Efficiency Classification*

*W: Water, E: Energy, SW: Solid Waste, Infra: Infrastructure, OSN: Open Space Networks.*

| *Administrative limit* | **Resource Use (RU)** *UM flows* | | | **Resource access (RA)** *Resource infrastructure / Open Space Networks* | | | | **Resource Efficiency (RE)** *Classification based on RU and RA values* | |
|---|---|---|---|---|---|---|---|---|---|
| *Boroughs* | *W flows index* | *E flows index* | *SW flows index* | *W infra index* | *E infra index* | *SW infra index* | *OSN index* | *RE Rating* | *Less-efficient criteria* |
| 1. Álvaro Obregón | - 0.37 | - 0.30 | - 0.18 | + 0.27 | - 0.04 | + 0.20 | - 0.16 | High | E infrastructure, and OSN |
| 2. Azcapotzalco | + 0.57 | + 0.50 | - 0.26 | - 0.08 | - 0.02 | + 0.31 | - 0.20 | Low | W and E efficiency, and OSN |
| 3. Benito Juárez | + 0.56 | + 0.59 | + 0.57 | - 0.04 | - 0.04 | - 0.13 | - 0.04 | Very Low | All resources efficiency, and OSN |
| 4. Coyoacán | - 0.41 | - 0.37 | - 0.30 | - 0.21 | - 0.07 | + 0.25 | + 0.37 | High | SW infrastructure |
| 5. Cuajimalpa de Morelos | - 0.36 | + 0.52 | - 0.19 | - 0.20 | + 0.33 | - 0.00 | + 0.31 | Medium high | E flows, W and SW infrastructure |
| 6. Cuauhtémoc | + 0.63 | + 0.80 | + 0.50 | - 0.01 | + 0.46 | + 0.20 | + 0.25 | Medium low | All resources flows and W infrastructure |
| 7. Gustavo A. Madero | - 0.26 | - 0.23 | - 0.32 | - 0.10 | - 0.02 | + 0.41 | - 0.11 | Medium high | SW infrastructure and OSN |
| 8. Iztacalco | - 0.26 | - 0.26 | - 0.34 | - 0.11 | - 0.08 | - 0.00 | - 0.11 | Medium low | All resources infrastructure and OSN |
| 9. Iztapalapa | - 0.26 | - 0.23 | - 0.25 | + 0.43 | - 0.05 | + 0.35 | - 0.12 | High | E infrastructure and OSN |
| 10. Magdalena Contreras | + 0.54 | - 0.14 | - 0.22 | + 0.36 | - 0.04 | - 0.00 | - 0.06 | Medium low | W efficiency and OSN |
| 11. Miguel Hidalgo | + 0.95 | + 1.00 | + 0.46 | - 0.13 | - 0.05 | - 0.15 | + 0.23 | Low | All resources efficiency |
| 12. Milpa Alta | - 0.38 | - 0.08 | - 0.18 | + 0.32 | + 0.33 | - 0.06 | + 0.25 | High | SW infrastructure |
| 13. Tláhuac | - 0.22 | - 0.12 | - 0.20 | + 0.32 | - 0.00 | - 0.00 | + 0.36 | High | E and SW infrastructure |
| 14. Tlalpan | + 0.59 | - 0.27 | - 0.26 | + 0.29 | - 0.01 | - 0.08 | + 0.37 | Medium high | W flows, E and SW infrastructure |
| 15. Venustiano Carranza | - 0.25 | + 0.44 | + 0.91 | - 0.06 | - 0.02 | + 0.42 | + 0.29 | Medium low | W and E infrastructure |
| 16. Xochimilco | - 0.38 | - 0.15 | + 0.70 | + 0.36 | - 0.05 | - 0.13 | - 0.20 | Medium low | SW efficiency, E infrastructure and OSN |


Figure 3.8: Borough Pattern Scan results by type of resource flow. Synthesis map overlapping resource infrastructures, public OSN, productive landscapes, and vulnerable communities within communal lands and indigenous areas.. Underlying data for this figure are available in Table S3.3 of the Supporting Material.

Mexico City limit
Conservation Land limit

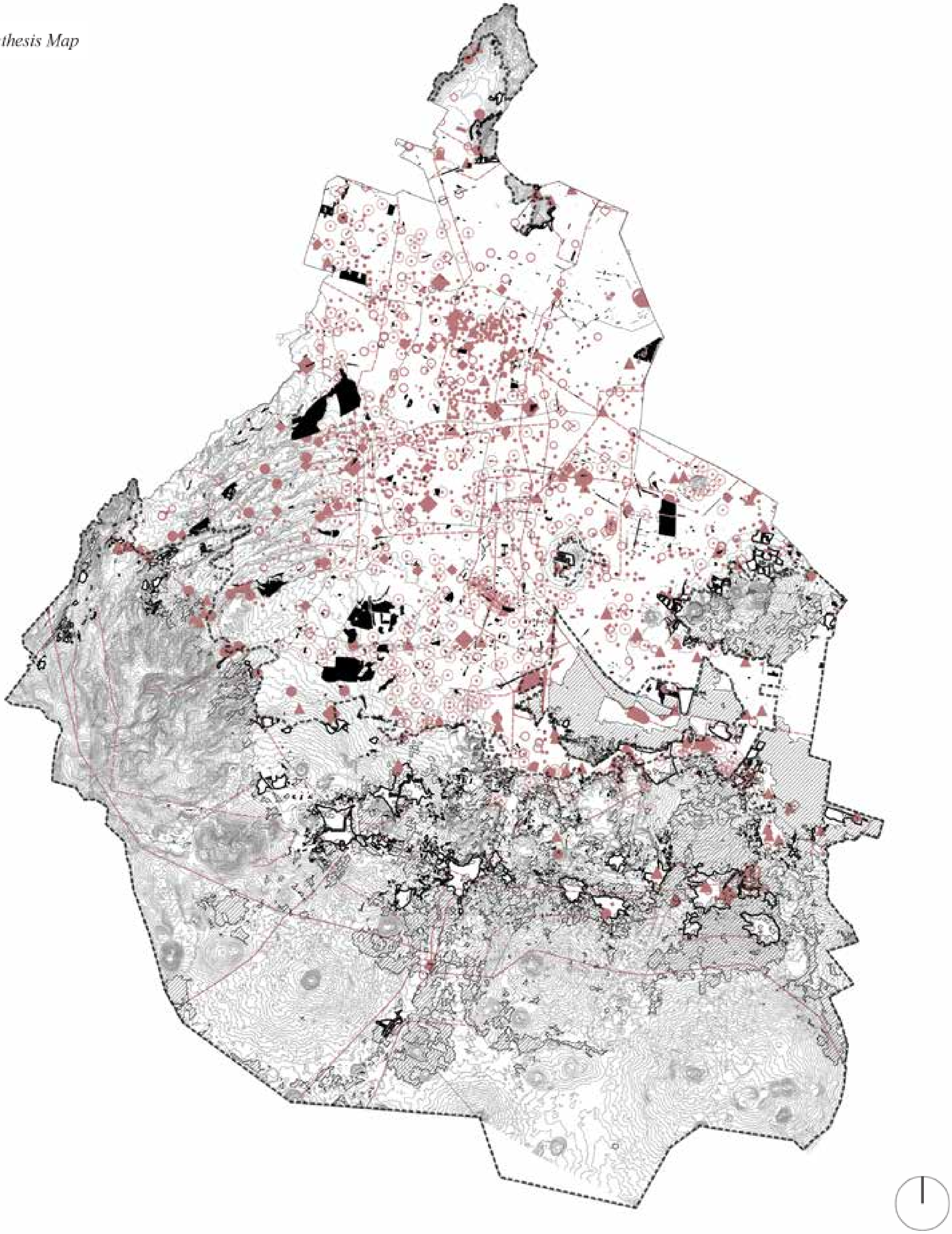
Resources infrastructure

*Geographic features*
Public open space networksw
Productive landscapes

*Informality, vulnerability*, and *governance*
Vulnerable communities

0 5 10 15 20 km

*b. Synthesis Map*



### *3.4 Discussion*

#### *3.4.1 OSN as a medium to increase resource efficiency*

The table and maps presented in the *Results* section highlight the location and proximity of areas in which urban flows and infrastructure are concentrated, both at the city and the borough scale. Our aim is to present a methodological strategy to investigate how spatially explicit information and data on resource use, resource infrastructure, and OSN can improve the applicability of UM assessments in the planning and management of green-blue-gray public spaces. We focused on OSN as a medium to increase resource efficiency while considering the specific socio-economic conditions of vulnerable communities as well as the assets of the local natural capital.

While Mexico City counts 67 $m^2$ of public green areas per inhabitant, including the nature reserves, these areas are not equally distributed across all parts of the city; they can vary depending on the type of spaces included (e.g., squares, parks, nature reserves) or type of calculation (e.g., based on ground cover or tree coverage) as shown in previous research (Maldonado-Bernabé et al., 2019; PAOT, 2018). In rural areas, our results show that the available public green area is limited to 3.44 $m^2$/inhab.; this does not include nature reserves within the Conservation Land, which are not considered to be accessible (lack of pathways and benches for elderly and disabled people), nor safe (lack of illumination increasing the feeling of insecurity), nor functional (lack of facilities such as public toilets) to all inhabitants (WHO World Health Organization, 2010). Previous research demonstrated that the distribution of public green areas per inhabitant in Mexico City is directly related to each borough's socio-economic characteristics, with lower quantities of green areas in lower-income neighborhoods (Checa-Artasu, 2016; Fernández-Álvarez, 2017). We identified seven boroughs that have lower quantities of public green areas (less than 9 $m^2$/inhab.), including four boroughs with high resource use: *Azcapotzalco*, *Benito Juárez*, *Cuauhtémoc*, and *Venustiano Carranza*. Future plans to increase available green space in these boroughs could provide opportunities for integrating new utility infrastructure to improve resource access and enhance the transition from a linear to a circular metabolism.

*Xochimilco* has the second-highest MSW generation rate in the city (2.24 kg/day/capita). The borough could benefit from its productive agricultural land to reinforce the existing local composting systems, create new organic waste treatment plants, produce energy from waste (e.g., composting, anaerobic digestion), increase energy access for the local population, and provide compost and digestate for future agriculture production. Synergies among different urban functions could lead to mutual benefit in terms of resource cycling, especially for fertilizers and energy production (Wielemaker et al., 2018). Previous research in other contexts studied the energy potential from composting and incinerating all organic MSW; for example, in Denmark, this would be equivalent to 5% of the country's total energy consumption, including transport (Lehmann, 2011). The use of under- or unused surfaces in and around infrastructure facilities could be used to install renewable energy systems (e.g., photovoltaic panels). Previous studies suggest that, depending on the total amount of available area and local climatic characteristics, this energy could be used for private or public transport (Neumann et al., 2012), reducing fossil fuel consumption and associated GHG emissions while promoting the use of underexploited surfaces in the city to produce energy (among other benefits).

#### *3.4.2 Decentralized and multifunctional planning of OSN*

A long-term overexploitation of the city's underground aquifers and its complex drainage system has resulted in the depletion of the aquifers, causing shortages in the water supply system and subsidence in some areas of the city (Legorreta, 2006). To meet 42% of total urban water demand (SACMEX, 2018), the *Cutzamala-Lerma* system, an energy-intensive and expensive drinking water system (Tortajada, 2006), pumps water to Mexico City from rivers more than 1,000 km away. About 2.280 million kWh are required to pump all this water, equivalent to the total electricity consumption of the 6.5 million inhabitants of the neighboring city of Puebla (SACMEX, 2012).

Building on the assessment of resource use and available areas of OSN at the borough scale as summarized in the Borough Pattern Scan, planning strategies can be proposed to increase the accessibility and efficient use of these resources. For instance, highly urbanized boroughs with high drinking water consumption per capita can expand their water supply system by adding decentralized infrastructures. Since 2019, the Mexico City SCALL (*Sistema de Captación de Aguas de Lluvias*) program has developed rainwater harvesting (RWH) solutions for individual homes in boroughs with water accessibility issues. Although the number of beneficiaries increases every year, a considerable part of the city's vulnerable population is unable to benefit from the program, due to a lack of required official documentation such as residence certificates and planning permits (SEDEMA, 2019). Planning communal RWH systems in public spaces and in available, underused resource facilities (e.g., roofs and parking lots of water/electricity plants) can contribute to mutualizing efforts, reducing material costs, improving water accessibility for vulnerable communities, and reducing pressure on the current energy-intensive drinking water system through local and decentralized solutions (Agudelo-Vera et al., 2012; Valdez et al., 2016). Boroughs with high water consumption, in which utility infrastructures are mostly located in agricultural areas (e.g., *Milpa Alta*), could benefit from state-of-the-art design solutions for linear water catchment parks (Ibrahim et al., 2020). These could be constructed alongside existing aqueducts or below electric lines for use in agriculture irrigation, which could create an alternative or supplementary irrigation system and increase water storage capacity through wetland planning and landscaping. Moreover, the planning of a mixed RWH system on rooftops and publicly open green infrastructure could increase water accessibility for households not connected to the primary water drinking system while contributing to improving the connectivity of the whole OSN. As demonstrated in previous research, RWH systems can reduce household water and energy consumption as well as the overexploitation of groundwater consumption by providing an alternative water source, while preventing flooding by reducing stormwater flows in the rainy season (Jalife Acosta et al., 2018; Legorreta, 2006; Nanninga et al., 2013; Valdez et al., 2016).

Previous studies have demonstrated that informal settlements, together with other public and private infrastructure (e.g. highways and housing developments), contribute to the erosion of green areas in boroughs within the *Conservation Land* due to housing shortage and limited land accessibility (Aguilar & Santos, 2011). GIS mapping and spatial calculation are affecting the social construction, environmental impact, and regulation processes of informal settlements in the *Conservation Land*, as they are now mapped and subject to urban planning regulations (Connolly & Wigle, 2017). Southern boroughs could reinforce existing urban development plans (*Programas Delegacionales de Desarrollo Urbano*), integrating individuals and organized groups within the communities involved to preserve and enhance local resources (e.g., forests, grasslands, and agriculture fields). Moreover, involving community leaders in participatory design processes and GIS data collection, would strengthen local socio-environmental organizations and favor the decentralization of resource management (Santos et al., 2015; Silva, 2013).

### *3.4.3 OSN and the multi-scale UM approach – Limitations*

The selection of system boundaries and resource datasets used in UM studies depend on the research objectives and the level of disaggregation of available data at different urban scales (e.g., region, borough, street, building). The use of resource flows datasets, based within an industrial ecology framework, and the use of socio-economic and open space location datasets provided a hybrid analytical framework that allowed us to assess impacts on vulnerable communities to achieve our research objectives. Moreover, integrating available fine-grain data at borough scale allowed identifying specific areas with disadvantaged socio-economic characteristics at the *AGEB* level, which favored a more detailed multi-scale approach. For example, our results showed that approximately half of the total areas with vulnerable communities are located within indigenous areas and one third of the total areas with informal settlements are located in communal lands and indigenous areas. However, limiting our study to Mexico City excluded the possibility of studying the spatial relationship between resource use and infrastructure within the entire urban system of the *Metropolitan Zone of the Valley of Mexico*, which is home to a growing population vulnerable to OSN availability and resource accessibility (OECD, 2015)

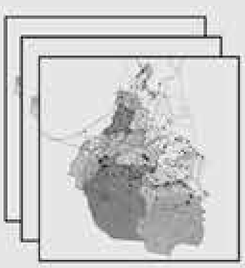
The use of the Borough Pattern Scan allowed us to classify spatially explicit data by resource type; through this, we were able to study their location, overlapping, and proximity in relation to the geographic and socioeconomic characteristics of Mexico City. However, this approach is limited in scope as it was focused on an analysis of per capita values at the borough scale, without allowing us to disaggregate values into areas of interest at the neighborhood scale. In addition, data on informal resource flows (e.g., solid waste collection and recycling by organized groups in communities) were not included in our study due to their limited availability. For the OSN datasets, information about land ownership was essential to pursue our research objectives based on publicly owned OSN. However, it is worth noting that the quantities of per capita private green areas (8.69 $m^2$) is almost triple that of public green areas (2.84 $m^2$ per capita). On the basis of current limitations, the Borough Pattern Scan could be calculated using different boundaries (e.g., AGEB, water catchments) in a specific urban area, adapting it to specific resource flows, its infrastructure, and internal diversity of OSN, to address future research objectives.

### *3.5 Conclusions*

Our research has provided a spatially explicit account of UM flows and infrastructure in Mexico City, integrating the mapping and assessment of OSN, and supported by datasets on vulnerable communities, communal lands, and indigenous areas. By presenting the *Borough Pattern Scan* and the spatialization of UM data on maps, we identified opportunities to increase resource efficiency by using OSN and their spatial configuration as a lever to sustainable urban and landscape planning. This research also contributed to a deeper understanding of the location and proximity of resource infrastructure and pointed to development opportunities for vulnerable communities in Mexico City. As shown in a previous study of the MSW system of Mexico City (Guibrunet et al., 2017), informal social organizations and alternative land/resource governance systems can engage different actors in the process of producing or transforming resource flows/stocks. The integration of socio-economic data in the UM study allowed us to identify spatial relations (and co-existence) between vulnerable communities, indigenous areas, and communal lands, which can enhance more resource-efficient urban and landscape planning strategies to mitigate vulnerabilities to resource access and enhance resource efficiency.

Despite limited access to spatially explicit datasets for Mexico City, we were able to compile spatially explicit UM datasets intended for use by planners and practitioners in planning and of OSN. This was possible by performing an integrated quantitative and qualitative spatial UM analysis based on classification of available GIS datasets as well as the plotting of existing quantitative data on maps. Then, through the use of *Borough Pattern Scan*, we could classify the type of spatial data needed to understand the dynamics of resource use and resource access and introduced the planning of OSN as a new strategy to leverage resource efficiency.

Based on the outcomes of our work, further research can focus on using finer-scale analysis for integrated UM and GIS analysis as a way to improve UM application in urban and landscape planning across different contexts. Such analyses can refine research results and provide a context- and community-specific understanding of metabolic dynamics, resource accessibility, resource governance and management, urban structure, economic and productive dynamics, and planning strategies for nature conservation. Spatially explicit data on informal resource extraction, distribution and consumption (e.g., illegal water wells) should be systematically integrated into future UM assessments to better express relations among resource intensity/availability and the configuration of OSN in vulnerable communities. This can enable researchers, practitioners and planners to jointly work toward decision-making and design strategies that could better respond to communities' ambitions toward more resilient and sustainable cities.



## ***Supporting Material***
## *Chapter 3 Resource Efficiency*
## *GIS-based data, mapping representation, and open space networks.*

*Summary*
This supporting material provides supplementary information that complements the methods and findings included in *Chapter 3*, including the compiled GIS datasets used in the study, the criteria and sub-criteria used to classify the boroughs, the *Borough Pattern Scan* detailed calculation by criteria, and a set of maps and tables including details of the selected boroughs analysis by resource flow type.

*This section was previously published for the supporting material of Chapter 3: Otero Peña, D., Perrotti, D., & Mohareb, E. (2022). Advancing urban metabolism studies through GIS data: Resource flows, open space networks, and vulnerable communities in Mexico City. Journal of Industrial Ecology, 26(4), 1333-1349. https://doi.org/https://doi.org/10.1111/jiec.13261. Compared to the published version, the formatting was changed.*

*Water (W)*

| ***Administrative limit*** | ***Index value classified by type*** | | |
|---|---|---|---|
| *Boroughs* | *W flows index* | *W infra index* | *OSN index* |
| Álvaro Obregón | - 0.37 | + 0.27 | - 0.16 |
| Azcapotzalco | + 0.57 | - 0.08 | - 0.20 |
| Benito Juárez | + 0.56 | - 0.04 | - 0.04 |
| Coyoacán | - 0.41 | - 0.21 | + 0.37 |
| Cuajimalpa de Morelos | - 0.36 | - 0.20 | + 0.31 |
| Cuauhtémoc | + 0.63 | - 0.01 | + 0.25 |
| Gustavo A. Madero | - 0.26 | - 0.10 | - 0.11 |
| Iztacalco | - 0.26 | - 0.11 | - 0.11 |
| Iztapalapa | - 0.26 | + 0.43 | - 0.12 |
| Magdalena Contreras | + 0.54 | + 0.36 | - 0.06 |
| Miguel Hidalgo | + 0.95 | - 0.13 | + 0.23 |
| Milpa Alta | - 0.38 | + 0.32 | + 0.25 |
| Tláhuac | - 0.22 | + 0.32 | + 0.36 |
| Tlalpan | + 0.59 | + 0.29 | + 0.37 |
| Venustiano Carranza | - 0.25 | - 0.06 | + 0.29 |
| Xochimilco | - 0.38 | + 0.36 | - 0.20 |

Mexico City limit
Conservation Land limit

*Drinkable water infrastructure*
- Extraction wells
- Aqueducts
- Treatment plants
- Water pumps
- Water tanks
- Administrative and storage facilities

*Sewage system infrastructure*
- Main collectors
- Treatment plants
- Water pumps
- Dams
- Retension basins
- Administrative and storage facilities

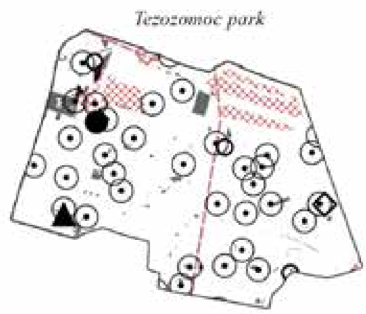
Public open space networks
Productive landscapes

Vulnerable communities within communal lands and indigenous areas
High urban marginality index

0 5 10 15 Kilometers

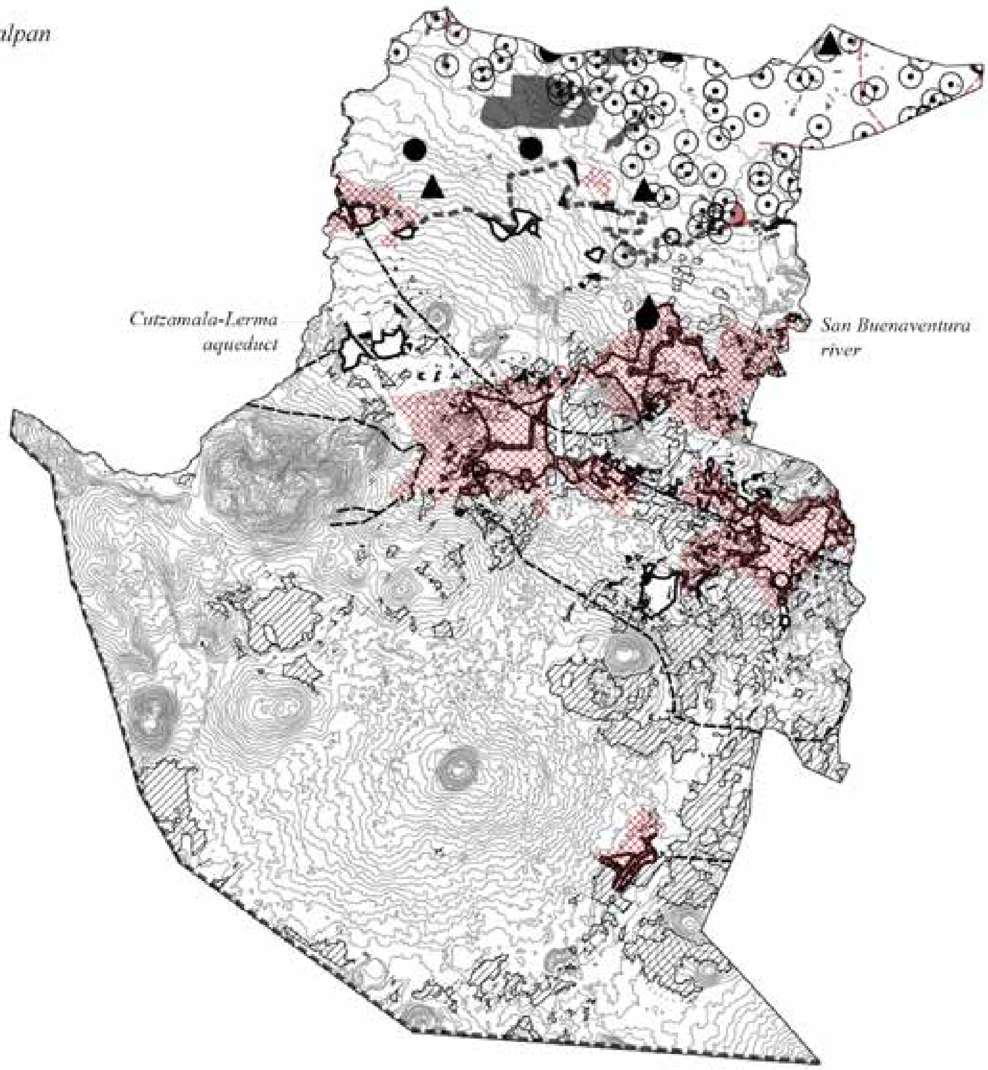
*Figure S3.1: Boroughs with high water consumption index: S3.1a) Azcapotzalco, S3.1b) Cuauhtéhmoc, S3.1c) Tlalpan; utility infrastructures are highlighted in the map.*

a. *Azcapotzalco*




b. *Cuauhtémoc*


c. *Tlalpan*



*Energy (E)*

| ***Administrative limit*** | ***Index value classified by type*** | | |
|---|---|---|---|
| *Boroughs* | *E flows index* | *E infra index* | *OSN index* |
| Álvaro Obregón | - 0.30 | - 0.04 | - 0.16 |
| Azcapotzalco | + 0.50 | - 0.02 | - 0.20 |
| Benito Juárez | + 0.59 | - 0.04 | - 0.04 |
| Coyoacán | - 0.37 | - 0.07 | + 0.37 |
| Cuajimalpa de Morelos | + 0.52 | + 0.33 | + 0.31 |
| Cuauhtémoc | + 0.80 | + 0.46 | + 0.25 |
| Gustavo A. Madero | - 0.23 | - 0.02 | - 0.11 |
| Iztacalco | - 0.26 | - 0.08 | - 0.11 |
| Iztapalapa | - 0.23 | - 0.05 | - 0.12 |
| Magdalena Contreras | - 0.14 | - 0.04 | - 0.06 |
| Miguel Hidalgo | + 1.00 | - 0.05 | + 0.23 |
| Milpa Alta | - 0.08 | + 0.33 | + 0.25 |
| Tláhuac | - 0.12 | - 0.00 | + 0.36 |
| Tlalpan | - 0.27 | - 0.01 | + 0.37 |
| Venustiano Carranza | + 0.44 | - 0.02 | + 0.29 |
| Xochimilco | - 0.15 | - 0.05 | - 0.20 |

Mexico City limit
Conservation land limit

*Energy infrastructure and facilities*
Electrical power plant (turbogas)
Waste-to-energy plant (anaerobic digestor)
Electrical substations
Electrical power lines
Administrative and storage facilities

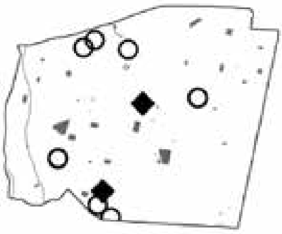
Public open space networks
Productive landscapes

Vulnerable communities within communal lands and indigenous areas
High urban marginality index

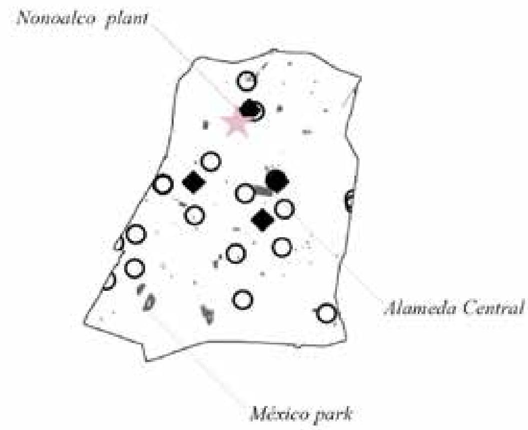
0 5 10 15 Kilometers

*Figure S3.2: Boroughs with high energy consumption index: S3.2a) Benito Juárez, S3.2b) Cuauhtéhmoc, S3.2c) Milpa Alta; utility infrastructures are highlighted in the map.*

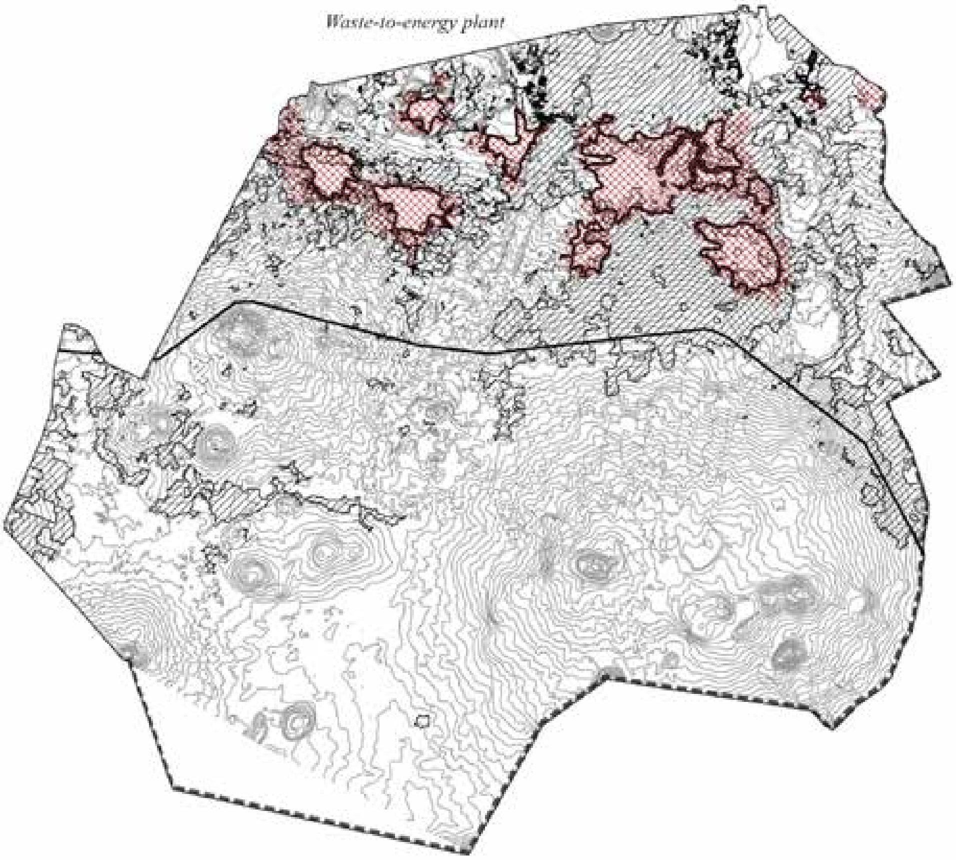
a. *Benito Juárez*

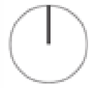


b. *Cuauhtémoc*




c. *Milpa Alta*



*Solid Waste (SW)*

| ***Administrative limit*** | ***Index value classified by type*** | | |
|---|---|---|---|
| *Boroughs* | *SW flows* | *SW infra* | *OSN index* |
| Álvaro Obregón | - 0.18 | + 0.20 | - 0.16 |
| Azcapotzalco | - 0.26 | + 0.31 | - 0.20 |
| Benito Juárez | + 0.57 | - 0.13 | - 0.04 |
| Coyoacán | - 0.30 | + 0.25 | + 0.37 |
| Cuajimalpa de Morelos | - 0.19 | - 0.00 | + 0.31 |
| Cuauhtémoc | + 0.50 | + 0.20 | + 0.25 |
| Gustavo A. Madero | - 0.32 | + 0.41 | - 0.11 |
| Iztacalco | - 0.34 | - 0.00 | - 0.11 |
| Iztapalapa | - 0.25 | + 0.35 | - 0.12 |
| Magdalena Contreras | - 0.22 | - 0.00 | - 0.06 |
| Miguel Hidalgo | + 0.46 | - 0.15 | + 0.23 |
| Milpa Alta | - 0.18 | - 0.06 | + 0.25 |
| Tláhuac | - 0.20 | - 0.00 | + 0.36 |
| Tlalpan | - 0.26 | - 0.08 | + 0.37 |
| Venustiano Carranza | + 0.91 | + 0.42 | + 0.29 |
| Xochimilco | + 0.70 | - 0.13 | - 0.20 |

○ Mexico City limit
◌ Conservation Land limit

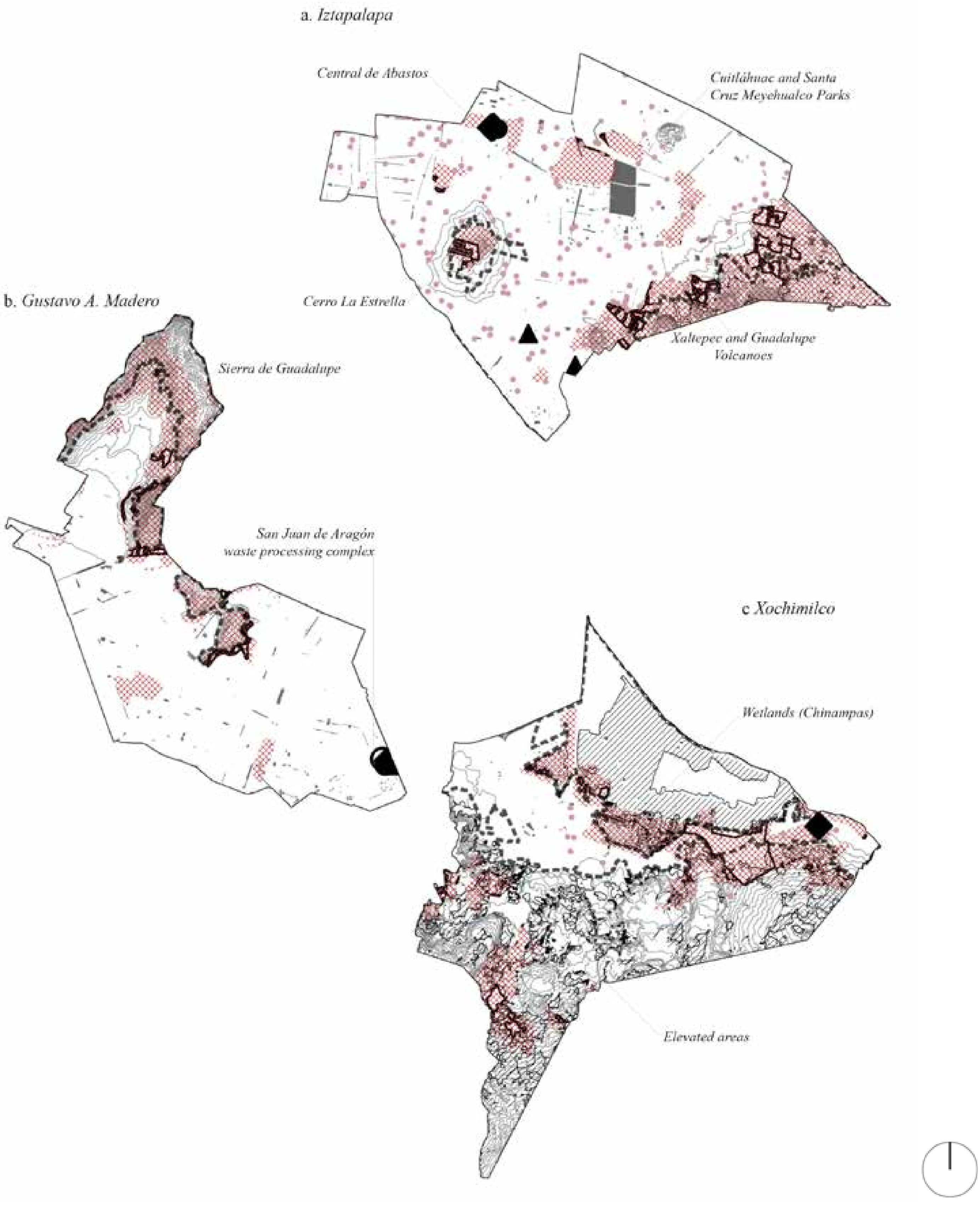
*Solid Waste infrastructure and facilities*
◆ Transfer stations
○ Recycling plants
● Compaction plants
▲ Compost plants
★ Landfills
• Illegal dumping sites

● Public open space networks
● Productive landscapes

○ Vulnerable communities within communal lands and indigenous areas
● High urban marginality index

0 5 10 15 Kilometers

*Figure S3.3: Boroughs with high/ low solid waste generation index: S3.3a) Iztapalapa, S3.3b) Gustavo A. Madero, S3.3c) Xochimilco; utility infrastructures are highlighted in the map.*


a. Iztapalapa
Central de Abastos
Cuitláhuac and Santa
Cruz Meyehualco Parks
Cerro La Estrella
Xaltepec and Guadalupe
Volcanoes
b. Gustavo A. Madero
Sierra de Guadalupe
San Juan de Aragón
waste processing complex
c Xochimilco
Wetlands (Chinampas)
Elevated areas

| Criteria | Type | Data elements | Year * | Units |
|---|---|---|---|---|
| WATER | Flows | Water consumtion | 2016 | l/day/cap |
| WATER | Infrastructure | Extraction wells | 2016 | l/day/cap |
| WATER | Infrastructure | Treatment Plants | 2016 | l/day/cap |
| WATER | Infrastructure | Aqueducts | 2012 | l/day/cap |
| WATER | Infrastructure | Water pump facilities | 2015 | l/day/cap |
| WATER | Infrastructure | Water tanks | 2015 | l/day/cap |
| WATER | Infrastructure | Administrative and storage facilities | 2015 | Units |
| WATER | Flows | Wastewater discharge | 2016 | l/day/cap |
| WATER | Infrastructure | Dams | 2015 | m3/cap |
| WATER | Infrastructure | Main collectors | 2015 | km |
| WATER | Infrastructure | Wastewater pump Facilities | 2015 | l/day/cap |
| WATER | Infrastructure | Sewage treatment plants | 2015 | Units |
| WATER | Infrastructure | Retention basins | 2018 | Units |
| ENERGY | Flows | Electricity consumption | 2017 | kWh/year/cap |
| ENERGY | Infrastructure | Electrical power plant (turbogas) | 2015 | kWh/year/cap |
| ENERGY | Infrastructure | Electrical substations | 2015 | KVA/cap |
| ENERGY | Infrastructure | Waste-to-energy electrical plant | 2017 | kWh/year/cap |
| ENERGY | Infrastructure | Electical power lines | 2018 | km |
| SOLID WASTE | Flows | Municipal solid waste (MSW) generation | 2017 | kg/day/cap |
| SOLID WASTE | Flows | Construction solid waste (CSW) generation | 2017 | kg/day/cap |
| SOLID WASTE | Infrastructure | Transfer stations | 2010 | kg/day/cap |
| SOLID WASTE | Infrastructure | Recycling plants | 2018 | kg/day/cap |
| SOLID WASTE | Infrastructure | Compaction plants | 2018 | kg/day/cap |
| SOLID WASTE | Infrastructure | Compost plants | 2016 | kg/day/cap |
| SOLID WASTE | Infrastructure | Landfills | 2018 | Units |
| OSN | - | Topography | - | m |
| OSN | Infrastructure | Crops landuse cover map | 2008 | km² |
| OSN | Infrastructure | Pasture grassland landuse cover map | 2008 | km² |
| OSN | Infrastructure | Forests landuse cover map | 2008 | km² |
| OSN | Infrastructure | Urban tree cover map | 2016 | km² |
| OSN | Infrastructure | Non productive grassland urban cover map | 2016 | m²/inhab |
| OSN | Infrastructure | Public green spaces | 2017 | m²/inhab |
| OSN | Infrastructure | Public blue spaces | - | m²/inhab |
| OSN | Infrastructure | Public gray spaces | 2017 | m²/inhab |
| OSN | Infrastructure | Private green spaces | 2017 | m²/inhab |
| OSN | Infrastructure | Nature reserves | 2013 | m²/inhab |
| OSN | Infrastructure | Streets | 2016 | km² |
| IAV | - | Informal settlements | 2010 | km² |
| IAV | - | High-density AGEB | 2015 | km² |
| IAV | - | High urban marginality index | 2010 | km² |
| AGS | - | Indigenous areas (*Pueblos Originarios* ) | 2012 | km² |
| AGS | - | Communal lands | 2018 | km² |

** Data was scaled up or down based on the year 2015 population totals.*

*Table S3.1: Mexico City GIS compiled datasets and new data plotted on maps (highlighted in gray) used in the study and classified by criteria, type of information, year, units, source, scale and detailed description of the dataset are included.*

| *Source* | *Scale* | *Description* |
|---|---|---|
| **SACMEX** Sistema de Aguas de la Ciudad de México | Borough | Drinkable water consumption of households, public services, industries, agriculture, and the commercial sector. It includes the total leakage in the distribution system (approximatively 42% of the total piped flow; SACMEX, 2018). |
| **SACMEX** Sistema de Aguas de la Ciudad de México *(GEO COMUNES)* | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **SACMEX** Sistema de Aguas de la Ciudad de México | Borough | Cutzamala, Lerma and other water distribution systems. |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **SEDEMA** Secretaría del Medio Ambiente | Borough | Wastewater discharge of industries, public services and the commercial sector. |
| **SACMEX** Sistema de Aguas de la Ciudad de México *(GEO COMUNES)* | Borough | - |
| **SACMEX** Sistema de Aguas de la Ciudad de México | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **CFE** Comisión Federal de Electricidad | Borough | Electricity consumption of households, public services, industry, agriculture, and the commercial and transportation sectors. |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **CONACYT** Consejo Nacional de Ciencia y Tecnología | Borough | - |
| **INEGI** Instituto Nacional de Estadística, Geografía e Informática | Borough | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Borough | MSW data are classified by source and type of waste (e.g. organic, inorganic including recycling options). |
| **SEDEMA** Secretaría del Medio Ambiente | Borough | CSW data includes the private and public sector. |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Borough | - |
| **SEDEMA** Secretaría del Medio Ambiente | Borough | _ |
| **SEDEMA** Secretaría del Medio Ambiente | Borough | - |
| **SEDEMA** Secretaría del Medio Ambiente | Borough | - |
| **SEDEMA** Secretaría del Medio Ambiente | ZMVM | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | Contour lines every 20 m |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | - |
| **CDMX** Gobierno de la Ciudad de México | Borough | Parks and gardens. |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Borough | Rivers, streams, channels, and lakes. Not included culverted rivers and streams. |
| **CDMX** Gobierno de la Ciudad de México | Borough | Squares and pedestrian walkways. Not included the street network. |
| **CDMX** Gobierno de la Ciudad de México / **INEGI** | Borough | Residential and commercial gardens and parks. |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Borough | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Mexico City | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Borough | Areas covered by informal settlements. |
| **GEOCOMUNES** Urban Collective | AGEB | - |
| **CONAPO** Consejo Nacional de la Población | AGEB | - |
| **PAOT** ProcuraduríaAmbiental y del Ordenamiento Territorial | Borough | Areas covered by indigenous areas. |
| **RAN** Registro Agrario Ncional | Borough | Areas covered by communal lands. |

*Table S3.2: Criteria and sub-criteria used to classify the boroughs. Each criterion is characterized by sub-criteria, which are described using spatially-explicit data.*

| Resource consumption/generation by type of flow | | | |
|---|---|---|---|
| *Criteria* | **Water flows** | **Energy flows** | **Solid waste flows** |
| *Sub-criteria* | . Drinkable water consumption<br>. Wastewater outflows | . Electricity consumption | . MSW generation<br>. CSW generation |

| Resource infrastructure by type of flow | | | |
|---|---|---|---|
| Criteria | **Water infrastructure** | **Energy Infrastructure** | **Solid waste infrastructure** |
| *Sub-criteria* | . Aqueducts (water distribution)<br>. Water wells/extraction systems<br>. Capacity of drinkable water treatment plans<br>. Water pump facilities<br>. Water tanks<br>. Wastewater treatment plants<br>. Dams | . Electricity generation by fossil fuel and waste -to-energy plants<br>. Capacity of the electrical substations | . Transfer stations processing<br>. Compaction plants processing<br>. Recycling plants processing<br>Compost plants processing<br>. Total amount of illegal dumping sites |

| Open space networks (OSN), informality and vulnerability (IAV), and alternative governance systems (AGS) total amount of surface areas | | | |
|---|---|---|---|
| *Criteria* | **OSN** | **IAV** | **AGS** |
| *Sub-criteria* | . Public green spaces (parks and gardens)<br>. Gray spaces (squares)<br>. Blue spaces (rivers, streams, channels, and lakes)<br>. Private green spaces (gardens)<br>. Nature reserves | . Informal settlements<br>. High-density AGEB (more than 25,000 inhabitants/m2)<br>. High urban marginality index | . Communal lands<br>. Indigenous areas |

*Table S3.3: Borough Pattern Scan detailed calculation by criteria. All values for each sub-criteria are highlighted in red and classified by borough.*

*Borough Patterns calculation*

## Water (W)

***W flows*** — Index formula: *W flows index = (Wf1+Wf2)/2*

***W infrastructure*** — Index formula: *W infrastructure index = (Wi1+Wi2+Wi3+Wi4+Wi5+Wi6+Wi7)/7*

| Variables | Wf1 | | Wf2 | | Wi1 | | Wi2 | | Wi3 | | Wi4 | | Wi5 | | Wi6 | | Wi7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Boroughs* | *Water consumption (l/day/cap)* | | *Waste water discharge (l/day/cap)* | | *Uncovered aqueducts (l/day/cap)* | | *Extraction wells (l/day/cap)* | | *Treatment plants capacity (l/day/cap)* | | *Water pump facilities (l/day/cap)* | | *Water tanks (l/day/cap)* | | *Sewage treatment plants (l/day/cap)* | | *Dams (l/day/cap)* | |
| Álvaro Obregón | 0,57 | 321 | 0,16 | 6 | 0,05 | 122 | 0,23 | 114 | 0,00 | 0 | 0,51 | 537 | 0,18 | 454 | 0,23 | 32 | 1,00 | 3994,76 |
| Azcapotzalco | 0,72 | 404 | 0,43 | 16 | 0,00 | 0 | 0,44 | 220 | 0,15 | 24 | 0,00 | 0 | 0,00 | 0 | 0,04 | 5 | 0,00 | 0 |
| Benito Juárez | 0,73 | 406 | 0,39 | 14 | 0,00 | 0 | 0,28 | 143 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Coyoacán | 0,63 | 355 | 0,19 | 7 | 0,00 | 0 | 0,64 | 324 | 0,00 | 0 | 0,22 | 236 | 0,00 | 0 | 0,80 | 114 | 0,00 | 0 |
| Cuajimalpa de Morelos | 0,52 | 293 | 0,19 | 7 | 0,31 | 655 | 0,05 | 26 | 0,00 | 0 | 0,95 | 1011 | 0,31 | 773 | 0,00 | 0 | 0,00 | 0,10 |
| Cuauhtémoc | 0,59 | 332 | 0,67 | 25 | 0,00 | 0 | 0,07 | 34 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,03 | 4 | 0,00 | 0 |
| Gustavo A. Madero | 0,42 | 237 | 0,10 | 4 | 0,00 | 0 | 0,01 | 7 | 0,13 | 20 | 0,05 | 49 | 0,06 | 160 | 0,32 | 45 | 0,00 | 0 |
| Iztacalco | 0,39 | 219 | 0,14 | 5 | 0,00 | 0 | 0,13 | 66 | 0,31 | 49 | 0,07 | 74 | 0,00 | 0 | 0,38 | 54 | 0,00 | 0 |
| Iztapalapa | 0,42 | 235 | 0,10 | 4 | 0,00 | 0 | 0,17 | 87 | 1,00 | 156 | 0,22 | 236 | 0,06 | 138 | 1,00 | 142 | 0,00 | 0 |
| Magdalena Contreras | 0,99 | 554 | 0,08 | 3 | 0,27 | 563 | 0,04 | 21 | 0,93 | 145 | 1,00 | 1062 | 0,51 | 1262 | 0,12 | 18 | 0,00 | 0 |
| Miguel Hidalgo | 0,90 | 502 | 1,00 | 37 | 0,00 | 0 | 0,45 | 228 | 0,00 | 0 | 0,22 | 237 | 0,09 | 211 | 0,31 | 44 | 0,00 | 0,77 |
| Milpa Alta | 0,73 | 410 | 0,02 | 1 | 1,00 | 2082 | 0,34 | 169 | 0,00 | 0 | 0,00 | 0 | 1,00 | 2471 | 0,26 | 38 | 0,00 | 0 |
| Tláhuac | 0,38 | 210 | 0,06 | 2 | 0,00 | 0 | 0,16 | 79 | 0,92 | 143 | 0,37 | 398 | 0,02 | 61 | 0,90 | 128 | 0,00 | 0 |
| Tlalpan | 1,00 | 560 | 0,18 | 7 | 0,31 | 648 | 0,54 | 272 | 0,00 | 0 | 1,00 | 1062 | 0,47 | 1153 | 0,04 | 5 | 0,00 | 0 |
| Venustiano Carranza | 0,36 | 203 | 0,13 | 5 | 0,00 | 0 | 0,06 | 30 | 0,10 | 16 | 0,13 | 135 | 0,01 | 26 | 0,00 | 0 | 0,00 | 0 |
| Xochimilco | 0,67 | 374 | 0,08 | 3 | 0,07 | 150 | 1,00 | 505 | 0,35 | 54 | 0,39 | 415 | 0,22 | 555 | 0,26 | 37 | 0,00 | 1,54 |

## Energy (E)

***E flows*** — Index formula: *E flows index = Wf1*

***E infrastructure*** — Index formula: *E infrastructure index =(Ei1+Ei2+Ei3)/3*

| Variables | Ef1 | | Ei1 | | Ei2 | | Ei3 | |
|---|---|---|---|---|---|---|---|---|
| *Boroughs* | *Electricity consumption (kWh/day/cap)* | | *Electrical power plant (kWh/day/cap)* | | *Waste-to-energy electrical plant (kWh/day/cap)* | | *Electrical substations (kVA/cap)* | |
| Álvaro Obregón | 0,30 | 1.404 | 0,00 | 0 | 0,00 | 0 | 0,13 | 0,93 |
| Azcapotzalco | 0,50 | 2.329 | 0,00 | 0 | 0,00 | 0 | 0,07 | 0,51 |
| Benito Juárez | 0,59 | 2.767 | 0,00 | 0 | 0,00 | 0 | 0,12 | 0,82 |
| Coyoacán | 0,37 | 1.726 | 0,00 | 0 | 0,00 | 0 | 0,21 | 1,47 |
| Cuajimalpa de Morelos | 0,52 | 2.442 | 0,00 | 0 | 0,00 | 0 | 1,00 | 6,97 |
| Cuauhtémoc | 0,80 | 3.740 | 1,00 | 1070 | 0,00 | 0 | 0,39 | 2,70 |
| Gustavo A. Madero | 0,23 | 1.088 | 0,00 | 0 | 0,00 | 0 | 0,06 | 0,44 |
| Iztacalco | 0,26 | 1.215 | 0,00 | 0 | 0,00 | 0 | 0,23 | 1,59 |
| Iztapalapa | 0,23 | 1.063 | 0,00 | 0 | 0,00 | 0 | 0,15 | 1,04 |
| Magdalena Contreras | 0,14 | 649 | 0,00 | 0 | 0,00 | 0 | 0,13 | 0,89 |
| Miguel Hidalgo | 1,00 | 4.672 | 0,00 | 0 | 0,00 | 0 | 0,14 | 0,94 |
| Milpa Alta | 0,08 | 371 | 0,00 | 0 | 1,00 | 0,46 | 0,00 | 0 |
| Tláhuac | 0,12 | 558 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Tlalpan | 0,27 | 1.275 | 0,00 | 0 | 0,00 | 0 | 0,03 | 0,20 |
| Venustiano Carranza | 0,44 | 2.051 | 0,00 | 0 | 0,00 | 0 | 0,06 | 0,45 |
| Xochimilco | 0,15 | 702 | 0,00 | 0 | 0,00 | 0 | 0,15 | 1,02 |

## Solid Waste (SW)

***SW flows*** — Index formula: *SW flows index =(SWf1+SWf2)/2*

***SW infrastructure*** — Index formula: *SW flows index =(SWi1+SWi2+SWi3+SWi4)/4*

| Variables | SWf1 | | SWf2 | | SWi1 | | SWi2 | | SWi3 | | SWi4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Boroughs* | *Municipal SW generation (kg/day/cap)* | | *Construction SW generation (l/day/cap)* | | *Transfer stations (kg/day/cap)* | | *Compaction plants (kg/day/cap)* | | *Recycling plants (kg/day/cap)* | | *Compost plants (kg/day/cap)* | |
| Álvaro Obregón | 0,37 | 0,91 | 0,00 | 0 | 0,64 | 12,93 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0,08 |
| Azcapotzalco | 0,52 | 1,30 | 0,00 | 0 | 1,00 | 20,32 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Benito Juárez | 0,69 | 1,72 | 0,46 | 0,29 | 0,42 | 8,48 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Coyoacán | 0,54 | 1,34 | 0,06 | 0,04 | 0,81 | 16,52 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Cuajimalpa de Morelos | 0,38 | 0,94 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0,21 |
| Cuauhtémoc | 1,00 | 2,49 | 0,00 | 0 | 0,64 | 12,94 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Gustavo A. Madero | 0,69 | 1,50 | 0,04 | 0 | 0,07 | 1,37 | 0,54 | 2,04 | 1,00 | 21,10 | 0,00 | 0,05 |
| Iztacalco | 0,50 | 1,24 | 0,18 | 0,12 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Iztapalapa | 0,50 | 1,24 | 0,00 | 0 | 0,33 | 6,73 | 1,00 | 3,80 | 0,00 | 0 | 0,00 | 0,01 |
| Magdalena Contreras | 0,43 | 1,08 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Miguel Hidalgo | 0,92 | 2,28 | 0,00 | 0 | 0,50 | 10,18 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Milpa Alta | 0,35 | 0,88 | 0,00 | 0 | 0,20 | 4,13 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0,32 |
| Tláhuac | 0,40 | 1,00 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Tlalpan | 0,52 | 1,29 | 0,00 | 0 | 0,26 | 5,35 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0 |
| Venustiano Carranza | 0,81 | 2,02 | 1,00 | 0,63 | 0,56 | 11,28 | 0,00 | 0 | 0,00 | 0 | 1,00 | 21356,87 |
| Xochimilco | 0,90 | 2,24 | 0,50 | 0,31 | 0,41 | 8,39 | 0,00 | 0 | 0,00 | 0 | 0,00 | 0,17 |

## Open Space Networks (OSN)

***OSN areas*** — Index formula: *OSN index = (OSN1+OSN2+OSN3+OSN4+OSN5)/3*

| Variables | OSN1 | | OSN2 | | OSN3 | | OSN4 | | OSN5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Boroughs* | *Public green spaces (m²/hab)* | | *Public blue spaces (m²/hab)* | | *Public grey spaces (m²/hab)* | | *Private green spaces (m²/hab)* | | *Nature reserves (m²/hab)* | |
| Álvaro Obregón | 0,38 | 2,67 | 0,00 | 0 | 0,06 | 0,02 | 0,33 | 8,51 | 0,03 | 38,04 |
| Azcapotzalco | 0,34 | 2,39 | 0,00 | 0 | 0,25 | 0,09 | 0,40 | 10,33 | 0,00 | 0 |
| Benito Juárez | 0,16 | 1,10 | 0,00 | 0 | 0,03 | 0,01 | 0,03 | 0,70 | 0,00 | 0 |
| Coyoacán | 1,00 | 7,04 | 0,00 | 0 | 0,53 | 0,20 | 0,34 | 8,70 | 0,00 | 0 |
| Cuajimalpa de Morelos | 0,40 | 2,81 | 0,00 | 0 | 0,00 | 0 | 1,00 | 25,75 | 0,14 | 213,54 |
| Cuauhtémoc | 0,15 | 1,03 | 0,00 | 0 | 1,00 | 0,37 | 0,11 | 2,77 | 0,00 | 0 |
| Gustavo A. Madero | 0,12 | 0,85 | 0,03 | 0,21 | 0,17 | 0,06 | 0,24 | 6,17 | 0,01 | 9,98 |
| Iztacalco | 0,03 | 0,24 | 0,00 | 0 | 0,23 | 0,08 | 0,31 | 7,96 | 0,00 | 0 |
| Iztapalapa | 0,24 | 1,68 | 0,02 | 0,18 | 0,02 | 0,01 | 0,33 | 8,55 | 0,00 | 2,58 |
| Magdalena Contreras | 0,04 | 0,27 | 0,00 | 0 | 0,00 | 0 | 0,16 | 4,02 | 0,13 | 187,11 |
| Miguel Hidalgo | 0,49 | 14,49 | 0,00 | 0 | 0,06 | 0,02 | 0,60 | 15,51 | 0,00 | 0 |
| Milpa Alta | 0,00 | 0,03 | 0,00 | 0 | 0,19 | 0,07 | 0,05 | 1,25 | 1,00 | 1479,32 |
| Tláhuac | 0,31 | 2,17 | 1,00 | 8,31 | 0,09 | 0,03 | 0,39 | 10,08 | 0,03 | 42,18 |
| Tlalpan | 0,71 | 5,00 | 0,00 | 0 | 0,39 | 0,15 | 0,54 | 14,00 | 0,19 | 282,06 |
| Venustiano Carranza | 0,44 | 3,07 | 0,03 | 0,26 | 0,63 | 0,23 | 0,33 | 8,90 | 000 | 0 |
| Xochimilco | 0,07 | 0,53 | 0,67 | 5,56 | 0,00 | 0 | 0,23 | 5,90 | 0,05 | 72,99 |

## Informality and Vulnerability (IAV), and Alternative Governance Systems (AGS)

***IAV areas*** — Index formula: *IAV index =(IAV1+IAV2+IAV3)/3*

***AGS areas*** — Index formula: *AGS index =(AGS1+AGS2)/2*

| Variables | IAV1 | | IAV2 | | IAV3 | | AGS1 | | AGS2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Boroughs* | *Informal settlements (km²)* | | *Highly marginalized areas (km²)* | | *Highly dense areas (km²)* | | *Communal lands (km²)* | | *Indigenous areas (km²)* | |
| Álvaro Obregón | 0,02 | 0,18 | 0,07 | 2,10 | 0,43 | 6,86 | 0,07 | 0,92 | 0,13 | 2,32 |
| Azcapotzalco | 0,00 | 0 | 0,05 | 2,33 | 0,29 | 4,68 | 0,00 | 0 | 0,00 | 0 |
| Benito Juárez | 0,00 | 0 | 0,00 | 0 | 0,01 | 0,12 | 0,00 | 0 | 0,00 | 0 |
| Coyoacán | 0,00 | 0 | 0,01 | 0,29 | 0,35 | 5,69 | 0,00 | 0 | 0,00 | 0 |
| Cuajimalpa de Morelos | 0,27 | 2,61 | 0,27 | 8,05 | 0,01 | 0,11 | 0,18 | 2,25 | 0,24 | 4,14 |
| Cuauhtémoc | 0,00 | 0 | 0,00 | 0 | 0,35 | 5,69 | 0,00 | 0 | 0,00 | 0 |
| Gustavo A. Madero | 0,03 | 0,28 | 0,54 | 16,25 | 0,88 | 14,13 | 0,00 | 0 | 0,00 | 0 |
| Iztacalco | 0,00 | 0 | 0,00 | 0 | 0,30 | 4,81 | 0,00 | 0 | 0,00 | 0 |
| Iztapalapa | 0,02 | 0,24 | 0,94 | 28,16 | 1,00 | 16,12 | 0,04 | 0,47 | 0,00 | 0 |
| Magdalena Contreras | 0,02 | 0,24 | 0,13 | 3,79 | 0,07 | 1,08 | 0,00 | 0 | 0,16 | 2,76 |
| Miguel Hidalgo | 0,00 | 0 | 0,00 | 0 | 0,10 | 1,65 | 0,00 | 0 | 0,00 | 0 |
| Milpa Alta | 0,41 | 4,03 | 0,74 | 22,05 | 0,00 | 0 | 0,80 | 10,10 | 1,00 | 17,51 |
| Tláhuac | 0,44 | 4,28 | 0,26 | 7,79 | 0,06 | 1,02 | 0,66 | 8,40 | 0,51 | 8,96 |
| Tlalpan | 1,00 | 9,81 | 1,00 | 29,98 | 0,05 | 0,87 | 1,00 | 12,70 | 0,66 | 11,54 |
| Venustiano Carranza | 0,00 | 0 | 0,00 | 0 | 0,29 | 4,68 | 0,00 | 0 | 0,00 | 0 |
| Xochimilco | 0,58 | 5,71 | 0,83 | 24,89 | 0,00 | 0 | 0,00 | 0 | 0,56 | 9,74 |


*Rainwater harvesting and storage equipment at a temporary occupation communal project in Brussels. Photo by author, 2022.*

# 4 Community Involvement
*Alternative resource governance systems and fine-grained data.*

*Abstract*
Implementing Urban Metabolism (UM) frameworks in urban design holds significant potential for developing strategies to reduce urban resource consumption. However, recent UM studies have often overlooked the practical application of their results by design practitioners. Integrating refined spatially explicit data from alternative resource governance systems (ARGS) can help the development of design strategies based on the stakeholders involved and socio-ecological activities and practices observed, enhancing the applicability of resource-sensitive and community-led urban design strategies. Our study introduces a methodological approach that combines data based on in-depth fieldwork in a case-study city (Brussels Capital Region, Belgium), including geographical information system (GIS) mapping, 3D spatial modeling, and semi-structured interviews with ARGS. The results highlight the substantial impact of ARGS in increasing the per capita area of publicly accessible spaces (more than 20%) and resource management at different scales, while showing that only one-third of those ARGS are located in areas with vulnerable communities and municipalities with high resource consumption. Furthermore, they point to recommendations for design practitioners to integrate specific features into urban regeneration projects (e.g., revitalize neglected sites in collaboration with neighboring communities) and categorize different types of spaces underpinning ARGS (spaces for resource management, working activities, and meeting and sharing). This study contributes to the applicability of UM in urban design by leveraging a bottom-up, finer-grained UM assessment, complementary to more widely-used top-down city-scale approaches. Combination of both approaches can help shed light on site-specific socio-ecological activities and practices that can function as drivers for increased resource efficiency and community involvement.

*Keywords*
Industrial ecology, landscape infrastructure, grassroots practices, social innovation, governance, circular economy.

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### *4.1 Introduction*

#### *4.1.1 Urban metabolism and alternative resource governance systems*

Human-caused climate change, stemming from net greenhouse gas emissions associated with energy use, land use change, consumption patterns, and resource mismanagement, has significantly affected the urban infrastructure of many cities, including transportation, water, sanitation, and energy systems, causing economic losses and service disruptions (IPCC, 2023). Urban metabolism (UM) studies provide valuable insights that can improve resource efficiency in cities by analyzing the flows of energy and materials within urban systems (Broto et al., 2012; Pincetl et al., 2012). An increasing body of literature highlights the relevance of implementing UM frameworks to urban design as a means to develop strategies that reduce resource consumption and enhance resource accessibility in cities (Dijst et al., 2018; Kennedy et al., 2011; Voskamp et al., 2018). In recent years, UM research has evolved to adopt interdisciplinary and multiscale approaches, examining urban systems at the regional and neighborhood levels as well as at the level of individual public spaces (Codoban & Kennedy, 2008; Doussard et al., 2024; Tuffaha & Sallay, 2025; Zhang et al., 2015). Previous research has demonstrated the potential of UM methods, particularly when applied to local case studies, to optimize urban systems by analyzing sociotechnical processes in the design of resilient cities (Agudelo-Vera et al., 2012; Chelleri et al., 2015). These works have also addressed resource-related vulnerabilities based on material flow accounting (Athanassiadis et al., 2017; Barles, 2009) and economy-wide material accounts (Kovanda & Hak, 2007; Wiedmann et al., 2023), mapped greenhouse gas emissions and resource flows across multiple urban areas in the context of global climate change (Kennedy et al., 2009; Kennedy et al., 2015), and integrated life cycle thinking and machine learning into UM frameworks to support the design of smart and regenerative urban environments (Peponi & Morgado, 2021; Peponi et al., 2022). Despite these advances, the transfer of scientific knowledge to design practitioners, i.e., urban designers, architects, researchers, and activists, among others, is scarce due to the variety of methodologies, data availability, and complexity of the theoretical frameworks (Perrotti, 2019).

Recent studies underscore a growing interest in spatially explicit UM research, which involves geo-referenced visual analyses of resource flows, infrastructure, and their socio-ecological context within specific urban areas (Bahers et al., 2022; Geremicca & Bilec, 2024). These studies have advanced the notions of space in terms of power relations, organization of supply chains, socio-ecological activities and practices, governance, and accounting of UM flows/stocks (Bahers et al., 2022). Building on previous research (Otero Peña et al., 2022), this article considers urban public and private open spaces (e.g. streets, squares, gardens, parks, nature reserves, riverbanks) as an asset to minimize resource consumption and waste generation through urban design strategies while preserving and enhancing existing socio-ecological activities and practices. Examples include integrating nature-based solutions into utility infrastructure to increase urban green spaces and fostering synergies among various urban functions to enhance mutual benefits for resource recycling. Previous spatially explicit UM research has developed maps of resource consumption, stocks, and infrastructure across scales while integrating spatial socio-ecological data (Currie et al., 2017; Kolkwitz et al., 2022; Lanau & Liu, 2020; Soto et al., 2024), spatialized environmental and socio-economic data (Choe & Thorne, 2019; Juwet & Ryckewaert, 2018), quantified energy consumption and production infrastructure from global to urban scales (Duval & Bahers, 2023; Tanguy et al., 2020), explored circular economy transitions (Furlan et al., 2024; Tsui et al., 2022), developed an integrated UM analysis tool that captures the influence of multi-scale spatial interactions on urban system parameters (Mostafavi et al., 2014), and examined carbon metabolism linked to energy consumption emissions (Xia et al., 2022). Despite recognizing the spatial dimension's importance in enhancing urban resource efficiency (Pistoni & Bonin, 2017; Voskamp et al., 2018), these studies predominantly focus on quantifying resource flows and stocks, analyzing their circulation within urban systems, and introducing novel theoretical models for UM assessment, without thoroughly examining the practical applicability of the results in urban space.

Localizing and quantifying urban flows and stocks could be of great value for identifying infrastructure deficiencies, resource harvesting hotspots, and unequal resource accessibility for vulnerable population groups (Amenta & Van Timmeren, 2018; Miatto et al., 2019; Montealegre et al., 2022; Otero Peña et al., 2022; Wielemaker et al., 2020). These vulnerable communities are defined as urban and rural areas with most of the population living with precarious access to basic services, public space (i.e., public open spaces and proximity facilities), and housing quality conditions due to their socio-economic status or irregular land occupation. Moreover, the integration of refined spatially explicit data from bottom-up, context-sensitive, and practice-based resource collection and management structures can help the development of local design strategies based on the stakeholders involved and socio-ecological activities and practices observed (Kaviti Musango et al., 2020; Perrotti, 2020). In addition, this approach enhances the understanding of existing spatial qualities to inform urban design, as well as the volume of resource flows managed at the local scale, aspects that are often overlooked in UM studies conducted at the city scale. This research defines these alternative resource governance systems (ARGS) as publicly accessible spaces subject to a local-scale and community-led approach towards decentralized resource management, aiming to increase community attachment and social cohesion while enhancing the preservation of their cultural heritage, identity, and habitat.

Previous research on ARGS and UM frameworks has illustrated the improvement of resource use and shift behavior to achieve environmental benefits by organized cooperatives of waste pickers (Espinosa-Aquino et al., 2023; Estrada et al., 2023; Guibrunet et al., 2017), presented spatiotemporal dynamics of resource flows and infrastructure within informal settlements (Kaviti Musango et al., 2020; Putri & Moulaert, 2017; Smit et al., 2019), and analyzed and classified the community composting practices within a city organic waste management system (Bahers & Giacchè, 2019). Other studies have developed a system of indicators for citizen initiatives based on social inclusion, resource efficiency, and spatial potential for future planning (Berigüete et al., 2023), mapped socio-ecological activities and practices of different stakeholders within green infrastructure networks (Chelleri et al., 2016; Pietta & Tononi, 2021), and estimated resource use and food production using residential complex rooftops (Toboso-Chavero et al., 2021). Estrada et al. (2023) analyzed the urban transformation of a female-predominant cooperative of informal waste pickers in Pune, India. The study demonstrated the resource efficiency improvement in the metabolic cycle of the city by diverting solid waste from material flows that tend to contribute to landfilling, increasing the urban recycling performance and providing waste collection services to informal settlements. Furthermore, Kaviti Musango et al. (2020) highlighted the emergence of UM research including co-designing with communities, i.e., the need to include local knowledge and practices to create appropriate sustainable development indicators in situations where informality prevails. However, none of these studies develop a methodology to extract fine-grained spatially explicit data on existing ARGS (e.g., spatial configurations in public space or detailed resource harvesting devices), that could be used by design practitioners in the development of resource-sensitive urban design strategies.

The decentralization of resource management in cities through citizen-led practices could help to efficiently manage resources and thus reduce the emission of pollutants and urban waste while advancing the understanding of the intricate interplay between social and biophysical factors (Perrotti, 2022). In this research, the role of design results from a comprehensive process where both individual and collective efforts converge to conceptualize projects that address the specific needs and aspirations of a community (de Waal & de Lange, 2019). This process is broad and encompasses a wide range of outcomes, including the design of urban spaces, objects, or services, each characterized by varying degrees of interdependence and reflecting the intricate and interconnected nature of community-driven projects. Despite the increasing attention given to the relevance of ARGS to achieve more sustainable cities through social inclusion and resource efficiency, there is still a need to advance spatially explicit and fine-grained assessments of resources generated, transformed, or stored in urban spaces to inform design practitioners. Such methods may be particularly valuable to assess resource flows that are often overlooked in standard city-scale assessments and for understanding their relevance across different urban scales, thereby offering more actionable insights for design practitioners.  Based on these considerations and knowledge gap, the aim of this study is to present a methodological approach which combines spatially explicit quantitative and qualitative analyses at multiple scales to address the following research questions: i) which spatially explicit socio-ecological activities and practices of ARGS can be identified as drivers to enhance the applicability of resource-sensitive and community-led urban design strategies?, ii) what kind of finer-grain spatially explicit data could be collected to enhance a context- and community-specific UM analysis? Implementing geographical information system (GIS) mapping, 3D spatial modeling methods, and semi-structured interviews with ARGS, we conduct an in-depth exploration through a combined top-down and bottom-up analysis to improve the application of UM frameworks in urban design. This bottom-up assessment of local case studies is intended to complement city-scale top-down UM assessments (unpacking and quantifying internal *black box* processes) that are more commonly used in research focusing on the spatialization of resource consumption patterns and infrastructure locations (Lanau & Liu, 2020; Otero Peña et al., 2022; Yeow & Cheah, 2019).

The first section of the article introduces the significance of UM and urban design to enhance resource efficiency in cities, provides the definition of ARGS used emphasizing their relevance in promoting decentralized resource management and social cohesion, and outlines the significance of the selected case study (Brussels, Belgium). The methodology section presents the data employed and describes the GIS quantitative analysis, the qualitative analysis of selected ARGS through field visits and semi-structured interviews with key stakeholders, as well as the spatial analysis of socio-ecological activities and practices using 3D spatial models. In the results section, we present the maps, diagrams, and illustrations in relation to the ARGS location, main characteristics, stakeholders involved, socio-ecological activities and practices observed, opportunities and barriers outlined, and spatial configurations analyzed. The subsequent section analyzes the results, focusing on the types of spaces used by all ARGS, their significant impact at the city-region scale, and identifies challenges for design practitioners aiming to promote similar ARGS projects in other urban systems. Finally, the conclusion synthetizes the research insights and suggests future research developments.

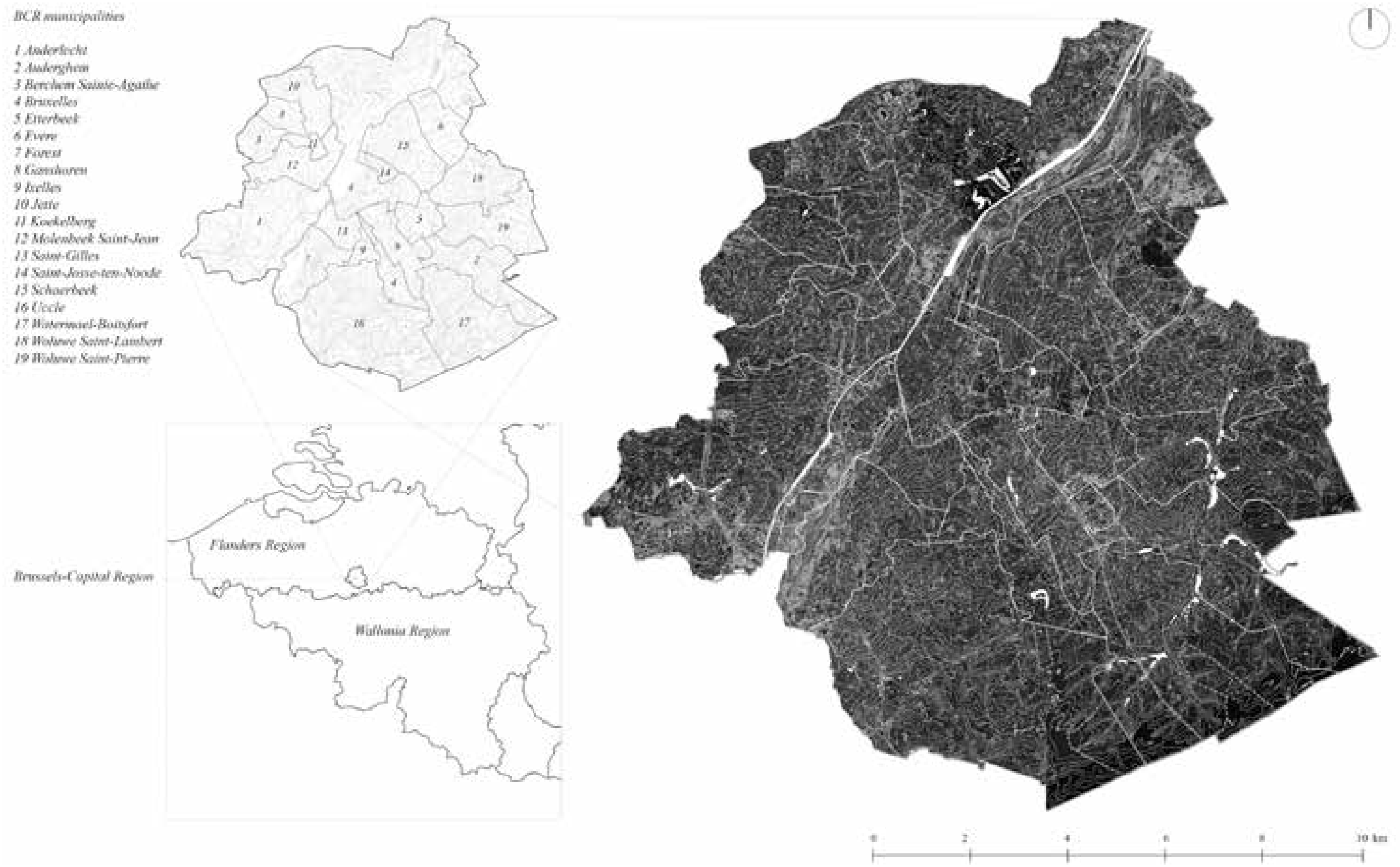



*Figure 4.1: The geographic location of BCR with its nineteen municipalities subdivision and the administrative boundaries of Flanders, Wallonia, and Brussels regions.*

### *4.1.2 Case Study: Brussels Capital Region*

The Brussels Capital Region (BCR) is a city-region located in the center of Belgium, surrounded by the Flanders Region and close to the Wallonia Region (see *Figure 4.1*), with approximately a total area of 162 km$^2$ and a population of 1.2 million inhabitants (IBSA, 2022). A regional government (*Region de Bruxelles*) manages the BCR and includes 19 independent municipalities (*communes*) with diverse geographic and socio-economic characteristics. The municipalities are subdivided into neighborhoods (*quartiers*) and these are divided into administrative units for statistical analysis. An estimated 35% of the population is at risk of poverty or social exclusion due to monetary distress (STATBEL, 2022), this means that more than a third of households encounter difficulty in generating adequate revenues to meet their financial obligations. This socioeconomic vulnerability may also affect access to essential services and adequate housing due to over-demand and waiting times to access social housing (BCR Brussels Capital Region, 2018). The Brussels-Charleroi Canal runs through BCR and extends from the northern part of the city to the southern neighborhoods, covering a distance of approximately 14 kilometers within the region. The areas located mainly in the canal zone and linked to the railway infrastructure have become highly impoverished and degraded in recent decades due to deindustrialization, leading to large brownfield sites and low-income neighborhoods on which the region seeks to develop new neighborhoods, public open spaces, and facilities (BCR Brussels-Capital Region, 2017). In 1993, the BCR created the *contrats de quartiers* (literally 'neighborhood contracts') to focus on these vulnerable communities, strengthen urban infrastructure renewal, and develop new housing units. *Contrats de quartiers* are action plans limited in time and space to improve the inhabitants' quality of life and respond to local needs through a program of actions to be carried out within a defined budget jointly managed by the region, the municipalities, and the residents of a given neighborhood (CDQ Contrats de Quartiers Durables, 2023). In 2010, the regional government added the environmental dimension as a transversal axis to these action plans (*contrats de quartiers durables*) and reinforced social participation as a driving force for all action themes, including housing, proximity facilities, public space, social cohesion, and production spaces. Previous initiatives of *contrats de quartiers durables* have functioned as essential participatory instruments in urban governance. These initiatives have involved a broad array of stakeholders at earlier stages of urban policy making, facilitated collaboration among public housing agencies to promote social diversity, provided both low- and middle-income housing, and supported the relocation of manufacturing activities within city limits, thereby enhancing urban sustainability and community development (Bonello et al., 2022; ). Following the region's interest in accentuating the integration of sustainable issues into public open space proposals, the BCR's environmental agency (*Bruxelles Environvement*) launched in 2008 a call for projects called sustainable neighborhood citizens (*quartiers durables citoyens*). The objective of the region was to finance collective, participative, and sustainable projects to improve the quality of life in their neighborhoods while respecting the environment and promoting solidarity (BE Bruxelles Environnement, 2022). Once selected, citizens received funding, expert coaching, and networking with similar projects related to food, solid waste, resource management, preservation of public open spaces, nature and biodiversity, mobility, and energy performance. Both initiatives, *contrats de quartiers durables* and *quartiers durables citoyens*, have in common among other objectives depending on the type of project, promoting community participation and independent governance to decentralize resource management (e.g., collective gardens, compost sites, recycling centers) while fostering new types of urban commons within public open spaces. These urban commons refer to shared urban resources and spaces that are collectively managed by a community; this involves establishing explicit legal relationships between public and private stakeholders, ensuring public accessibility, and fostering dynamic interactions among various resource management actors, including providers, producers, and users (Aernouts & Ryckewaert, 2018; Ostrom, 1990).

BCR has a wide range of research projects that have used UM approaches to study the city-region. In the mid-seventies, Paul Duvigneaud and collaborators published their seminal work on the Brussels UM, illustrating resource consumption and emissions on a regional scale employing spatially explicit territorial cross-sections (Duvigneaud & Denayer-De Smet, 1977). Researchers recently updated Duvigneaud's study and advanced on quantifying energy, water, material, and pollution flows considering temporal and spatial evaluations (Athanassiadis et al., 2017). Other UM studies have compared territorial-based and consumption-based approaches to assess local and global resource use and pollution emissions (Athanassiadis et al., 2018), developed detailed analyses and mapping of single groups of resource flows and waste footprints at different scales (Bortolotti et al., 2020; Kampelmann, 2021; Papangelou et al., 2020; Towa, Zeller, Merciai, et al., 2021; Zeller et al., 2019), performed participatory action research within biowaste and water management systems (De Muynck & Nalpas, 2021), compared local circular economy practices (Scialpi & Perrotti, 2023; Verga & Khan, 2022), and proposed new metrics to assess the degree circularity and the trade of waste between regions (Towa, Zeller, & Achten, 2021). Many of these studies conclude on the need for hybrid methodologies that combine accuracy and comprehensiveness in UM assessment through interdisciplinary multi-stakeholder collaboration, multi-scale data analysis (local/global), and policy implications in circular economy and urban design frameworks. Following the publication of a UM assessment of BCR by *Bruxelles Environnement* (BE Bruxelles Environnement, 2015), BCR has been implementing its *Regional Circular Economy Plan* since 2016 to establish a favorable regulatory framework, economic support, developing innovation, generating sustainable and innovative public tendering, and guiding new training within the construction, resources, waste, logistics, commerce, and food sectors (BE Bruxelles Environnement, 2016). In 2020, these strategies were incorporated into the official political plan of the regional government (BCR Brussels Capital Region, 2020) with the objective of attaining economic, social, and ecological transition through a comprehensive approach that goes beyond a singular focus on circular initiatives.

The opportunity to have a large concentration of initiatives managing multiple resources, operating in diverse types of publicly accessible spaces, and led by organized groups of individuals (i.e., ARGS) makes BCR an interesting testbed for our approach. This case study is particularly relevant in addressing the challenges highlighted by recent metabolic studies at a regional scale regarding the collection of fine-grained data to improve the application of UM by design practitioners.

### *4.2 Methodology*

This study combines spatially explicit quantitative and qualitative analyses using GIS mapping, 3D spatial modeling, and semi-structured interviews with ARGS to provide a combined top-down and bottom-up methodological approach to improve UM application in urban design. The aim of the proposed spatially-explicit and multi-scale approach is: i) to provide a comprehensive understanding of resource consumption and waste generation patterns in relation to open space networks, vulnerable communities, and ARGS at the city scale using GIS mapping analysis; ii) to identify and classify the socio-ecological activities and practices carried out by the different stakeholders of ARGS at the local scale through site visits and interviews; and, iii) to extract fine-grained data from resource distribution and management systems, which are not accounted for in standard city-scale datasets, to understand their impact at different scales and usages and to illustrate the different types of spaces created by the community involved using 3D spatial modeling. All datasets used in the study were compiled from available primary and secondary data for BCR and systematically categorized by criteria, dataset type, indicator, year, unit, source, urban scale, type of analysis, and descriptive details (see *Table S4.1* in the *Suppotting Material*).

#### *4.2.1 City-region scale GIS mapping*

A GIS-based UM assessment of BCR was performed at the city-region and municipal scales. The following available datasets were used: (1) resource flows, including drinking water consumption, electricity and natural gas consumption, generation of organic and inorganic municipal solid waste; (2) location of utility infrastructure and resource management facilities; (3) geographic features of the city including open space networks; (4) location of vulnerable communities; and (5) location of ARGS and their administrative limits.

Resource consumption and waste generation include residential, commercial, industrial, public sector, and agricultural values. Resource infrastructure datasets include main generation, distribution, and storage facilities within the city-region administrative boundary (e.g., electrical power plants and substations, water distribution system and sewage network, and recycling and compost plants). Open space networks datasets include public and private green spaces (parks and gardens), blue spaces (rivers, streams, channels, and lakes), gray spaces (squares and pedestrian walkways), street networks, and nature reserves. Vulnerable communities' datasets include low-income neighborhoods and neighborhoods with a higher share of social housing units (number of social housing units per 100 households) than the average in the region. ARGS's datasets include sustainable neighborhood initiatives at the neighborhood scale (*contrats de quartiers durables*) and citizen scale (*quartiers durables citoyens*), facilities with public open spaces (urban farms, squares), reusable materials sites, non-governmental organizations (NGO) headquarters, collective compost sites and compost guides, and co-creation research projects funded by the BCR research and innovation institute (*INNOVIRIS*).

#### *4.2.2 Semi-structured interviews and field visits*

Semi-structured interviews of selected ARGS's members were conducted based on the following criteria: projects were located in publicly accessible spaces within the administrative boundaries of BCR and were led or co-led by citizen collectives to manage at least one of the three key resources studied: water, energy, and solid waste. The interviews aimed to achieve the following specific objectives: firstly, to construct a comprehensive stakeholder profile; secondly, to identify the actions, activities, and projects carried out in the publicly accessible spaces; and finally, to identify potential opportunities and barriers that may affect the continuity and expansion of the project.

| | |
|---|---|
| ***QC1*** *STAKEHOLDER (information)* | *1. Stakeholder name.*<br>*2. Type pf organization (e.g. NGO, cooperative, organized group, company, academia).*<br>*3. Main objective of organization.*<br>*4. Date of creation.*<br>*5. Name and position of the interviewee.*<br>*6. Number of people directly involved.*<br>*7. Location of the organization.* |
| ***QC2*** *RESOURCES (projects)* | *1. Can you describe the resource collection and management projects (linked to water, energy, or waste) in which you are involved or have recently been involved?*<br>*2. Do you have partners, collaborators, or main actors involved in the project?*<br>*3. What is the scale of the project (buildings, neighborhood, commune, city, region)?*<br>*4. How is the project financed (public/private funding, independent research, activism, academia, other)?*<br>*5. What was the main inspiration for you to engage with this type of project?*<br>*6. What is the role of your organization in this project?*<br>*7. Can you describe specifically in which area of resource collection and management does your work focus (resource distribution, stockage, generation, community engagement)?*<br>*8. Do you work with any publicly available resource datasets for your project (consumption, generation, other)? How do you use them?*<br>*9. Do you quantify any resource data on partial or final results of your project (consumption, generation, other)? Are they publicly available?* |
| ***QC3*** *URBAN SPACE USE (socio-ecological activities and practices)* | *1. What kind of socio-ecological activities do you carry out in publicly accessible spaces (e.g. field trips, resource harvesting, activism, infrastructure construction, other)? What are their objectives within the project?*<br>*2. In what type of publicly accessible spaces are these activities focused (streets, squares, gardens, parks, natural reserve, other)?*<br>*3. Do you do any kind of mapping for your activities (GIS, collective cartography, mind mapping, other)? What is the objective of mapping within the project? Are they publicly available?* |
| ***QC4*** *COMMUNITY (involvement)* | *1. Which are the main reasons for the involvement of people from the community in your project (directly affected by limited resource accessibility, live in the area, activism, hobby, other)? How have you managed conflicts or opposing positions?*<br>*2. Can you describe the socioeconomic profile of people involved?*<br>*3. How have you promoted your project in the community?*<br>*4. Do you have an estimate of the number of people involved?* |
| ***QC5*** *CONCLUSSIONS (network expansion)* | *1. What are the main opportunities and/or barriers you have encountered while working with resource collection and management, public opens spaces or spaces with controlled public access, and communities in Brussels?*<br>*2. Could you suggest the name of another stakeholder that I could contact for further interviews and discussions?* |

*Figure 4.2: Question clusters (QC) classified by specific objectives.*

Among the sixty-six ARGS shortlisted and invited to participate (invitations were sent by email), sixteen members from different ARGS agreed to participate in the interviews. All participants were stakeholders playing a key role in the ARGS (citizens, researchers, NGO leaders) and represented all types of ARGS selected (sustainable neighborhood initiatives, public facilities, and co-creation research projects). The interviews were conducted face-to-face during ARGS's site visits between March and November 2022, with a maximum duration of one hour. All interviews were recorded and later transcribed for content and text-mining techniques (topic modeling) analyses.

Five question clusters (QC) were used to focus on specific objectives (see *Figure 4.2*): QC1 included questions regarding the general information of the stakeholders involved (type of organization, date of creation, number of people involved), QC2 included questions regarding the type of project undertaken (objectives, resources managed, funding, key partners, data quantification), QC3 included questions about the type of socio-ecological activities and practices carried out in publicly accessible spaces (resource harvesting, field trips, knowledge sharing, mapping), QC4 included questions about the type of community involvement (socio-economic profile, motivation), and QC5 included questions about the main barriers and opportunities encountered in this type of initiatives.

#### *4.2.3 3D spatial models (finer grain data collection)*

A spatial analysis was conducted on the ARGS projects that were visited and interviewed, specifically focusing on those located in publicly accessible spaces. Out of the sixteen ARGS considered that were previously interviewed, twelve fulfilled these criteria (i.e., ARGS with publicly accessible spaces led or co-led by citizen collectives to manage at least one of the three key resources studied). The other four excluded ARGS consisted of research projects (that conducted temporary on-site studies in public space prior to our research) and a private NGO headquarters that did not feature any publicly accessible spaces.

The main objective of the spatial analysis was to gather fine-grained quantitative and qualitative data on resource management (rainwater harvesting, energy generation, or waste treatment) and community involvement (socio-ecological activities and practices and types of spaces used) in relation to total land occupation (square meter ratio). Through 3D digital models, the different socio-ecological activities and practices undertaken were identified and spatialized: type of publicly accessible spaces used (working and gathering spaces), resource collection infrastructures (compost bins, rainwater harvesting artifacts, solar panels), people directly involved and common users (within public and private spaces), as well as mapping other spatial relationships linked to the urban environment.

To assess the local-scale impact of ARGS, percentage values were calculated in relation to the total number of community members engaged. These values accounted for the potential supply or treatment of the key resources studied (water, energy, and solid waste) and the increase in publicly accessible spaces, considering the per capita values of resource consumption, waste generation, and square meters of publicly accessible spaces at the municipal level where the ARGS are located. Three user scales were defined to evaluate varying degrees of community impact: core group, network, and street scales. The core group refers to the individuals responsible for managing the project and actively engaged in the resource governance within the community; the user network includes all participants involved in the project's activities (based on interview data or *WhatsApp* and *Facebook* private groups total numbers); and the street scale refers to the total number of people living within proximity of less than 100 m radius of the project site. For the street scale, we calculated the number of postal addresses in the desired distance (through field visits) and multiplied it by the average number of inhabitants per household in the neighborhood (MDQ Monitoring des Quartiers, 2022).

*Water flows and infrastructure*

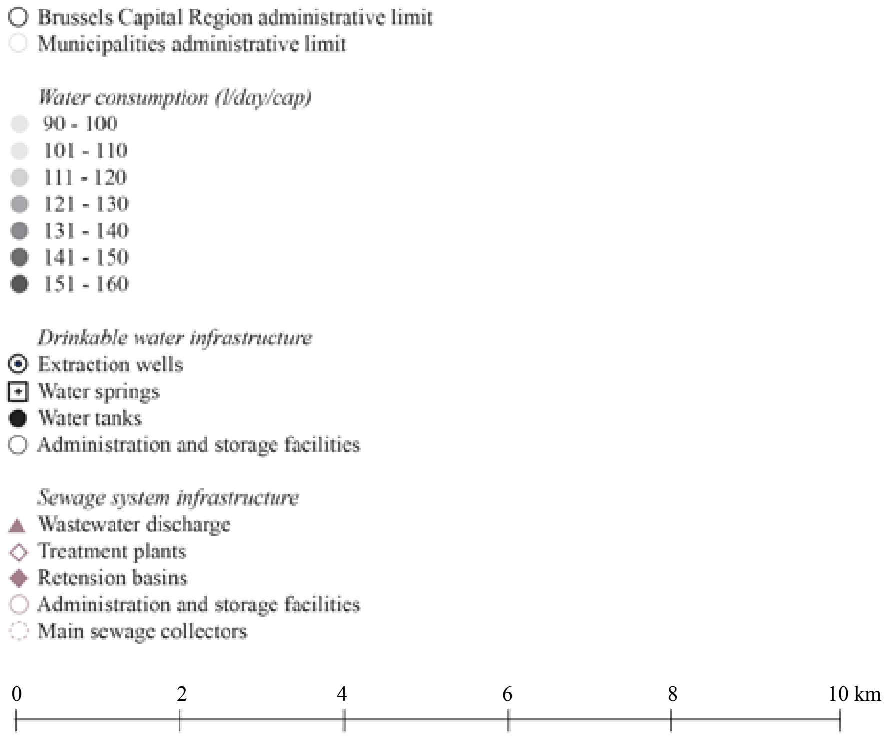
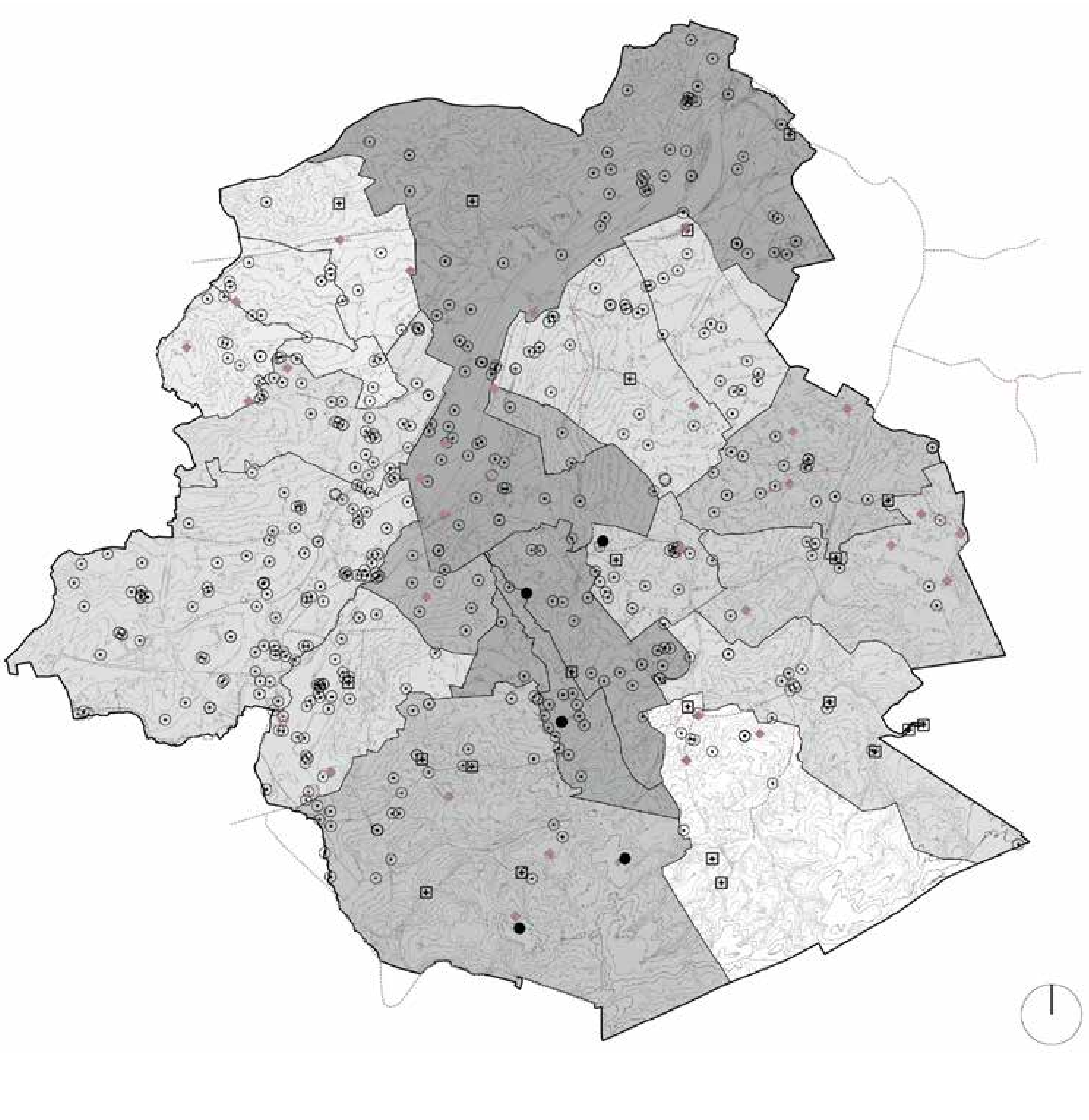



*Figure 4.3: Spatial distribution of drinking water and sewage system flows and infrastructure. Water consumption and wastewater outflows are quantified by municipality. The localization of the infrastructure, resource-management facilities and main network for the drinking water and the sewage system is highlighted with specific symbols and colors by type.*



*Energy flows and infrastructure*

Brussels Capital Region administrative limit
Municipalities administrative limit

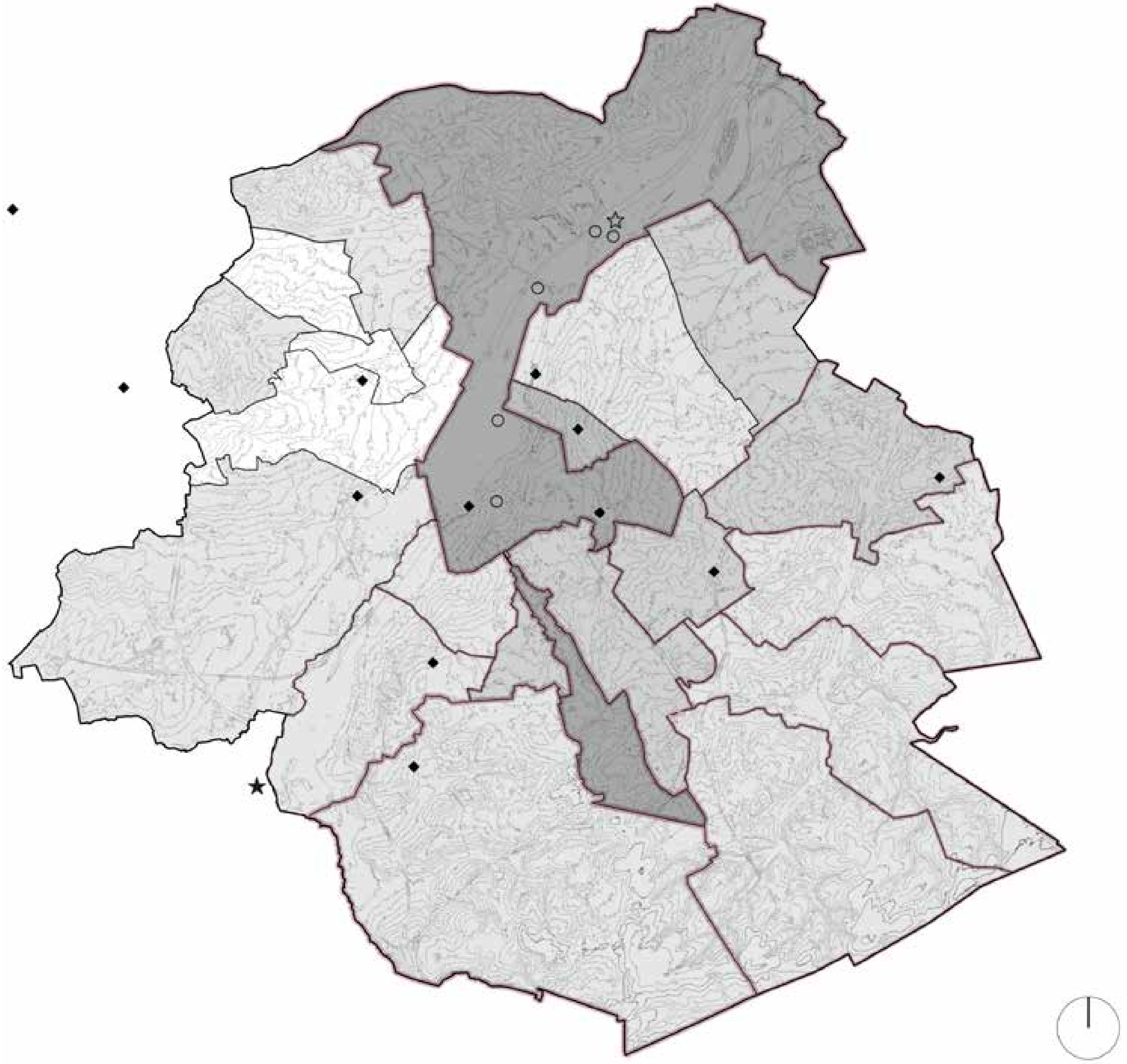
*Electricity consumption (kWh/cap)*
- 1,000 - 2,000
- 2,001 - 3,000
- 3,001 - 4,000
- 4,001 - 5,000
- > 5,000

*Natural gas consumption (kWh/cap)*
- 4,000 - 5,000
- 5,001 - 6,000
- 6,001 - 7,000
- 7,001 - 8,000
- 8,001 - 9,000
- 9,001 - 10,000

*Infrastructure and facilities*
- ★ Electrical power plant (turbojet)
- ☆ Waste-to-energy plant (incineration)
- ◆ Electrical substations
- ○ Administration and storage facilities

0 2 4 6 8 10 km

*Figure 4.4: Spatial distribution of electrical energy and natural gas flows and infrastructure. Electricity and natural gas consumption is quantified by municipality. The localization of the infrastructure, resource-management facilities and main distribution network is highlighted with specific symbols and colors by type.*



*Solid waste flows and infrastructure*

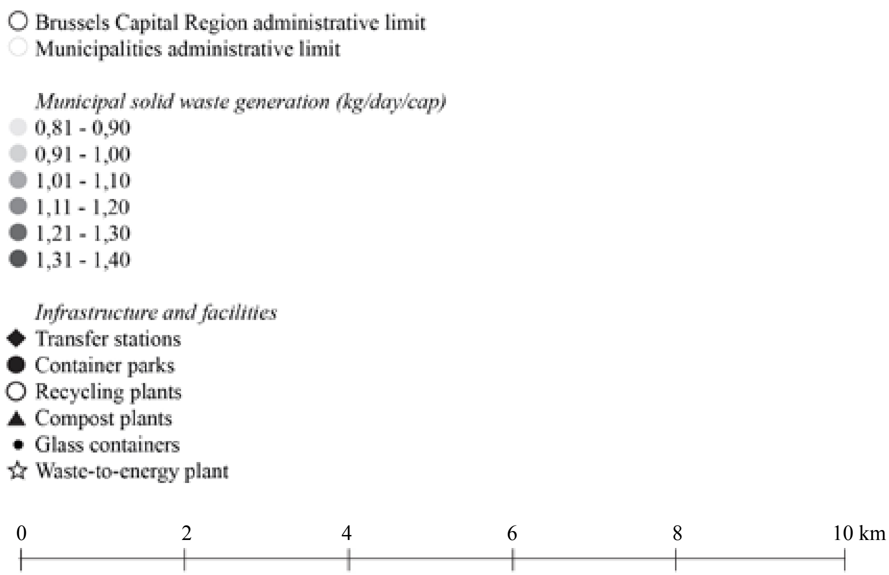



*Figure 4.5: Spatial distribution of solid waste flows and infrastructure. Municipal solid waste is quantified by municipality. The localization of the infrastructure and resource-management facilities is highlighted with specific symbols by type.*

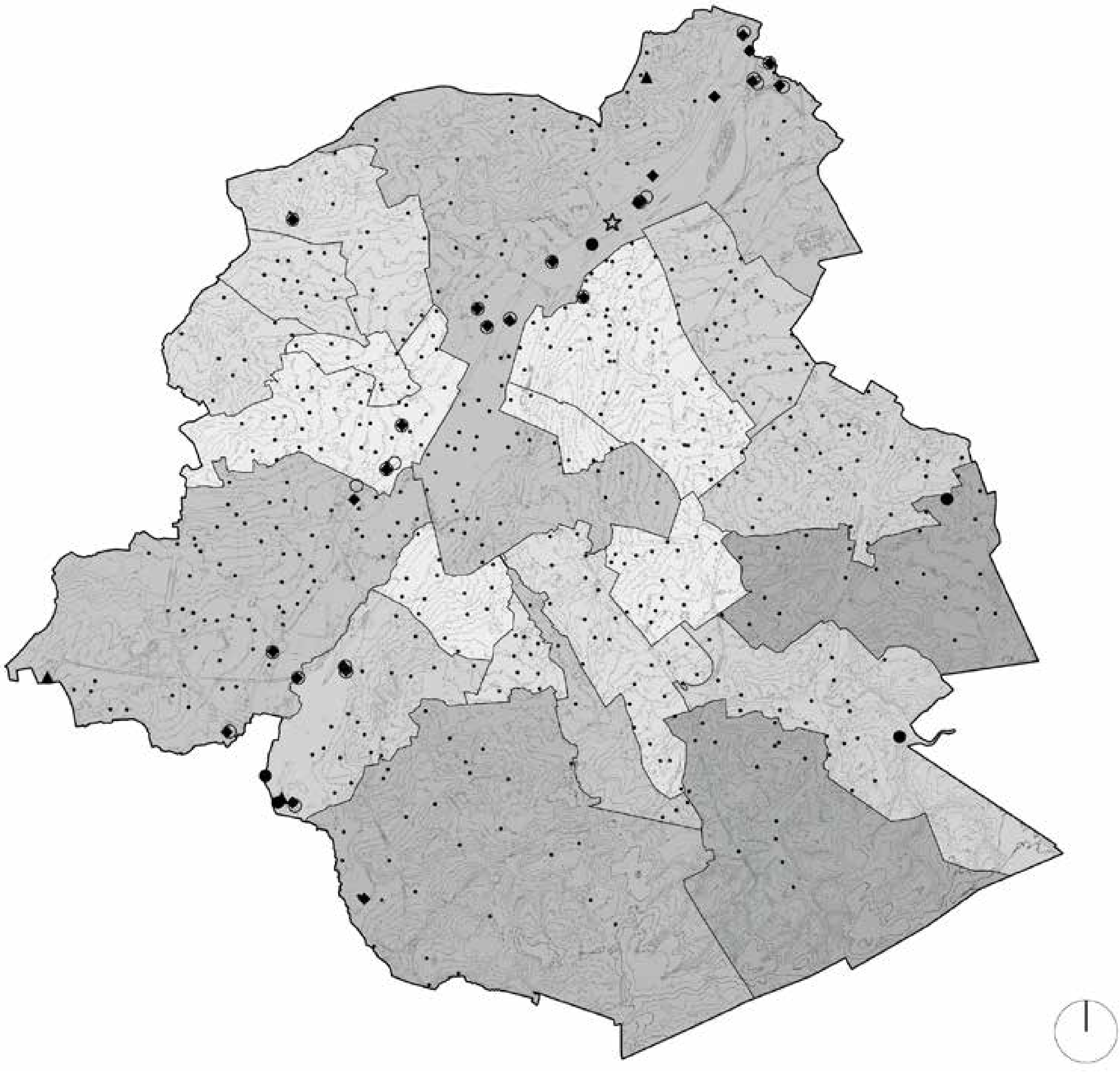
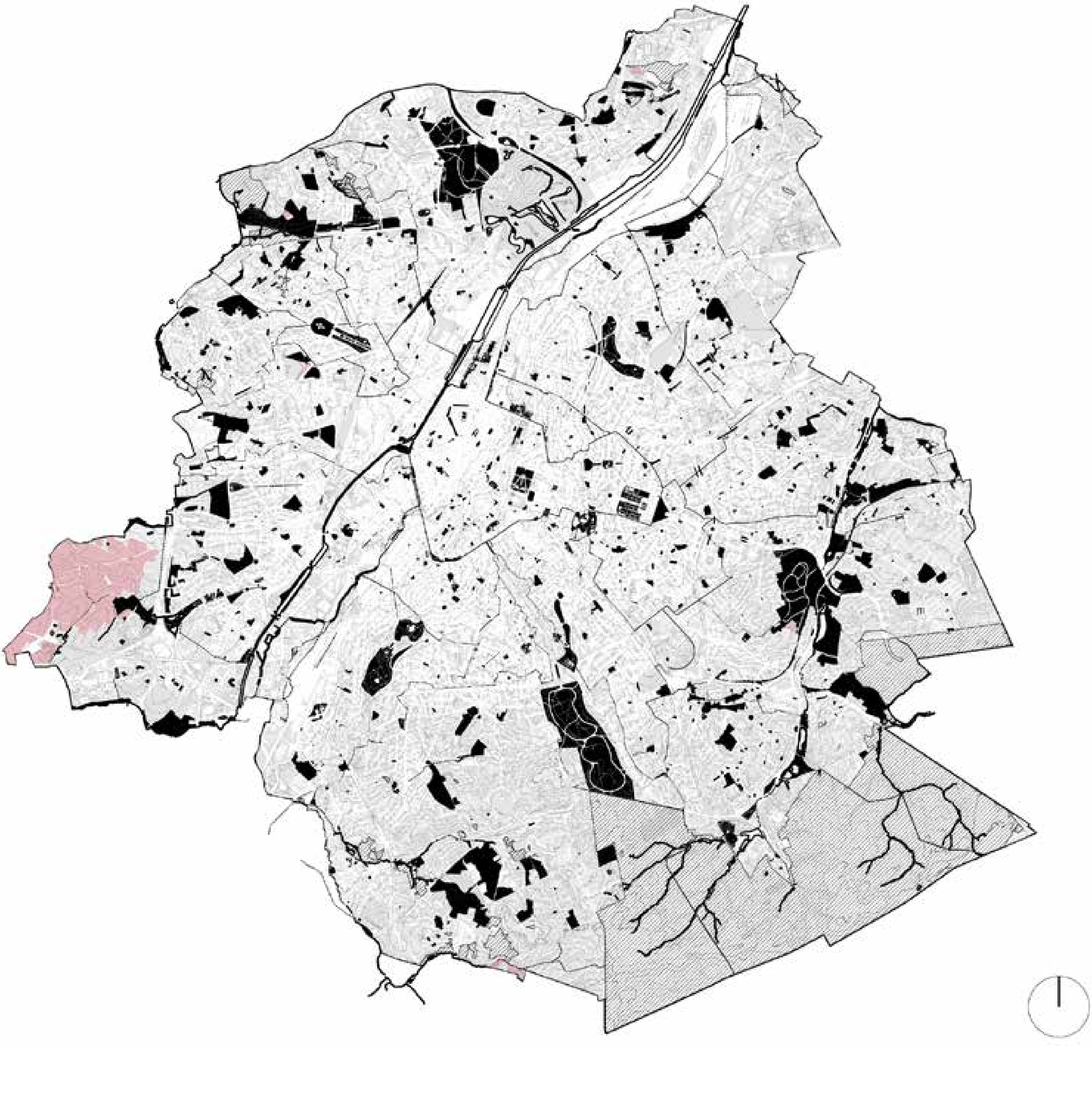



*Figure 4.6: Spatial distribution of the open space networks, including public green, blue, and grey infrastructure, as well as the street network, private gardens, and nature reserves.*



Vulnerable communities

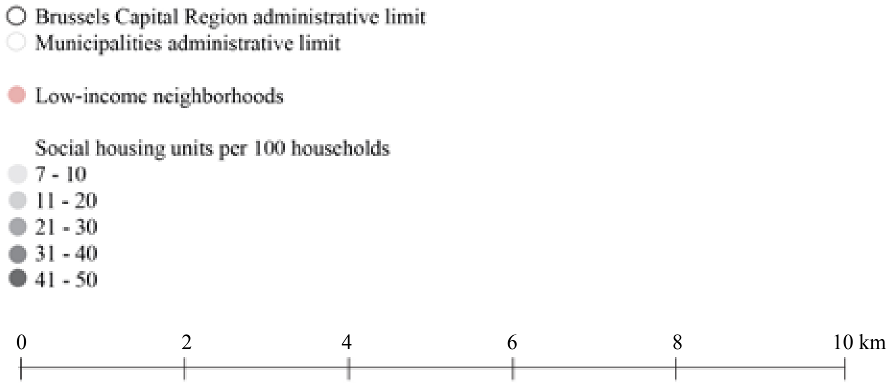
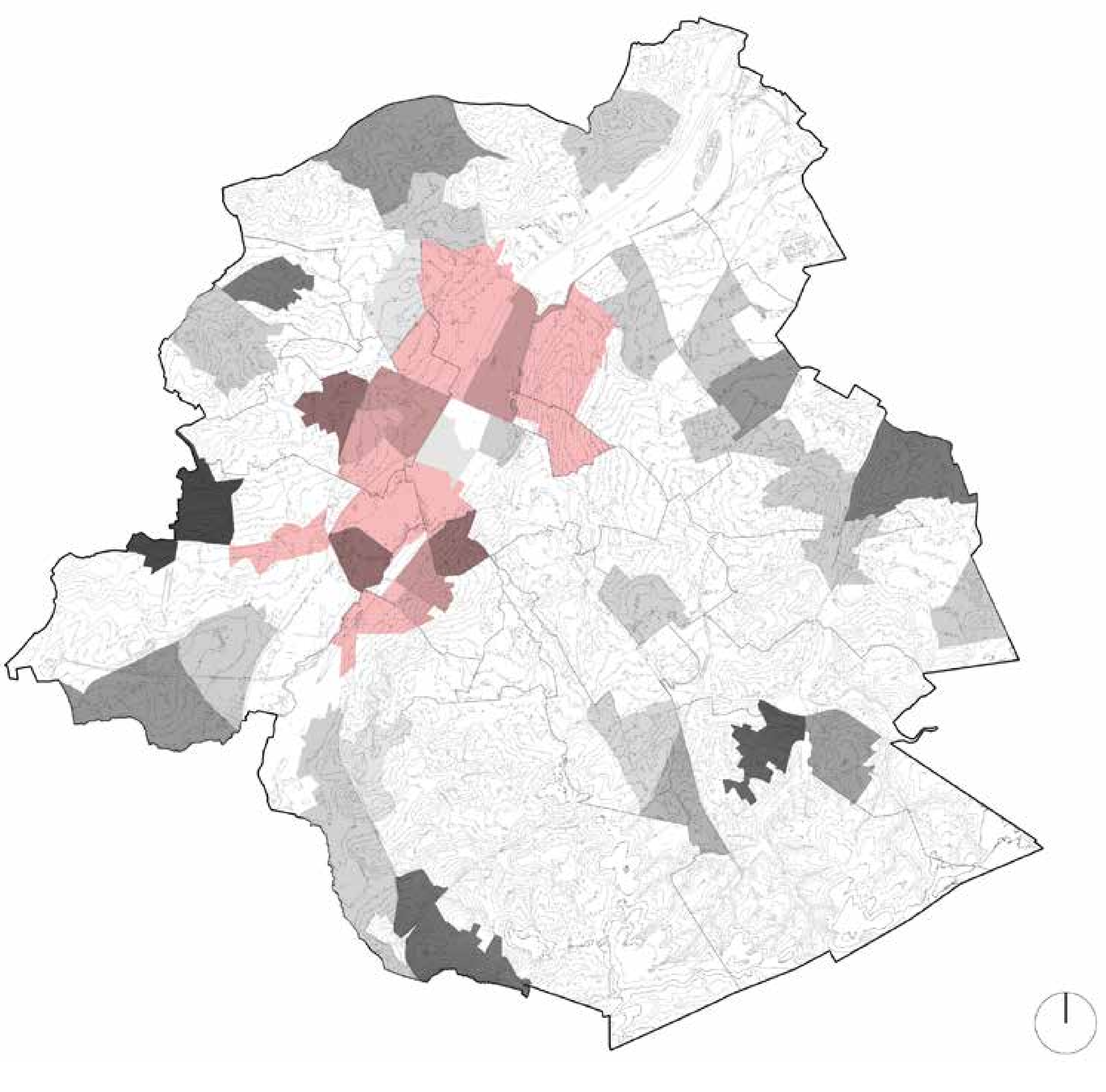



*Figure 4.7: Spatial distribution of low-income neighborhoods and neighborhoods with a high share of social housing units per 100 households.*



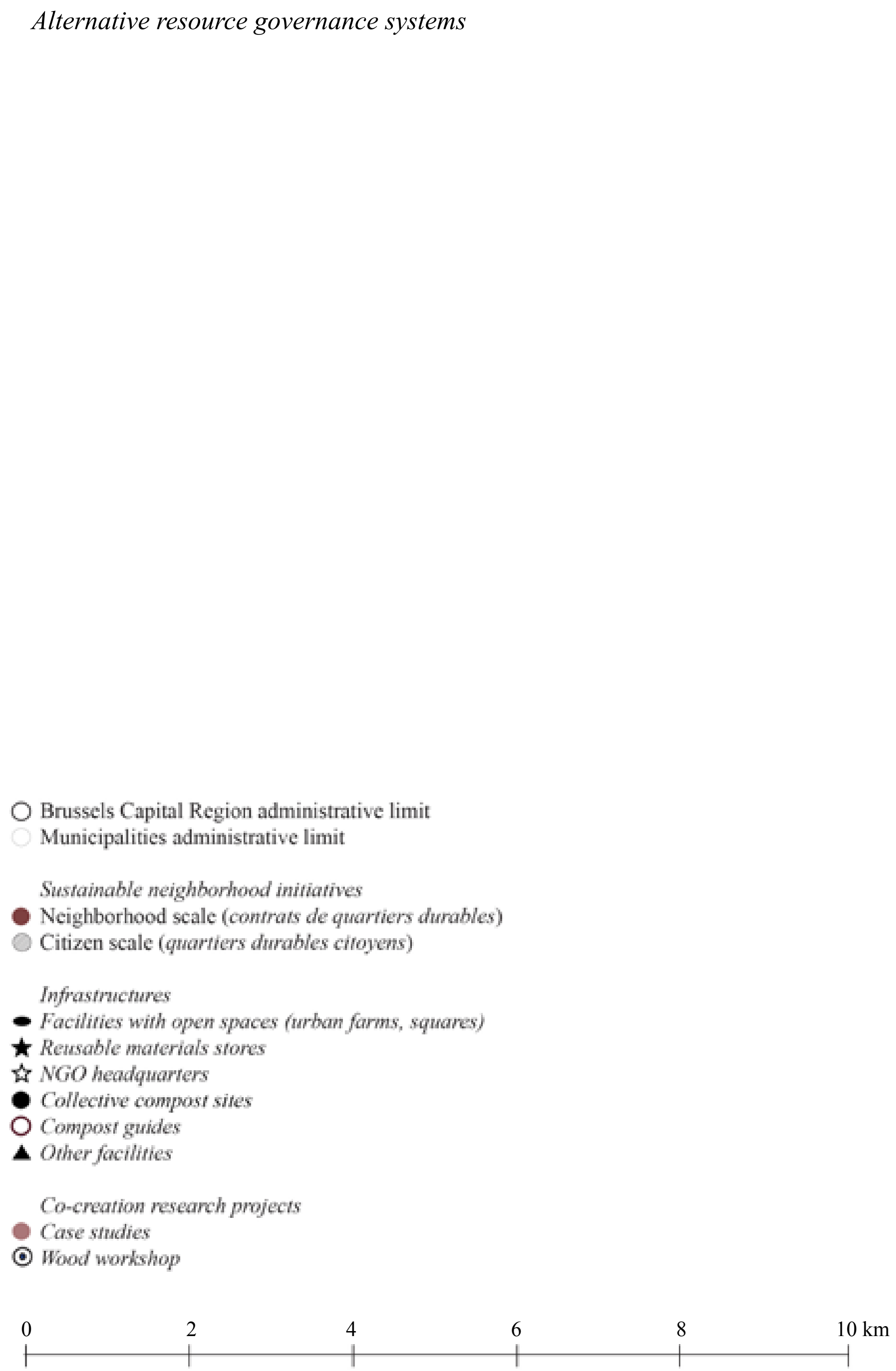
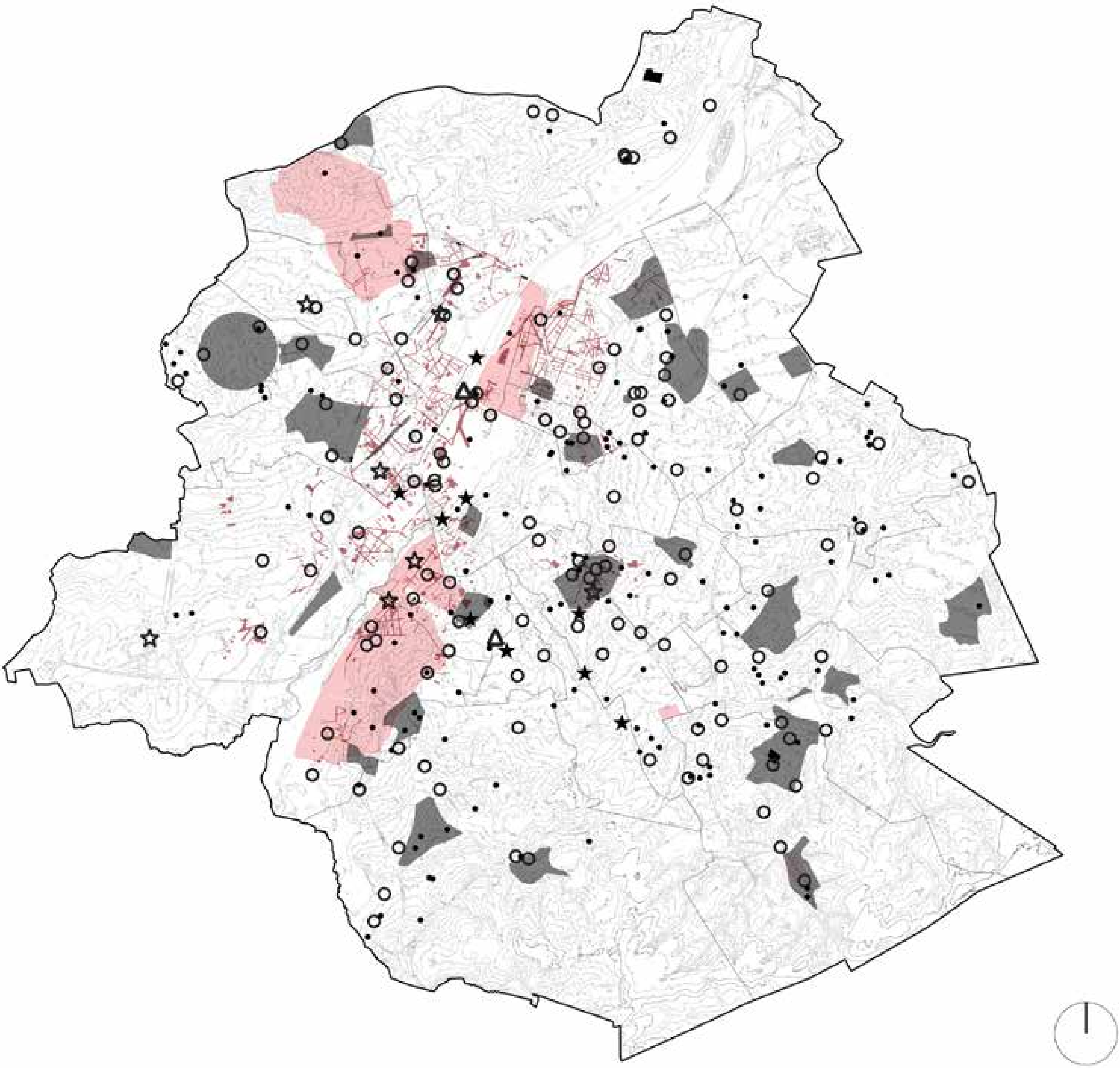



*Figure 4.8: Spatial distribution of alternative resource governance systems, including sustainable neighborhood initiatives, infrastructures and facilities, and co-creation research projects.*



*Synthesis map*

Brussels Capital Region administrative limit
Municipalities administrative limit

Highly resource consumption areas in multiple flows

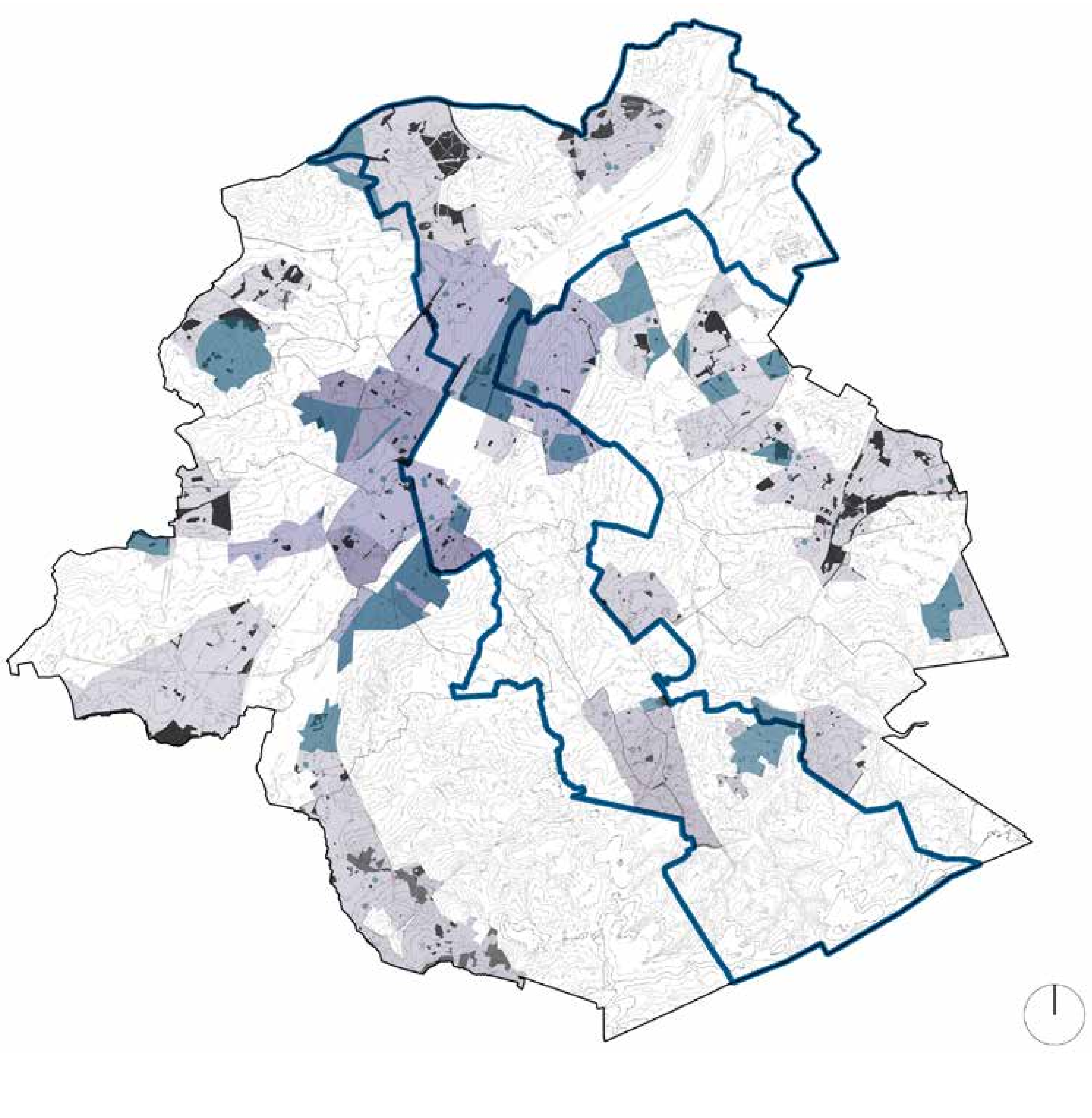
Public open space networks

Low-income neighborhoods
Neighborhoods with a highly share of social housing units

Alternative resource governance systems

+ Selected ARGS


*Figure 4.9: Spatial distribution of ARGS (highlighted in light blue) and public open spaces (highlighted in black) within neighborhoods with vulnerable communities (highlighted in purple), and municipalities with very high resource consumption in multiple flows (highlighted in dark blue). and selected ARGS for site visits and interviews. ARGS selected for interviews and field visits are indicated with a cross symbol.*



### *4.3 Results*

The first set of maps (see *Figures 4.3-4.8*) refer to the spatial distribution of resource flows and utility infrastructure, open space networks, vulnerable communities, and ARGS by municipality. Results highlight that neighborhoods with vulnerable communities occupy approximately 31% of BCR's surface. Notably, half of this area is located within the eight municipalities exhibiting the highest levels of resource consumption, which only account for 15% of the total open-space network surface. Furthermore, 44% of all identified ARGS are located within areas with vulnerable communities, and 29% are located in municipalities classified as having very high resource consumption (see *Figure 4.9*).

#### *4.3.1 Resource flows, open space networks, ARGS, and vulnerable communities*

The first set of maps (see *Figures 4.3-4.8*) refer to the spatial distribution of resource flows and utility infrastructure, open space networks, vulnerable communities, and ARGS by municipality. *Figure 4.9* illustrates ARGS and public open spaces within neighborhoods with vulnerable communities, municipalities with high resource consumption, and selected ARGS for site visits and interviews. Additionally, *Tables S4.2-S4.7* in the *Supporting Material* illustrate all quantitative data used for the GIS analysis.

The resource consumption and waste generation maps highlight that eight out of nineteen municipalities in BCR have very high resource consumption and waste generation levels in at least one type of the studied flows, and four of these in multiple of the studied flows: *Bruxelles*, *Ixelles*, *Saint-Josse-ten-Noode*, and *Watermael-Boitsfort*. These municipalities also consume more than 50% of the total annual water electricity, and natural gas consumption (28,782,366 $m^3$/year of water, 2,482 GWh of electricity and 5,077 GWh of natural gas) and 48% of municipal solid waste generated (218,456 tons), have 45% of the total population (543,997 inhabitants), and cover 57% of the total surface area (93 $km^2$). Additionally, all low-income neighborhoods are concentrated in eight south-central municipalities, including *Bruxelles* and *Anderlecht*, which, together with six other peripheral municipalities, also concentrate all the neighborhoods with a high share of social housing units. Quantitative data used in the GIS analysis are provided in *Tables S4.2–S4.8*.

#### *4.3.2 Qualitative analysis of selected ARGS*

The semi-structured interviews and site visits conducted across sixteen selected ARGS enabled the classification of these initiatives by typology, illustrated their defining characteristics, identified key socio-ecological activities and practices, and revealed critical challenges relevant to future design approaches. The selected ARGS were categorized into four typologies, representing a subset of the previously identified sixty-six cases: twenty-three Collective Infrastructures (CI), three Networking Platforms (NP), thirty-five Organized Groups (OG), and five Research Studies (RS). CI are facilities with publicly accessible spaces, such as community centers, reusable material stores, and urban farms, managed by NGOs or private and are located in underdeveloped areas (i.e., public or private unused urban space such as brownfields, vacant lots, abandoned buildings, and parking sites), parks, or nature reserves. NP are virtual spaces that foster the clustering of similar resource management initiatives and are led by NGOs , such as online network of collective compost sites and an international association of recycling centers. OG are grassroots practices operating in public open spaces, such as community gardens and collective composts, managed by citizens and located in underdeveloped areas, parks, streets, and sidewalks. RS are multi-scale and multidisciplinary projects, such as rainwater harvesting in urban commons and collective solar power production research studies, jointly led by universities and diverse stakeholders and depending on their objectives, the study areas cover all types of open spaces.

The main characteristics of the sixteen selected ARGS were analyzed according to their location, scale of participation, the type of publicly accessible space utilized, activities undertaken, and resources managed (see *Figure 4.10*). Most CI operate at the municipal level and support multiple activities with team sizes ranging from under five to over fifty people. The NP functions regionally, with a large team and a strong focus on knowledge exchange and infrastructure development. OG projects are neighborhood-based, centered on social interaction and self-management, and usually led by small core groups. RS projects operate at the regional scale, with smaller teams focused on research, knowledge transfer, and stakeholder engagement. Notably, six of the sixteen ARGS, spanning all four typologies, included design practitioners as core participants.

Socio-ecological activities and practices were identified and categorized through a topic modeling analysis of the interview transcripts (see *Figure 4.11*), focusing on resource management, public space use, and community involvement. Resource management practices were organized by both resource type and by operational phase. Key examples include rainwater harvesting, solar thermal water heating, and composting. Activities conducted in publicly accessible spaces were classified according to their purpose and these included organizational and social events, such as planning meetings and communal gatherings; practical, hands-on work, such as the construction of raised garden beds and eco-building; educational and knowledge-sharing initiatives, including composting workshops and training sessions; networking activities, involving engagement with government agencies and participation in thematic events; and participatory mapping, which encompassed the identification of local stakeholders and relevant infrastructure. Community involvement emerged in three primary forms: activism, including voluntary initiatives such as the establishment of collective composting sites or the development of new governance models; social cohesion, expressed through efforts to promote collective labor and ensure inclusive, safe environments, particularly for women and children; and economic resilience, which involved increasing food sovereignty and fostering resource autonomy.

Finally, the interviewees highlighted several design-related opportunities (see *Figure 4.12*), such as the potential to develop new techniques for resource harvesting and to replicate successful models in different locations. Many viewed underdeveloped public open spaces as promising environments for engaging diverse social groups and fostering collaboration among multiple stakeholders. Nevertheless, several interviewees expressed concerns about the physical degradation of shared spaces, the high maintenance demands of such projects, a general lack of habits related to resource sharing among users, and the aesthetic outcomes of these resource-sensitive design approaches. In particular, the unconventional architectural finishes were sometimes perceived negatively by users, which created a sense of detachment or exclusion for those who did not identify with the resulting spatial qualities. From a governance perspective, while some interviewees acknowledged supportive measures from local and regional authorities, such as flexible frameworks for temporary occupations, many raised concerns about restrictive legal conditions for resource sharing, limited financial support resulting in precarious labor conditions, and protracted administrative processes for permits and renewals.

### *4.3.3 Local-scale spatial analysis*

3D spatial models of twelve ARGS (seven collective infrastructures and five organized groups) were built based on interviews and site visits data (see *Figure 4.13*). All models are represented at the same scale to illustrate the variety of sizes and urban contexts. To facilitate the legibility of the fine-grained data relative to each project and to illustrate its spatial quality, the models are presented as a catalogue of spatial configurations containing twelve sheets that illustrate each project. Each catalogue sheet contains a 3D spatial model that illustrates and describes the existing socio-ecological activities and practices, a detailed quantitative analysis of the devices used for resource capture and management, and an estimate of the project's impact within the community (see *Figures 4.14-4.25* with all individual catalogue sheets of the twelve ARGS selected).

The analysis reveals a wide range of spatial configurations, which are shaped by the specific resource harvesting goals and the intended functions of community spaces. A key finding indicates that, across all projects, ARGS led to an increase of per capita values of public space by at least 20% in all projects. However, while the total amount of resources harvested or transformed at the street level remains relatively low, ranging from a 1% to 3% increase in per capita values, per-capita organic waste processing achieved more substantial coverage, addressing up to 50% at the street scale in most cases. The local-scale impact of each project was calculated at three different user scales (each column represents the core group, network, and street scales, respectively). For instance, considering the percentage values of water consumption supplied by the rainwater harvesting system of project *OG03* at different scales, the system could potentially provide up to 16% of the total per capita water consumption for core group members, nearly 2% for the network scale, and 1% for the street scale (corresponding to approximately 10, 278, and 75 individuals, respectively). A summary of key metrics for the selected ARGS, including community involvement, publicly accessible urban space created, and resource management and treatment, and the spatial dimension of these projects by assessing the values per square meter across various analyzed themes are presented in *Figure 4.26*.

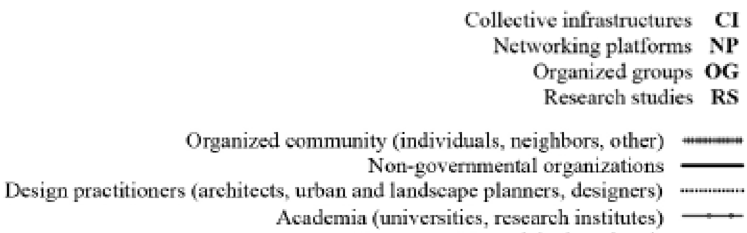



*Figure 4.10: Main characteristics of selected ARGS (CI are highlighted in cyan, NP are highlighted in green, OG are highlighted in magenta, and RS are highlighted in orange), including scale of intervention, type of stakeholder involved, location, number of people involved, type of urban space used, activities, and key resources managed. For a detailed breakdown of the main characteristics and stakeholders involved, please refer to Table S4.8 in the Supporting Material.*

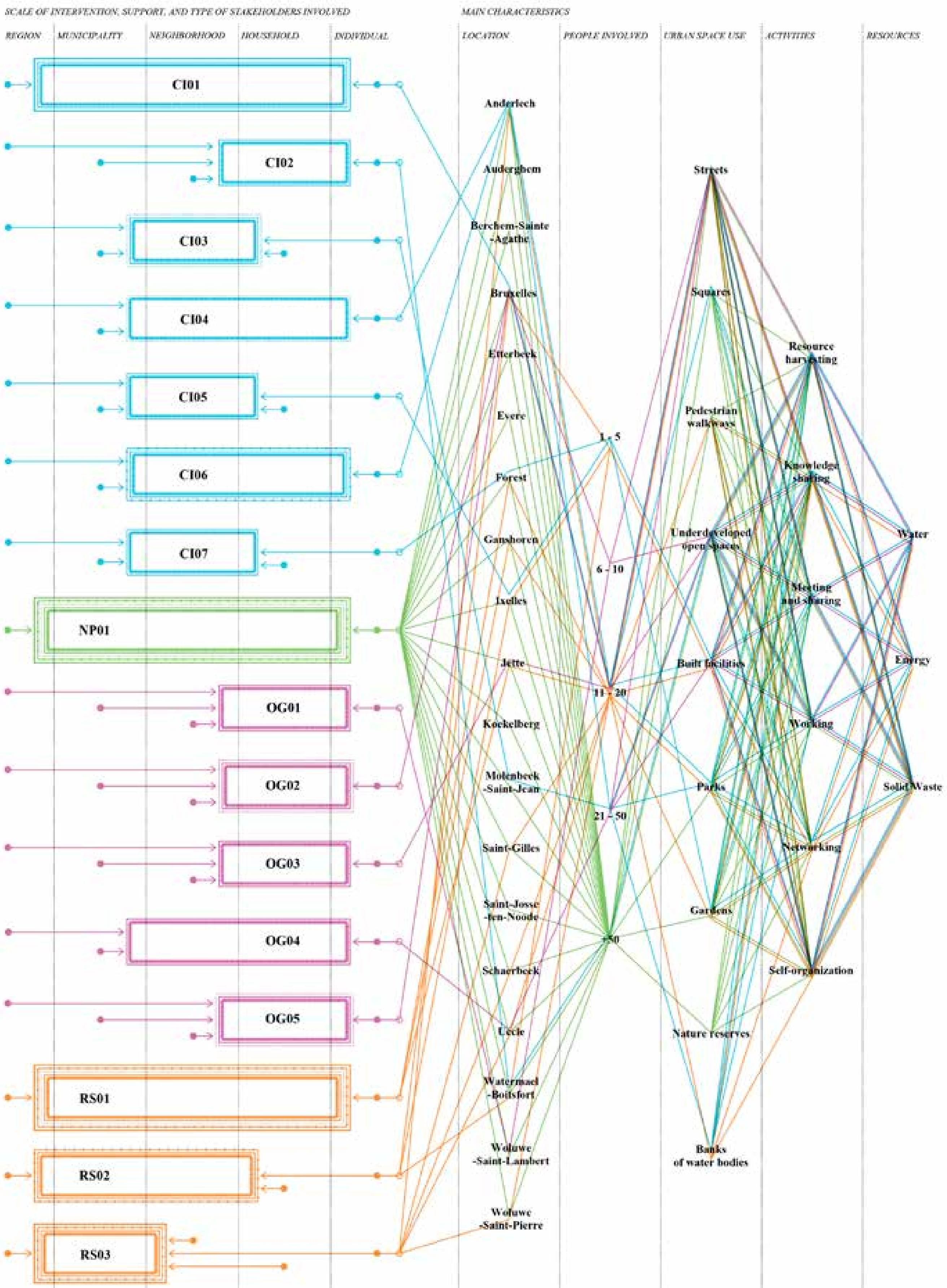

SCALE OF INTERVENTION, SUPPORT, AND TYPE OF STAKEHOLDERS INVOLVED
MAIN CHARACTERISTICS
REGION
MUNICIPALITY
NEIGHBORHOOD
HOUSEHOLD
INDIVIDUAL
LOCATION
PEOPLE INVOLVED
URBAN SPACE USE
ACTIVITIES
RESOURCES
CI01
CI02
CI03
CI04
CI05
CI06
CI07
NP01
OG01
OG02
OG03
OG04
OG05
RS01
RS02
RS03
Anderlech
Auderghem
Berchem-Sainte -Agathe
Bruxelles
Etterbeek
Evere
Forest
Ganshoren
Ixelles
Jette
Kockelberg
Molenbeek -Saint-Jean
Saint-Gilles
Saint-Josse -ten-Noode
Schaerbeek
Uccle
Watermael -Boitsfort
Woluwe -Saint-Lambert
Woluwe -Saint-Pierre
1 - 5
6 - 10
11 - 20
21 - 50
+50
Streets
Squares
Pedestrian walkways
Underdeveloped open spaces
Built facilities
Parks
Gardens
Nature reserves
Banks of water bodies
Resource harvesting
Knowledge sharing
Meeting and sharing
Working
Networking
Self-organization
Water
Energy
Solid Waste

*Figure 4.11: Socio-ecological activities and practices of selected ARGS based on qualitative content analysis (topic modeling) on the interview's transcriptions.*

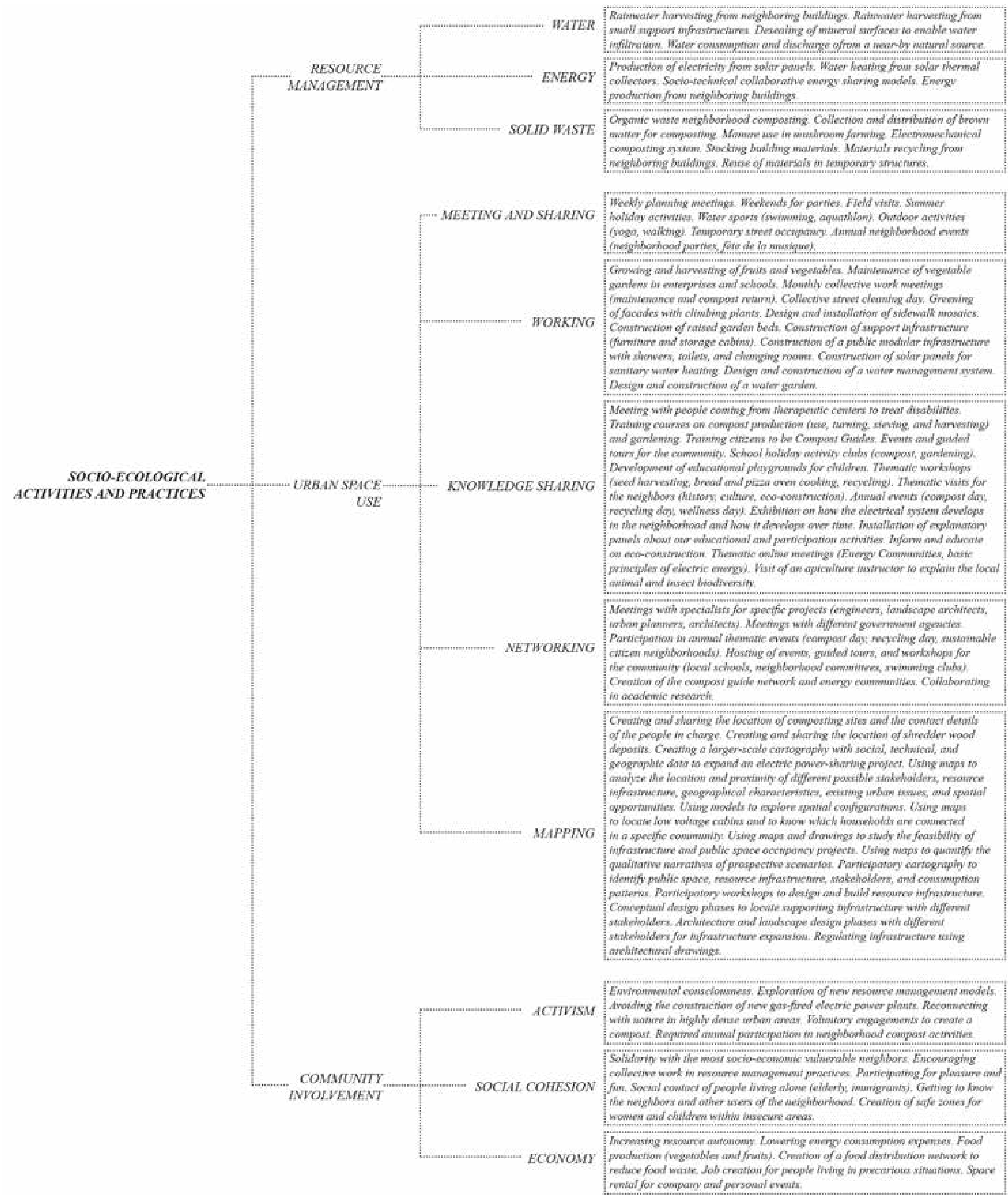

SOCIO-ECOLOGICAL ACTIVITIES AND PRACTICES
RESOURCE MANAGEMENT
WATER
Rainwater harvesting from neighboring buildings. Rainwater harvesting from small support infrastructures. Desealing of mineral surfaces to enable water infiltration. Water consumption and discharge ofrom a near-by natural source.
ENERGY
Production of electricity from solar panels. Water heating from solar thermal collectors. Socio-technical collaborative energy sharing models. Energy production from neighboring buildings.
SOLID WASTE
Organic waste neighborhood composting. Collection and distribution of brown matter for composting. Manure use in mushroom farming. Electromechanical composting system. Stocking building materials. Materials recycling from neighboring buildings. Reuse of materials in temporary structures.
URBAN SPACE USE
MEETING AND SHARING
Weekly planning meetings. Weekends for parties. Field visits. Summer holiday activities. Water sports (swimming, aquathlon). Outdoor activities (yoga, walking). Temporary street occupancy. Annual neighborhood events (neighborhood parties, fête de la musique).
WORKING
Growing and harvesting of fruits and vegetables. Maintenance of vegetable gardens in enterprises and schools. Monthly collective work meetings (maintenance and compost return). Collective street cleaning day. Greening of facades with climbing plants. Design and installation of sidewalk mosaics. Construction of raised garden beds. Construction of support infrastructure (furniture and storage cabins). Construction of a public modular infrastructure with showers, toilets, and changing rooms. Construction of solar panels for sanitary water heating. Design and construction of a water management system. Design and construction of a water garden.
KNOWLEDGE SHARING
Meeting with people coming from therapeutic centers to treat disabilities. Training courses on compost production (use, turning, sieving, and harvesting) and gardening. Training citizens to be Compost Guides. Events and guided tours for the community. School holiday activity clubs (compost, gardening). Development of educational playgrounds for children. Thematic workshops (seed harvesting, bread and pizza oven cooking, recycling). Thematic visits for the neighbors (history, culture, eco-construction). Annual events (compost day, recycling day, wellness day). Exhibition on how the electrical system develops in the neighborhood and how it develops over time. Installation of explanatory panels about our educational and participation activities. Inform and educate on eco-construction. Thematic online meetings (Energy Communities, basic principles of electric energy). Visit of an apiculture instructor to explain the local animal and insect biodiversity.
NETWORKING
Meetings with specialists for specific projects (engineers, landscape architects, urban planners, architects). Meetings with different government agencies. Participation in annual thematic events (compost day; recycling day, sustainable citizen neighborhoods). Hosting of events, guided tours, and workshops for the community (local schools, neighborhood committees, swimming clubs). Creation of the compost guide network and energy communities. Collaborating in academic research.
MAPPING
Creating and sharing the location of composting sites and the contact details of the people in charge. Creating and sharing the location of shredder wood deposits. Creating a larger-scale cartography with social, technical, and geographic data to expand an electric power-sharing project. Using maps to analyze the location and proximity of different possible stakeholders, resource infrastructure, geographical characteristics, existing urban issues, and spatial opportunities. Using models to explore spatial configurations. Using maps to locate low voltage cabins and to know which households are connected in a specific community. Using maps and drawings to study the feasibility of infrastructure and public space occupancy projects. Using maps to quantify the qualitative narratives of prospective scenarios. Participatory cartography to identify public space, resource infrastructure, stakeholders, and consumption patterns. Participatory workshops to design and build resource infrastructure. Conceptual design phases to locate supporting infrastructure with different stakeholders. Architecture and landscape design phases with different stakeholders for infrastructure expansion. Regulating infrastructure using architectural drawings.
COMMUNITY INVOLVEMENT
ACTIVISM
Environmental consciousness. Exploration of new resource management models. Avoiding the construction of new gas-fired electric power plants. Reconnecting with nature in highly dense urban areas. Voluntary engagements to create a compost. Required annual participation to neighborhood compost activities.
SOCIAL COHESION
Solidarity with the most socio-economic vulnerable neighbors. Encouraging collective work in resource management practices. Participating for pleasure and fun. Social contact of people living alone (elderly, immigrants). Getting to know the neighbors and other users of the neighborhood. Creation of safe zones for women and children within insecure areas.
ECONOMY
Increasing resource autonomy. Lowering energy consumption expenses. Food production (vegetables and fruits). Creation of a food distribution network to reduce food waste. Job creation for people living in precarious situations. Space rental for company and personal events.

*Figure 4.12: Opportunities and barriers in creating and managing ARGS. In bold are the topics that can be directly related to the involvement of design practitioners.*

| | OPPORTUNITIES | BARRIERS |
|---|---|---|
| *RESOURCE HARVESTING* | *Moving from techno-economic models to socio-technical models (RS02, RS03) .*<br>***Exploration of techniques for resource recovery (CI05, CI06) .***<br>***Replicate the resource harvesting systems in neighboring municipalities (CI06, OG02) .*** | *. Complex infrastructure system and resource flows (RS02)*<br>*. Lack of collective resource sharing habits (OG05, RS03)*<br>*. Soil, water, and air pollution (CI01)*<br>***. Degradation of public space and continuous maintenance requirement (OG03, NP01)***<br>*. Reused materials costs higher than new materials costs (CI03)*<br>*. Abstract terminology for many stakeholders, i.e. sustainability, circularity (CI03)* |
| *URBAN SPACE USE* | ***Street and sidewalk occupancy optimizing vehicular/pedestrian use (OG04) .***<br>***Underestimated spaces for resource harvesting, e.g. private gardens and common spaces (RS01) .***<br>*Cost efficiency compared to other types of public spaces (OG02).* | *. Short-term occupancy agreements (CI05, CI07)*<br>*. Available open spaces decrease due to real estate pressure (CI02, CI07)*<br>*. Noise pollution due to proximity to highways or fire stations (CI01)*<br>*. Neighborhood disagreements regarding use of public space (OG04, CI06)* |
| *COMMUNITY INVOLVEMENT* | ***Co-creation with multiple stakeholders (RS02) .***<br>*Collective effort with varied socio-economic profiles (OG01, OG03, CI01, CI03, RS02) .*<br>*Networking between people and projects (NP01, CI01, CI02, CI05) .*<br>*Interest in reducing the cost of living (CI01, CI07) .* | *. Lack of interest to participate due to hierarchy of personal commitments, e.g. time, precariousness (RS01)*<br>*. Lack of long-term participation (OG01, OG02, OG05, NP01)*<br>*. Lack of motivation to participate due to rough weather (OG01)* |
| *GOVERNANCE AND SUPPORT* | *Promotion, funding, and assistance from the Region and its Municipalities (CI01, CI03, CI07, NP01, OG02) .*<br>***Flexible and less stringent frameworks in temporary occupations (CI05) .***<br>*Generate spaces for participatory democracy (RS03) .* | *. Isolation of key governmental and non-governmental stakeholders (RS03)*<br>*. Insufficient funding for employment stability (CI05, CI07, OG05)*<br>*. Short time to demonstrate results with multiple stakehlders (RS02)*<br>***. Economic and productive approach of an ecological transition rather than an environmental approach (RS01)***<br>***. Lack of spatial practitioners to have effective dialogue with authorities (OG02)***<br>*. Legal framework with local and regional governments, e.g. resource sharing restrictions (CI02, CI05, CI07, OG05, RS01)*<br>*. Long administrative times to validate projects (OG04, RS03)* |
| *AESTHETICS* | ***Change of design methodologies according to available resources (CI03, CI04) .*** | ***. Negative predisposition and judgements towards finishes with recycled materials (CI03, CI04)***<br>***. Unwelcoming or neglected spaces for some users (CI05)***<br>*. Reused materials costs higher than new materials costs (CI03)* |

| | Urban space increase (%) Publicly accessible spaces | | |
|---|---|---|---|
| | Core | Network | Street |
| CI01 | 3194 | 72 | 74 |
| CI02 | 1521 | 152 | 537 |
| CI03 | - | 35 | 63 |
| CI04 | 376 | 151 | 12 |
| CI05 | 1633 | 0.82 | 26 |
| CI06 | 139 | 20 | - |
| CI07 | 1356 | 8 | 29 |
| OG01 | 329 | 39 | 23 |
| OG02 | 21 | 4 | 0.76 |
| OG03 | 338 | 12 | 45 |
| OG04 | 37 | 17 | 2 |
| OG05 | 749 | 19 | 28 |

| | Water consumption (%) Drinkable water | | |
|---|---|---|---|
| | Core | Network | Street |
| CI01 | 138 | 3 | 3 |
| CI02 | 295 | 29 | 104 |
| CI03 | - | 1.32 | 2 |
| CI04 | - | - | - |
| CI05 | 21 | - | 0.33 |
| CI06 | 16 | 2 | - |
| CI07 | 103 | 0.62 | 2 |
| OG01 | 16.40 | 1.95 | 1.15 |
| OG02 | 0.97 | 0.17 | 0.03 |
| OG03 | 25 | 0.89 | 3 |
| OG04 | 6 | 3 | 0.32 |
| OG05 | - | - | - |

| | Energy consumption (%) Electricity | | |
|---|---|---|---|
| | Core | Network | Street |
| CI01 | 2 | 0.04 | 0.04 |
| CI02 | - | - | - |
| CI03 | - | - | 0.01 |
| CI04 | - | - | - |
| CI05 | - | - | - |
| CI06 | 7 | 0.97 | - |
| CI07 | - | - | - |
| OG01 | - | - | - |
| OG02 | - | - | - |
| OG03 | - | - | - |
| OG04 | - | - | - |
| OG05 | - | - | - |

| | Solid Waste generation (%) All sources of waste (including organic and garden waste) | | |
|---|---|---|---|
| | Core | Network | Street |
| CI01 | 27 | 0.61 | 0.63 |
| CI02 | 8 | 0.76 | 3 |
| CI03 | - | 0.24 | 0.43 |
| CI04 | - | - | - |
| CI05 | 12 | 0.01 | 0.19 |
| CI06 | - | - | - |
| CI07 | 20 | 0.12 | 0.44 |
| OG01 | 30 | 4 | 2 |
| OG02 | 13 | 2 | 2 |
| OG03 | 22 | 0.80 | 3 |
| OG04 | 17 | 8 | 0.93 |
| OG05 | - | - | - |

| | Organic and garden waste | | |
|---|---|---|---|
| | Core | Network | Street |
| CI01 | 393 | 9 | 9 |
| CI02 | 109 | 11 | 39 |
| CI03 | - | 3 | 6 |
| CI04 | - | - | - |
| CI05 | 169 | 0.08 | 3 |
| CI06 | - | - | - |
| CI07 | 292 | 2 | 6 |
| OG01 | 434 | 52 | 30 |
| OG02 | 187 | 33 | 7 |
| OG03 | 320 | 12 | 42 |
| OG04 | 247 | 112 | 13 |
| OG05 | - | - | - |

*Figure 4.13: 3D models of twelve Selected ARGS and an estimate of the project's impact within the community. All models are represented at the same scale to illustrate the variety of sizes and urban contexts. The table quantifies the percentage increase in urban space created, resources captured, and waste processed at three different user scales (core group, network, and street). The values represent: i) the total percentage increase in square meters per capita of newly publicly accessible spaces created ; ii) the per capita percentage of resource generated in the ARGS new space (based on per capita consumption and waste generation data at the municipality level). Highlighted in green values greater than 100%, dark yellow values between 99% and 10%, light yellow values between 9% and 1%, and gray values below 1%.*

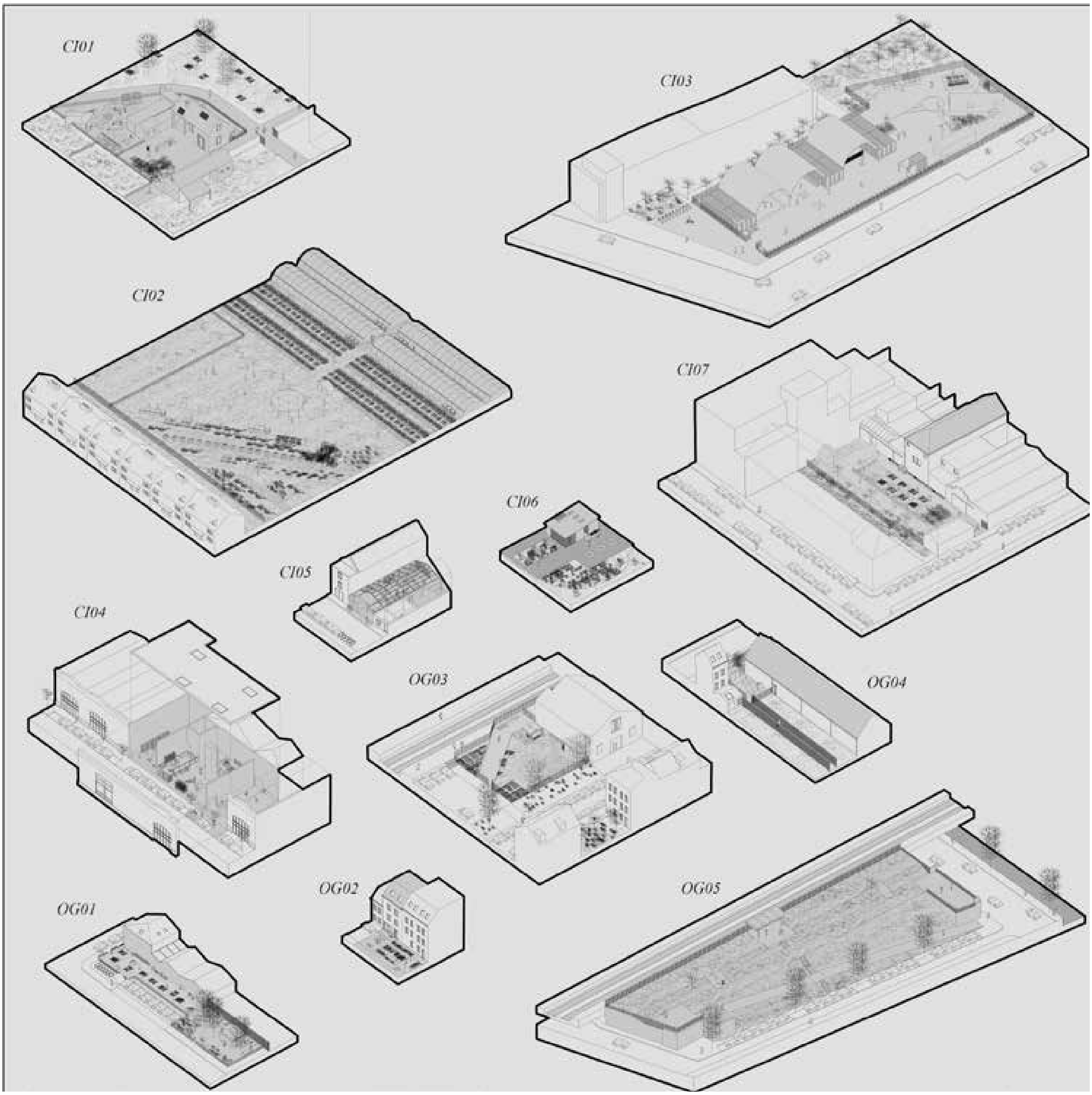
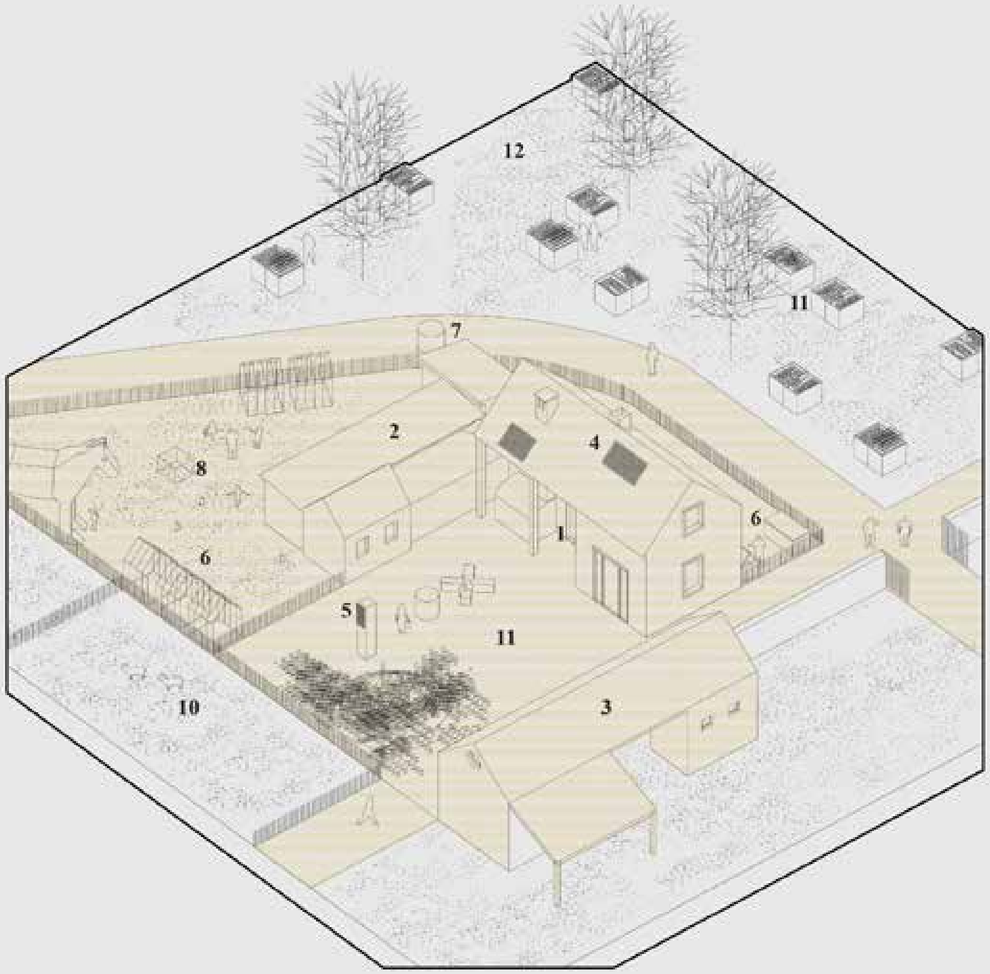

CI01
CI03
CI02
CI07
CI06
CI05
CI04
OG03
OG04
OG02
OG05
OG01

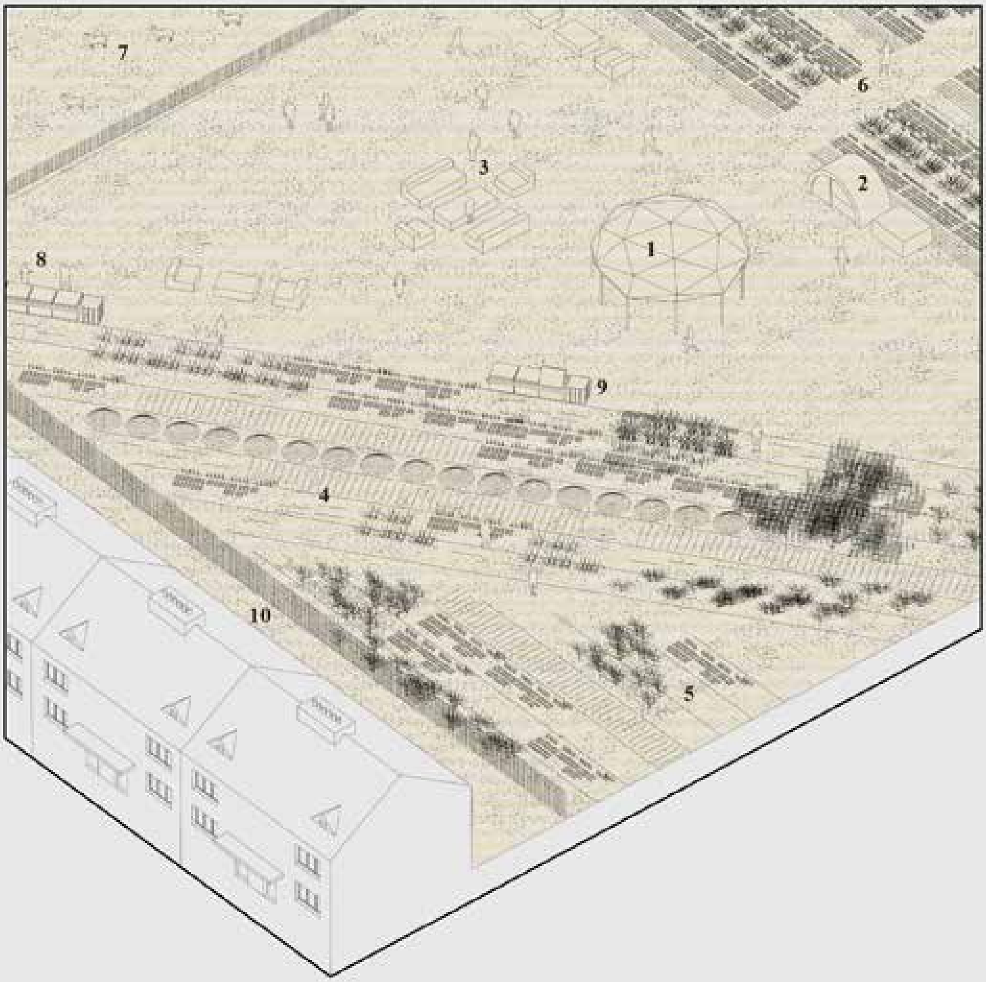

*Figure 4.14: Catalogue of spatial configurations: CI01 Collective Infrastructure. Photo by author, 2022.*




***An educational farm in the heart of the city***

1. Main building, 2. Storage rooms, 3. Animal barn, 4. Photovoltaic panels (7 units 1x1.2 m), 5. Solar thermal panel (1 unit 1x1.2 m), 6. Neighborhood compost (4 bins of 1 m3), 7. Rainwater harvesting from storage roof (1 tank of 1,000 liters capacity), 8. Chicken coop, 9. Greenhouses, 10. Pasture grasslands (2,783 m2), 11. Public vegetable garden (42 raised beds 1x0.5 m2), 12. Collective garden (1,370 m2), 11. Approximately 12,800 m2 of urban space use and 20 people directly involved.


*Figure 4.15: Catalogue of spatial configurations: CI02 Collective Infrastructure. Photo by author, 2022.*




***A cooperative urban farm***

1. Canopy for community meetings, 2. Community bulletin board, 3. Furniture made from recycled material, 4. Collective garden, 5. Pedagogical garden, 6. Agricultural exploitation for members' market, 7. Pasture grasslands, 8. Neighborhood compost (8 bins of 1 m3), 9. Rainwater harvesting from storage furniture (1 tank of 1,000 liters capacity), 10. Private gardens, 11. Approximately 26,993 m2 of urban space use, 80 gardeners directly involved, and 800 registered members.

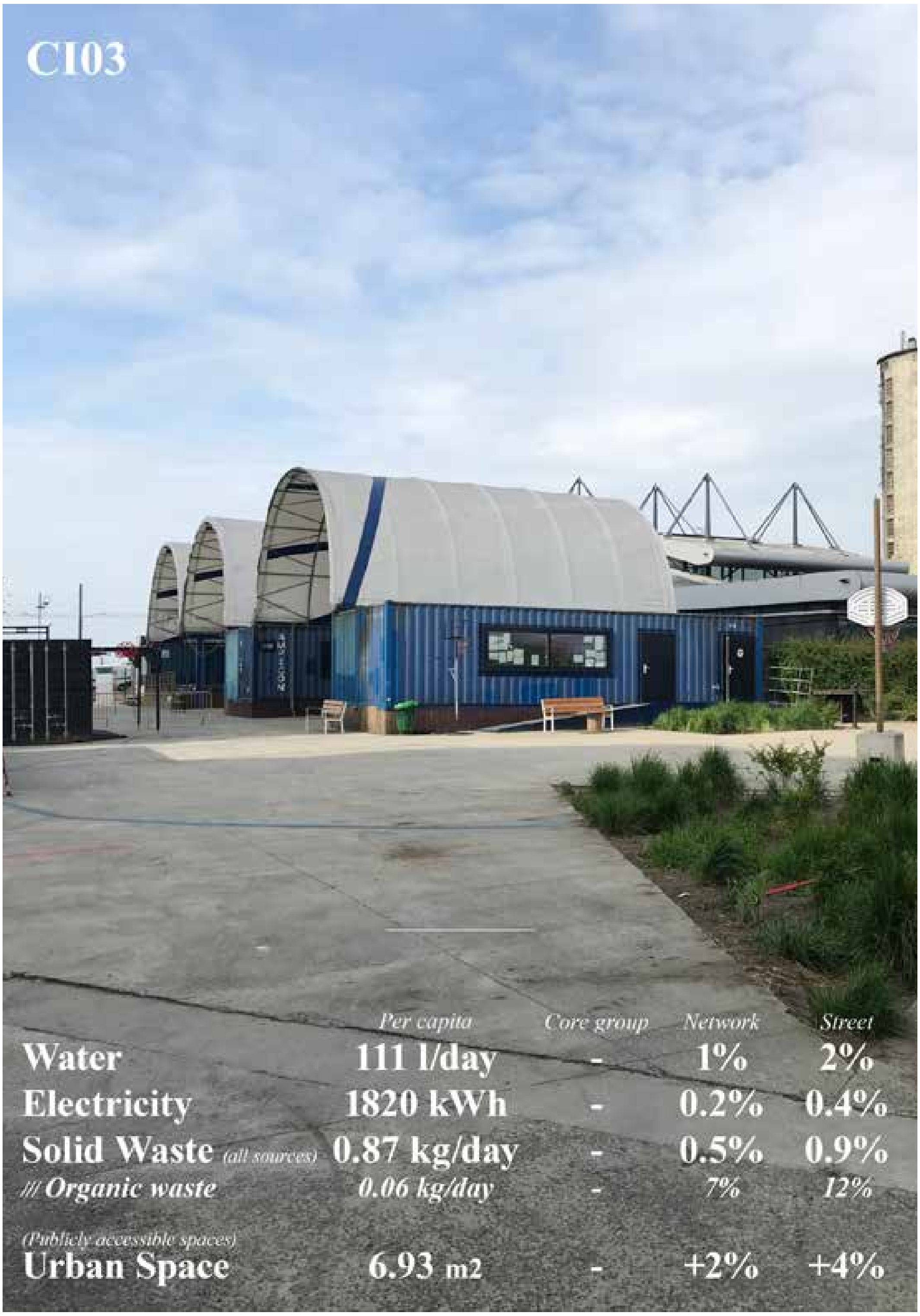



*Figure 4.16: Catalogue of spatial configurations: CI03 Collective Infrastructure. Photo by author, 2022.*


***Temporary urban square and community facilities***

1. Community facilities (12 adapted containers), 2. Canopies to carry out multifunctional activities, 3. Public square, 4. Rainwater hand pump from underground tank (unknown capacity), 5. Photovoltaic panel over mobile library (1 unit 0.5x0.5 m), 6. Wind turbine, 7. Infiltration garden, 8. Neighborhood compost (3 bins of 1 m3), 9. Chicken coop, 10. Collective garden (1 raised bed 6x5 m), 11. Stock space of materials for reuse, 12. Space for custodian (1 adapted container), 13. Approximately 2,430 m2 of urban space use and more than 5 NGOs directly involved.

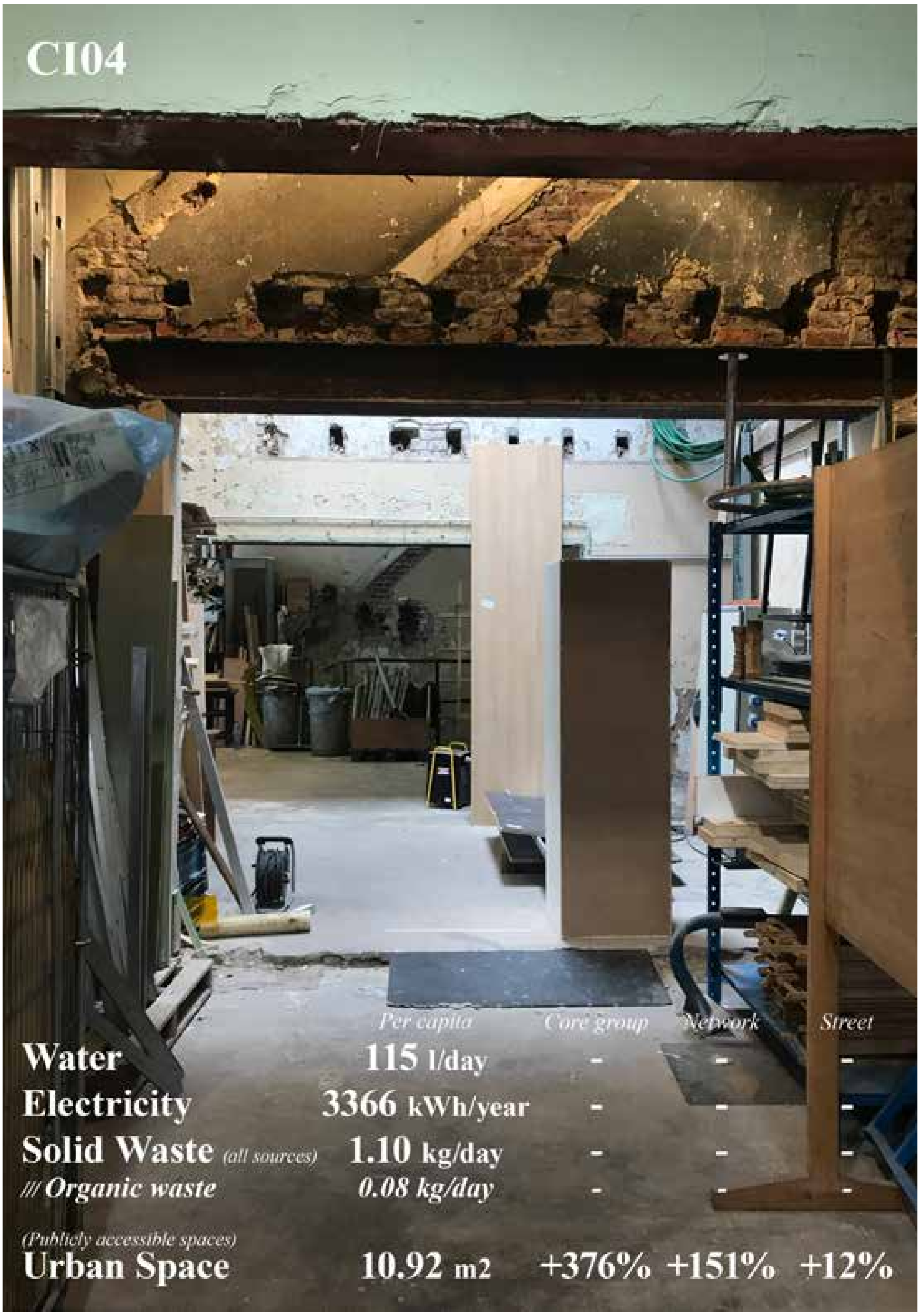
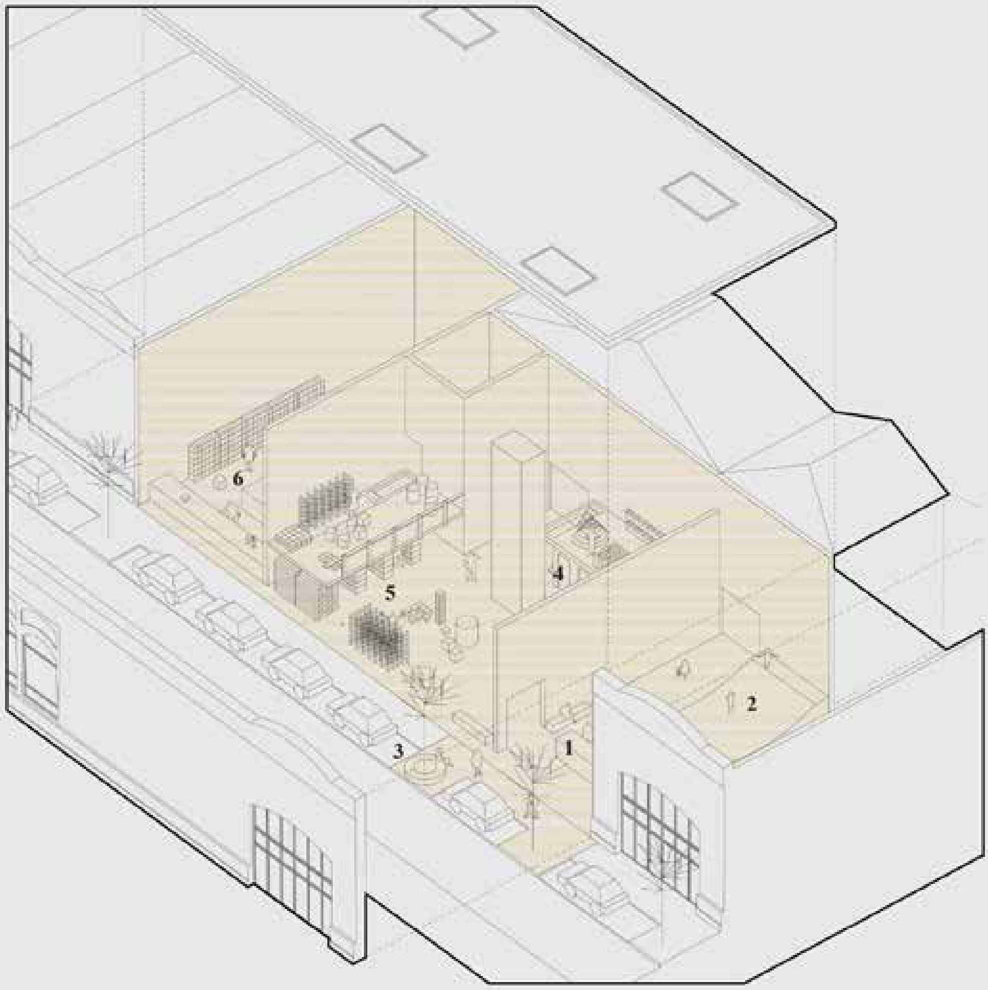



*Figure 4.17: Catalogue of spatial configurations: CI04 Collective Infrastructure. Photo by author, 2022.*




***Storage and exchange hub for reusable materials***

1. Furniture for visitor services, 2. Halfpipe skateboard ramp, 3. Furniture adapted to public space, 4. Workspace and meeting space for artists and designers, 5. Storage space for construction materials for reuse (wood, metal, bricks, carpets, among others), 6. Woodworking space for furniture design and construction. Approximately 411 m2 of urban space use and more than 10 people directly involved.

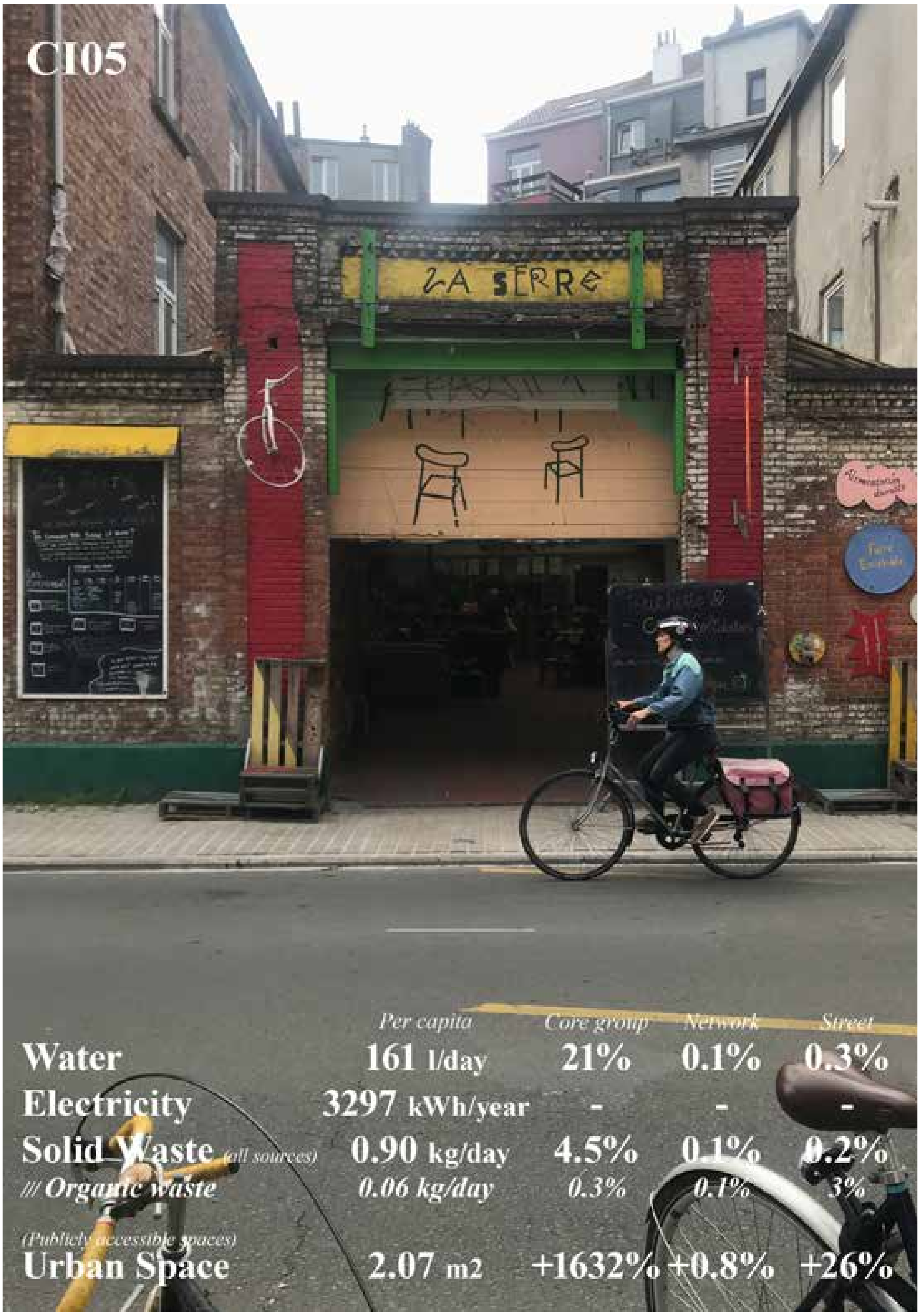
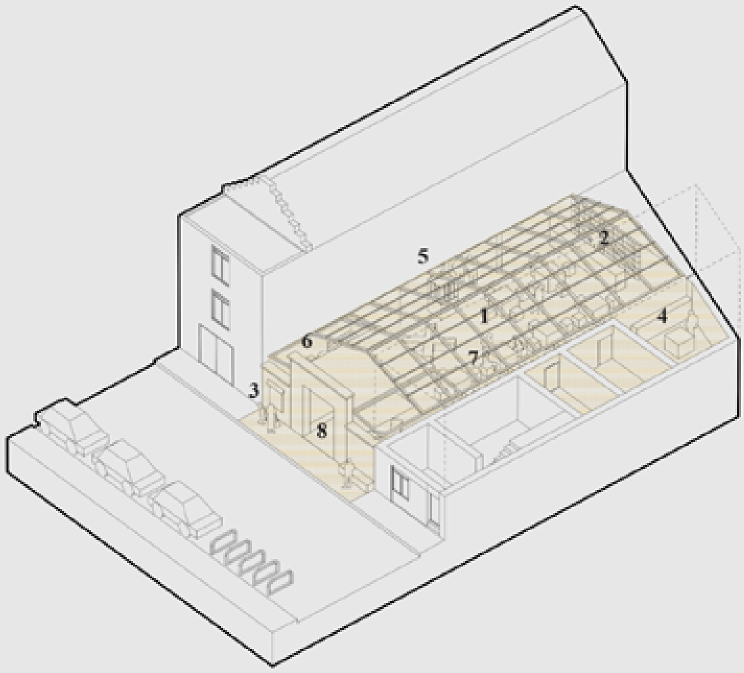



*Figure 4.18: Catalogue of spatial configurations: CI05 Collective Infrastructure. Photo by author, 2022.*




***Temporary occupation of a covered courtyard***

1. Translucent covered space for community activities, 2. Support bar for events and activities, 3. Community bulletin board, 4. Storage and cooking space for surplus food redistribution, 5. Rainwater harvesting from the roof (1 tank of 1,000 liters capacity), 6. Storage space for object exchange, 7. Worm composter, 8. Approximately 169 m2 of urban space use, and more than 10 people and 10 NGOs directly involved.

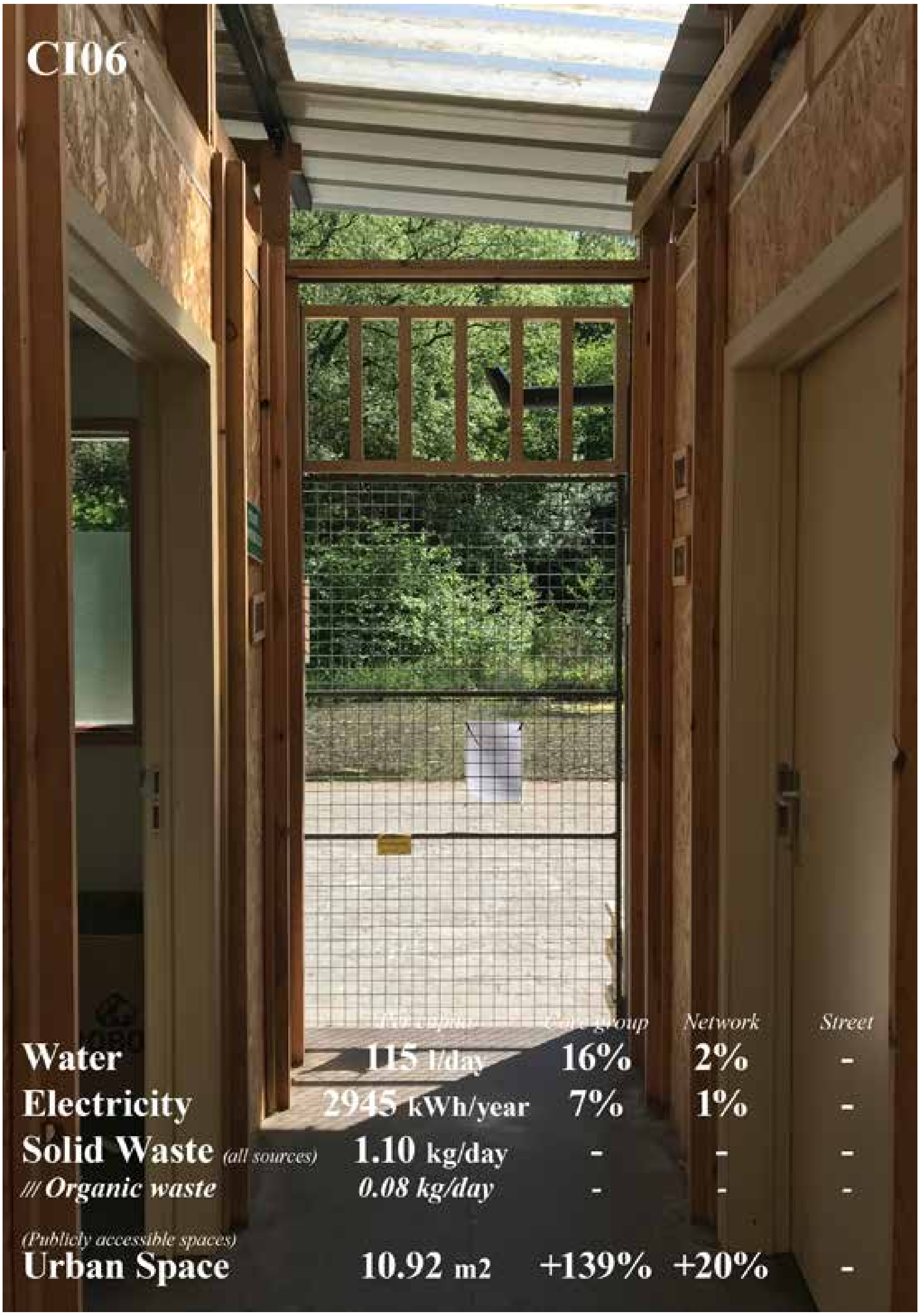
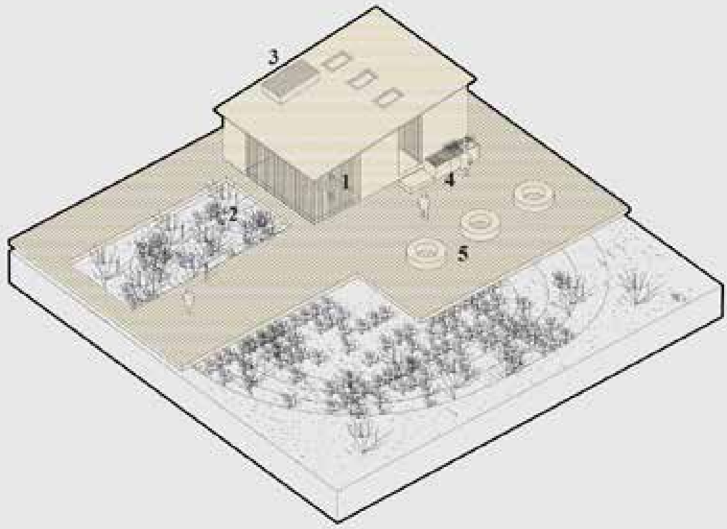



*Figure 4.19: Catalogue of spatial configurations: CI06 Collective Infrastructure. Photo by author, 2022.*




***Collective showers inside a retention lagoon park***

1. Showers and changing room for nautical activities, 2. Rainwater retention lagoon water used for showers, 3. Solar thermal panel (1 unit 1x1.2 m), 4. Public vegetable garden (6 raised beds 1x0.5 m), 5. Approximately 76 m2 of urban space use and more than 30 people involved.

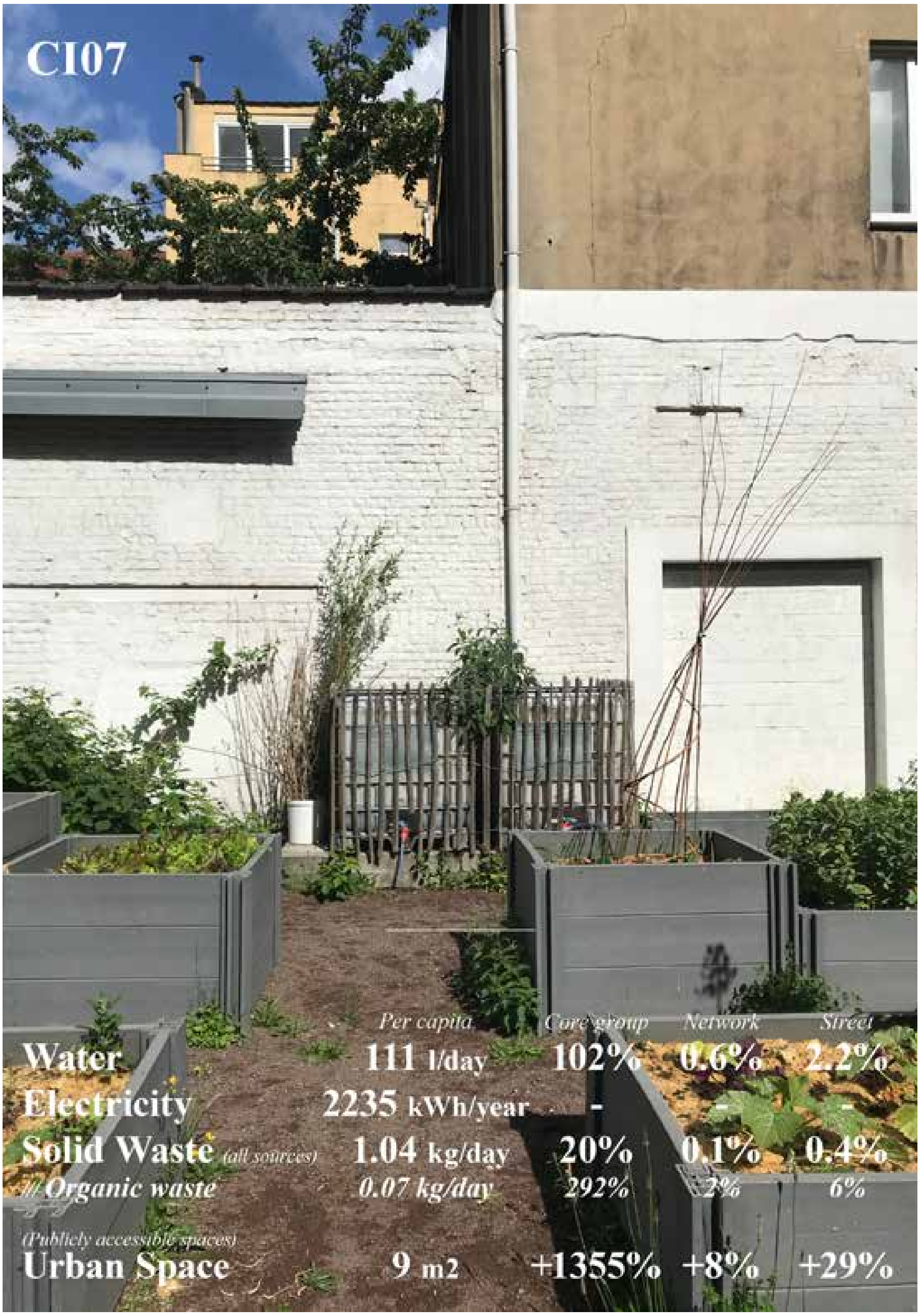
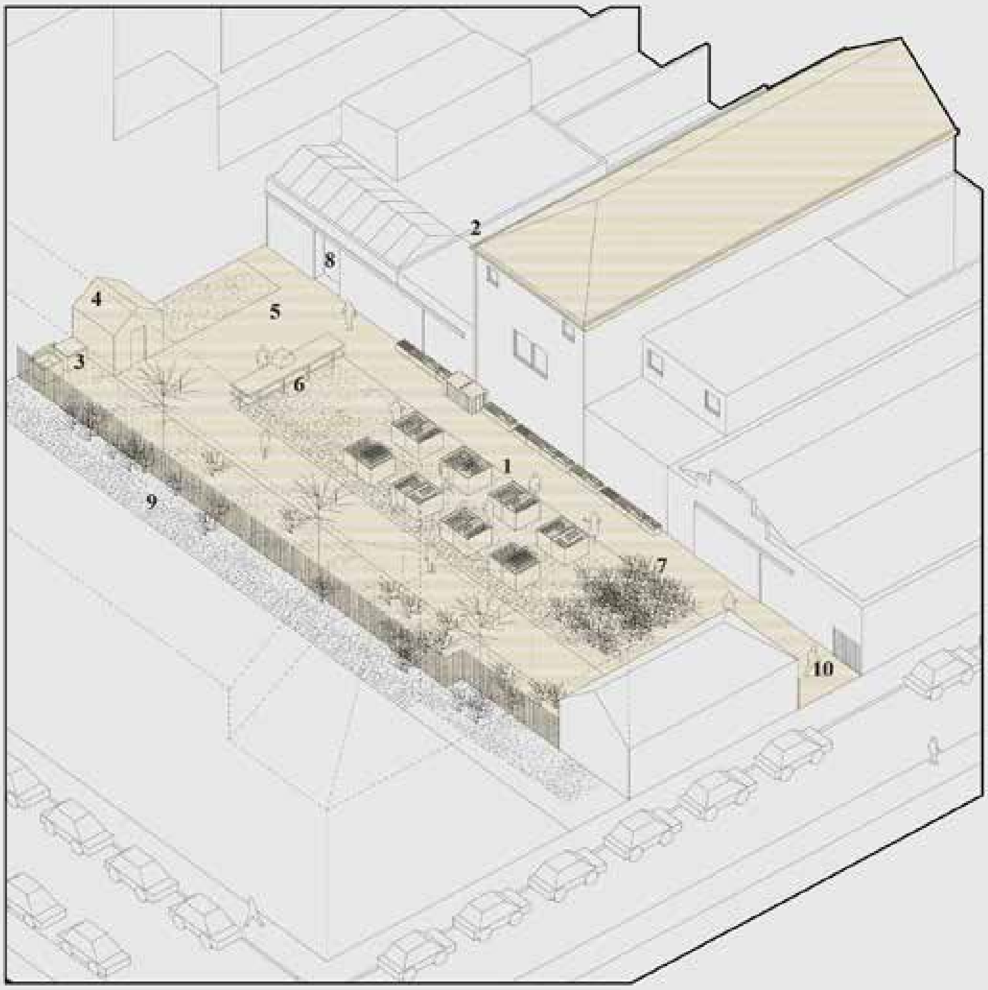



*Figure 4.20: Catalogue of spatial configurations: CI07 Collective Infrastructure. Photo by author, 2022.*




***Community garden within a public facility***

1. Vegetable garden (16 raised beds 1x1.5 m), 2. Rainwater harvesting from the roof of the neighboring building (2 tanks of 1,000 liters capacity), 3. Neighborhood compost (3 bins of 1 m3), 4. Storage space for reused materials and tools, 5. Underground rainwater tank (unknown capacity), 6. Barbecue infrastructure, 7. Wildflower garden, 8. Main access to community facility 9. Private gardens from neighboring building, 10. Approximately 610 m2 of urban space use and 5 people directly involved.

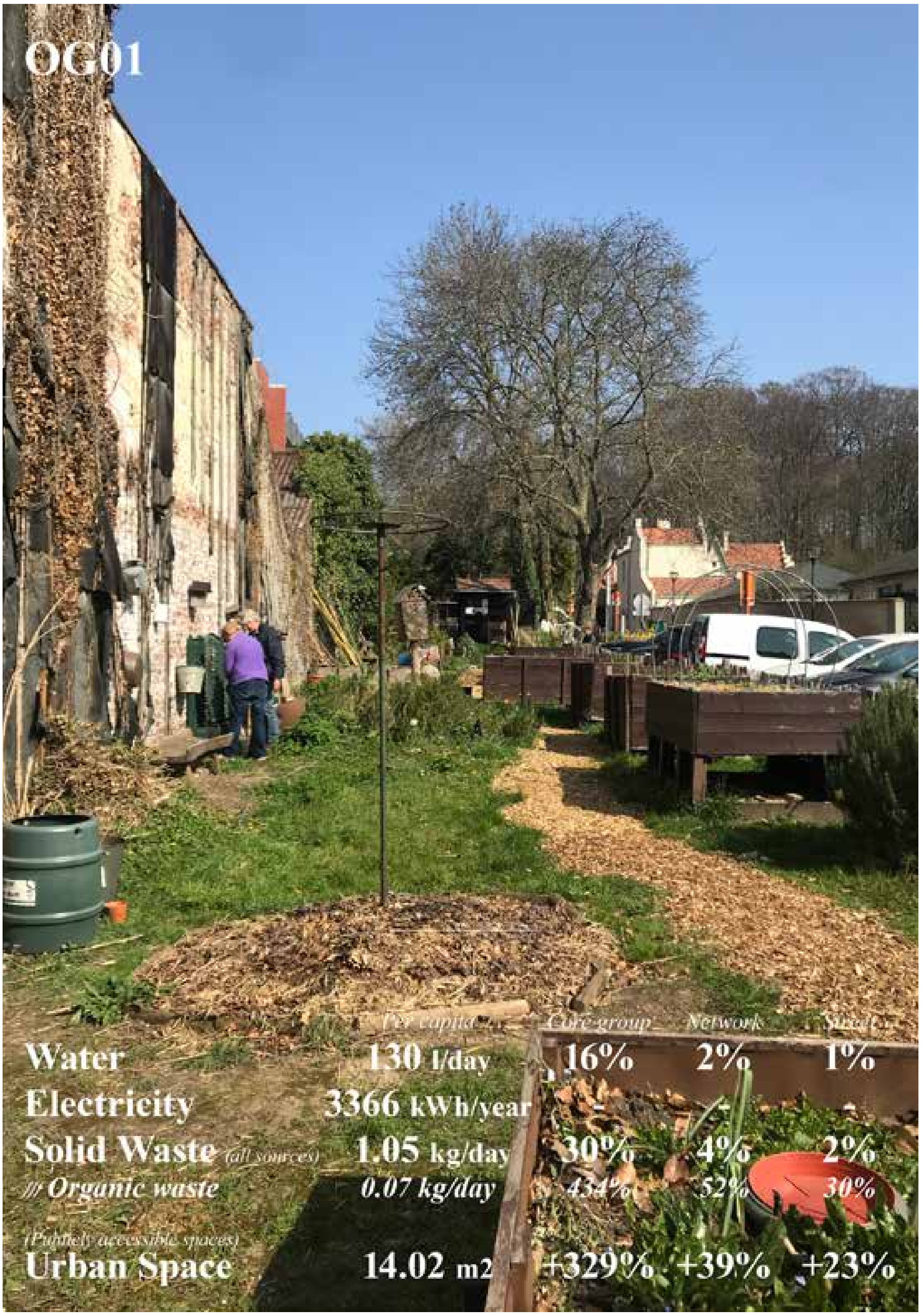
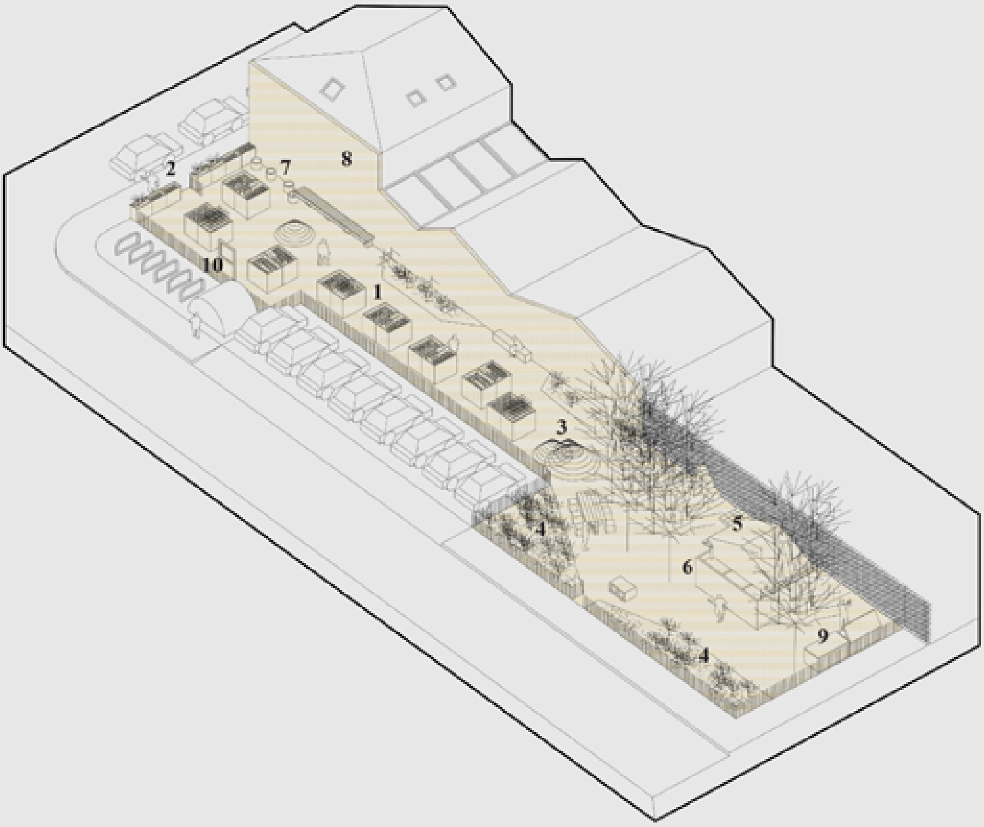


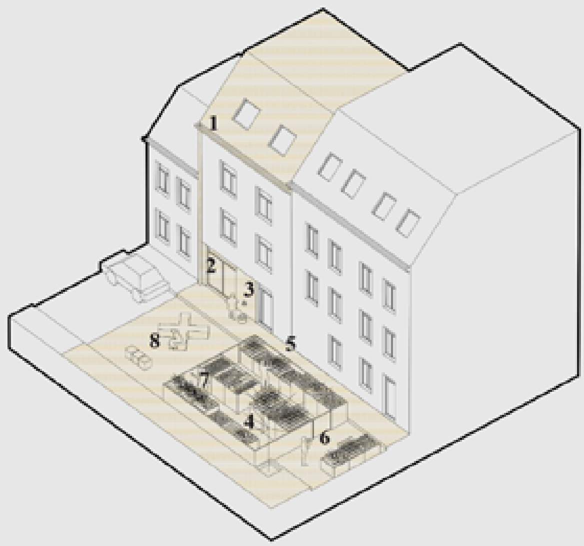

*Figure 4.21: Catalogue of spatial configurations: OG01 Organized Group. Photo by author, 2022.*




***Renovation of an abandoned urban space***

1. Vegetable garden (8 raised beds 1x1.5 m), 2. Public garden (6 raised beds 1x0.5 m), 3. Pond, 4. Wildflower gardens, 5. Storage space for reused materials and tools, 6. Rainwater harvesting from storage space roof (2 tanks of 1,000 liters capacity), 7. Rainwater harvesting device (3 buckets of 18 liters capacity), 8. Dividing wall with rainwater harvesting device (2 buckets of 18 liters capacity), 9. Neighborhood compost (3 bins of 1 m3), 10. Community bulletin board, 11. Approximately 461 m2 of urban space use, 10 people involved, and 84 registered members.


*Figure 4.22: Catalogue of spatial configurations: OG02 Organized Group. Photo by author, 2022.*




***Community garden on public street***

1. Rainwater harvesting from the roof of the neighboring building, 2. Water tank inside garage (1 tank of 1,000 liters capacity), 3. External rainwater valve for public use, 4. Neighborhood compost (2 bins of 1 m3), 5. Outdoor rainwater tank filled with indoor water tank (1 tank of 1,000 liters capacity), 6. Use of approximately 40 m2 of recycled wood for vegetable garden protection structure and garden raised beds, 7. Vegetable garden (14 raised beds 1x1 m), 8. Approximately 60m2 of urban space use, 14 people directly involved, and 80 registered members.

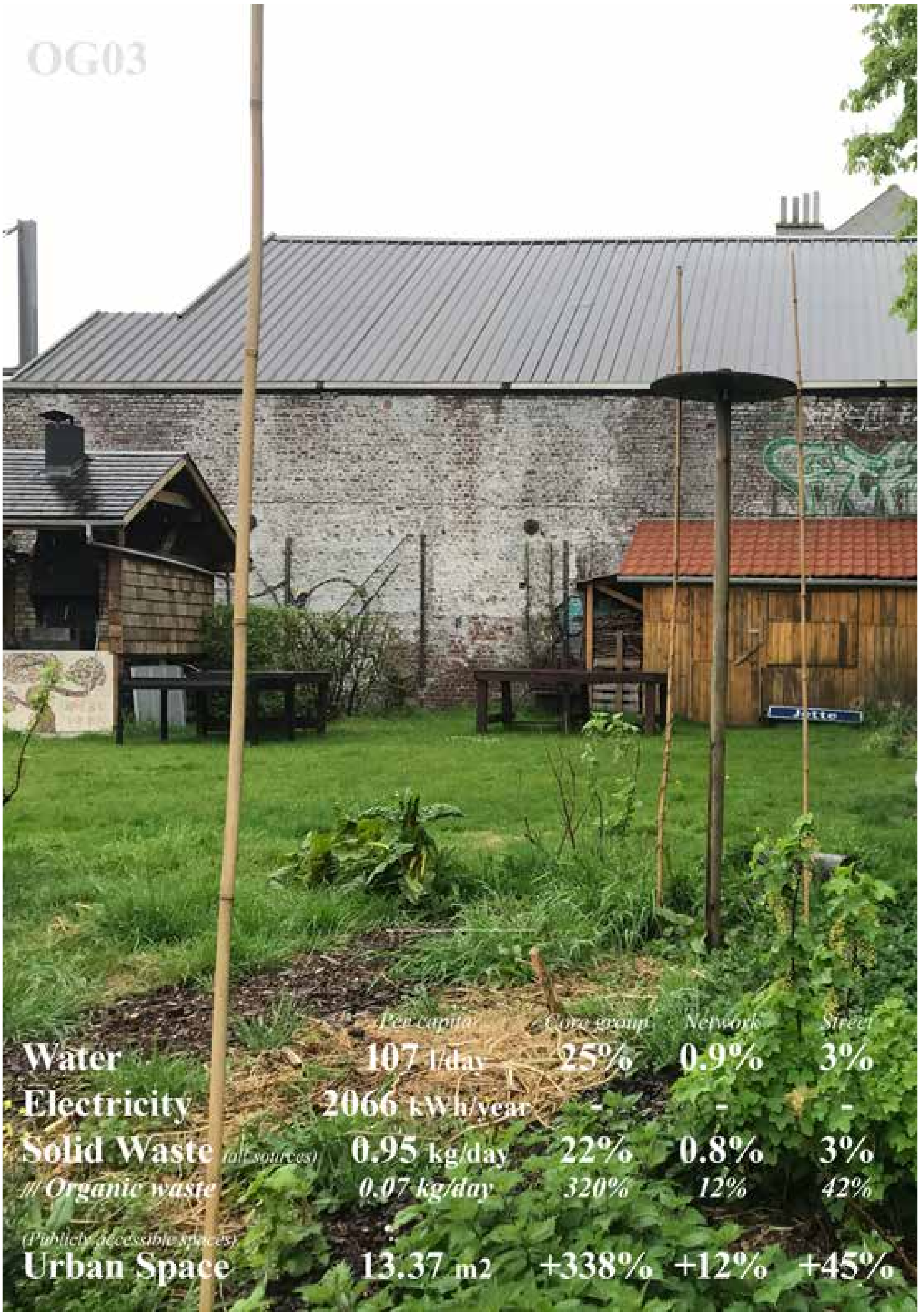
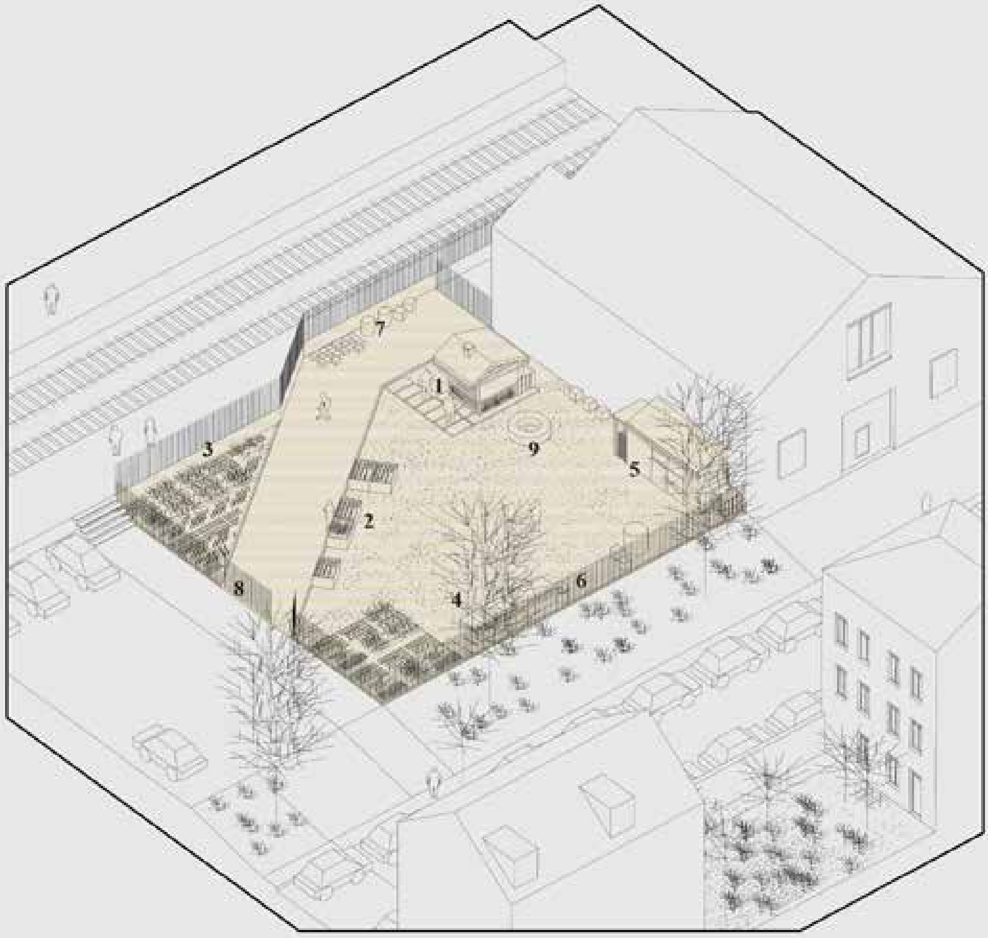


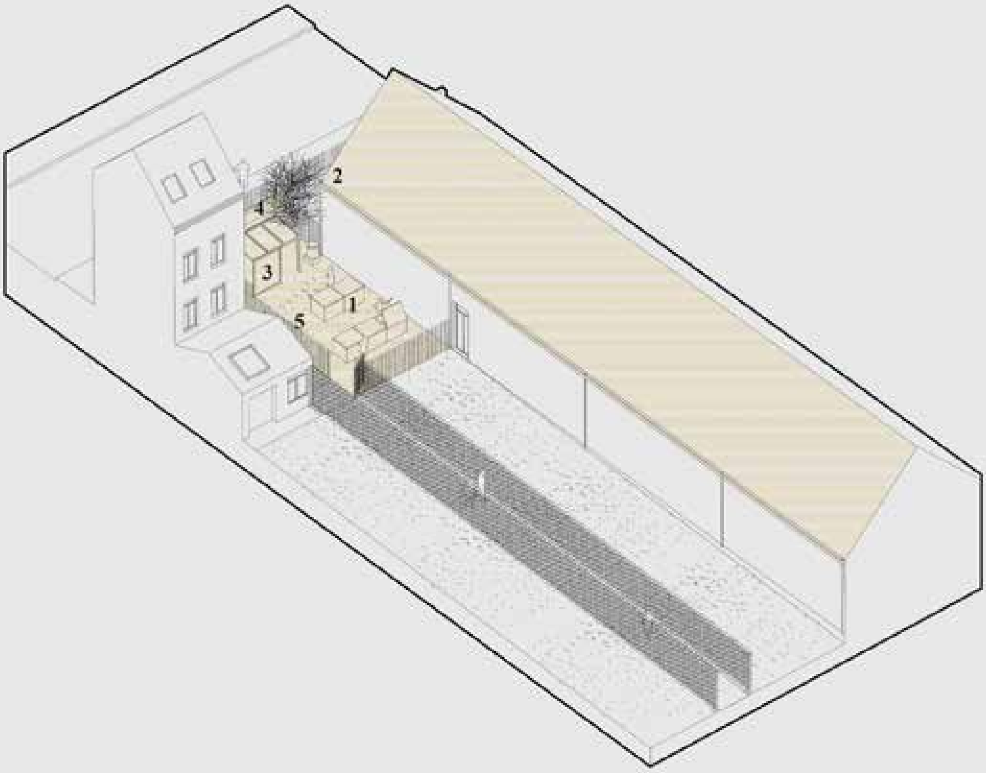

*Figure 4.23: Catalogue of spatial configurations: OG03 Organized Group. Photo by author, 2022.*




***Development and improvement of wastelands***

1. Pizza oven and rainwater harvesting from roof (1 tank of 1,000 liters capacity), 2. Vegetable garden (5 raised beds 1x1.5 m), 3. Collective garden, 4. Neighborhood compost (3 bins of 1 m3), 5. Storage space for reused materials and tools, 5. Rainwater harvesting from storage space roof (1 tank of 1,000 liters capacity), 6. Rainwater harvesting from compost bins (1 tank of 1000 liters capacity) 7. Stock space of materials for reuse 8. Community bulletin board, 9. Approximately 452 m2 of urban space use and 10 people directly involved.


*Figure 4.24: Catalogue of spatial configurations: OG04 Organized Group. Photo by author, 2022.*




***Neighborhood compost***

1. Neighborhood compost (5 bins of 1 m3), 2. Rainwater harvesting from the roof of the neighboring building (1 tank of 1,000 liters capacity), 3. Storage of reused materials and tools, 4. Wildflower gardens, 5. Approximately 58m2 of urban space use, 10 people directly involved, and 22 registered members.

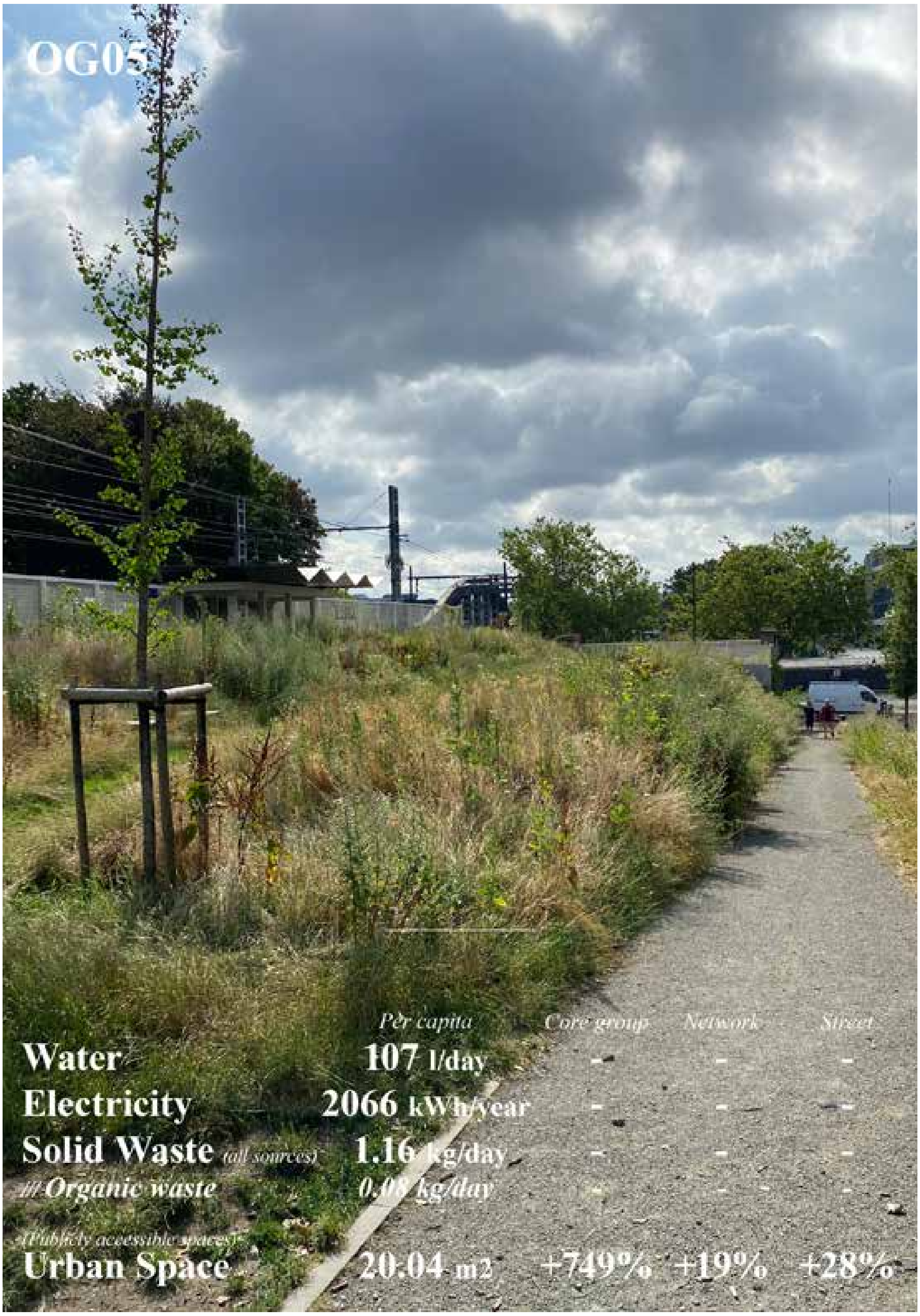
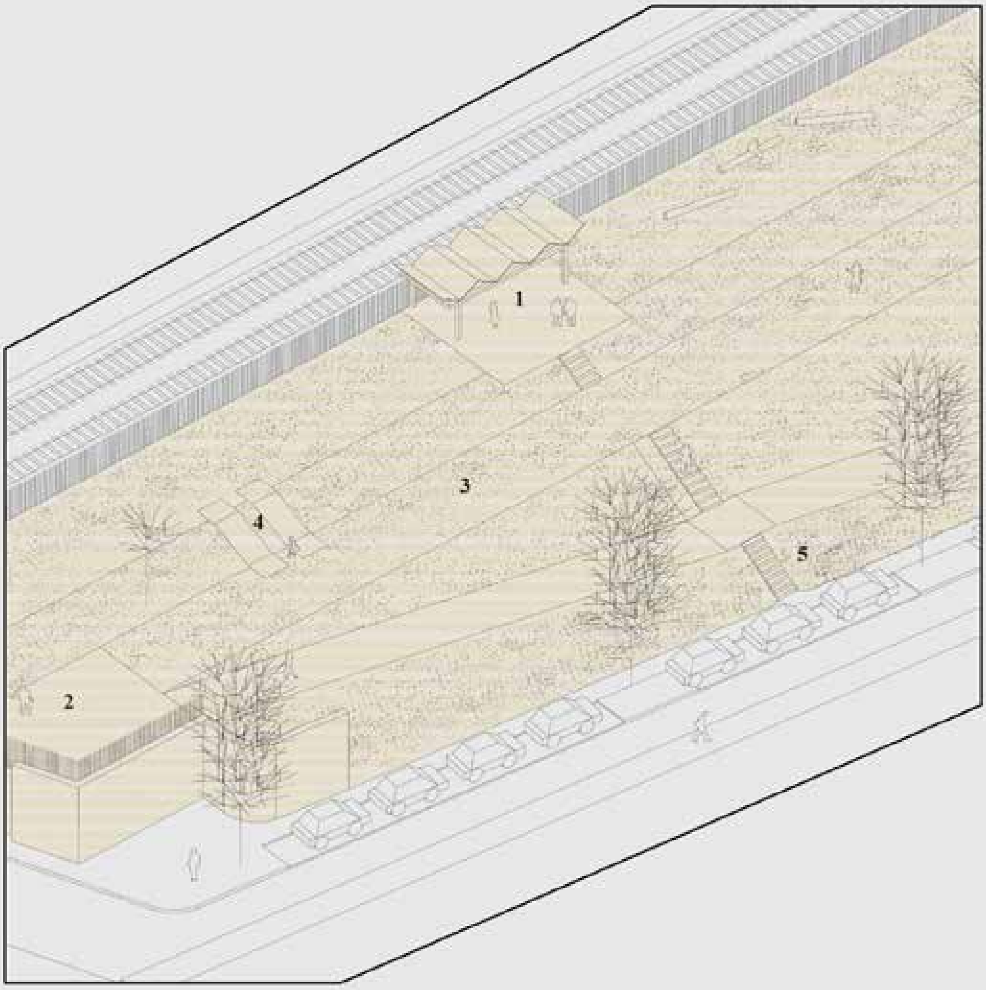



*Figure 4.25: Catalogue of spatial configurations: OG05 Organized Group. Photo by author, 2022.*




***Pocket park network along a railroad axis***

1. Canopy for community meetings, 2. Public viewpoint, 3. Landscaped lawn area for rainwater infiltration, 4. Furniture made from recycled materials, 5. Approximately 1,800 m2 of urban space use and more than 10 people directly involved.

| | CI01 | CI02 | CI03 | CI04 | CI05 | CI06 | CI07 | OG01 | OG02 | OG03 | OG04 | OG05 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***community*** | | | | | | | | | | | | |
| Core users scale (people) | 20 | 80 | - | 10 | 5 | 5 | 5 | 10 | 14 | 10 | 10 | 12 |
| Network scale (people) | 890 | 800 | 1000 | 25 | 10000 | 35 | 823 | 84 | 80 | 278 | 22 | 483 |
| Street scale (people) | 860 | 226 | 561 | 306 | 314 | - | 230 | 143 | 392 | 75 | 184 | 316 |
| ***urban space*** | | | | | | | | | | | | |
| Aprox. total size (m2) | 12800 | 26993 | 2430 | 411 | 169 | 76 | 610 | 461 | 60 | 452 | 58 | 1800 |
| Indoor spaces (m2) | 611 | 1122 | 210 | 411 | 169 | 76 | 6 | 12 | - | 19 | 5 | 18 |
| Outdoor spaces (m2) | 12189 | 25871 | 2220 | - | - | - | 604 | 449 | 60 | 433 | 53 | 1782 |
| Resource management spaces (m2) | 611 | 936 | 346 | 191 | 57 | 9 | 220 | 30 | 6 | 18 | 10 | 1405 |
| Working spaces (m2) | 4764 | 19531 | 23 | 130 | 55 | - | 19 | 152 | 36 | 147 | 38 | 0 |
| Meeting and sharing spaces (m2) | 8036 | 7462 | 2271 | 90 | 114 | 67 | 584 | 279 | 18 | 287 | 20 | 1800 |
| ***water*** | | | | | | | | | | | | |
| Rainwater harvesting (l/day) | 3578 | 3063 | 1464 | - | 168 | 95 | 569 | 213 | 22.1 | 264 | 76 | - |
| Water infiltration (l/day) | 15080 | 17133 | - | - | - | - | 519 | 503 | - | 301 | 56 | 1968 |
| ***energy*** | | | | | | | | | | | | |
| Electricity production (kWh/day) | 6.9 | - | 0.2 | - | - | 2.7 | - | - | - | - | - | - |
| ***solid waste*** | | | | | | | | | | | | |
| Organic waste processing (kg/day) | 6.3 | 8.4 | 2.1 | - | 0.5 | - | 0.63 | 2.5 | 2.1 | 2.1 | 2.1 | - |
| ***spatial dimension*** | | | | | | | | | | | | |
| Community network involved (people/m2) | 25 | 11 | 150 | 22 | 21598 | 168 | 492 | 67 | 487 | 224 | 138 | 98 |
| Rainwater caption (l/year/m2) | 102 | 41 | 220 | - | 363 | 456 | 340 | 169 | 134 | 213 | 478 | - |
| Water infiltration (l/year/m2) | 430 | 232 | - | - | - | - | 311 | 398 | - | 243 | 352 | 399 |
| Electricity production (kWh/year/m2) | 0.2 | - | 0.0 | - | - | 13 | - | - | - | - | - | - |
| Organic waste processing (kg/year/m2) | 0.2 | 0.1 | 0.3 | - | 1 | - | 0.4 | 2 | 13 | 2 | 13 | - |

*Figure 4.26: Summary of key metrics for all ARGS, including community involvement, publicly accessible urban space created, resource management and treatment, and the spatial dimension of these projects by assessing the values per square meter across various analyzed themes.*


CI07
Per capita
Water 111 l/day 102% 0.6% 2.2%
Electricity 2235 kWh/year - - -
Solid Waste 1.04 kg/day 20% 0.1% 0.4%
Organic waste 0.07 kg/day 292% 2% 6%
Urban Space 9 m2 +1355% +8% +29%
1
2
3
4
5
6
7
8
9
10
***Community garden within a public facility***
1. Vegetable garden (16 raised beds 1x1.5 m), 2. Rainwater harvesting from the roof of the neighboring building (2 tanks of 1,000 liters capacity), 3. Neighborhood compost (3 bins of 1 m3), 4. Storage space for reused materials and tools, 5. Underground rainwater tank (unknown capacity), 6. Barbecue infrastructure, 7. Wildflower garden, 8. Main access to community facility 9. Private gardens from neighboring building. 10. Approximately 610 m2 of urban space use and 5 people directly involved.

### *4.4 Discussion*

#### *4.4.1 Socio-ecological activities and practices, resource efficiency, and community involvement*

The catalogue of spatial configurations illustrated and quantified the socio-ecological activities and practices of twelve ARGS and their users in publicly accessible spaces. Based on this, we can classify the types of spaces developed by all ARGS and identify the type of space to be integrated by design practitioners in future projects. Three categories were identified: spaces for resource collection or management (e.g., rainwater harvesting systems, compost bins, solar panel systems), spaces for working activities (e.g., collective gardens, material workshops, storage rooms), and spaces for sharing and meeting (e.g., open air gathering areas, meeting rooms, playgrounds). The distribution of these spaces varies depending on the objectives of each project (see *Figures 4.13-4.26*). In almost all ARGS, spaces dedicated to resource management occupy a smaller proportion compared to other categories. This is due to the fact that the primary objectives of the analyzed ARGS are more closely aligned with promoting social cohesion than with ensuring efficient resource management. These areas highlight the types of resource management spaces that can be effectively overseen by individuals at the local level, typically focusing on rainwater harvesting systems (roof surfaces, gutters, water tanks, and pumping machines), electricity production through solar panels, and composting zones. In some cases, spaces for storing recyclable building materials are significant (*CI07*) and in others, extensive water collection systems in neighboring buildings (*CI04*) or rainwater infiltration areas (*OG05*) make up more than a third of the total occupied space. These types of resource storage and exchange spaces are often situated within expansive open areas or repurposed abandoned buildings, presenting a strategic opportunity for urban policy planning. Their integration into future public infrastructure projects could enhance resource efficiency, optimize land use, and contribute to the sustainable transformation of underdeveloped areas. Eight of the twelve ARGS include arrangements for work-related activities, highlighting two of the smaller projects, which have allocated approximately two-thirds of their spaces for specific community initiatives. *GC02* prioritizes collective gardening, while *GC04* focuses primarily on neighborhood composting, thus underlining a deliberate emphasis on community and sustainable practices within these particular locations. All ARGS allocate at least approximately one third of their space to establishing indoor and outdoor spaces to host community gatherings and shared experiences. Some projects achieve up to almost ninety percent of spaces related to recreational activities, potentially due to their defined short-term operational focus and dense urban contexts (*CI03*) or specifically tailored to support sports activities within a nature reserve (*CI06*). This highlights the need to incorporate resource management spaces with long-term permits into urban policy planning at the city scale. Establishing such spaces with stable legal frameworks would enable the development of permanent infrastructure, fostering greater institutional support and ensuring long-term benefits for both the city and its residents.

In three of the twelve projects analyzed (*OG02*, *CI03*, *CI07*), users installed a rainwater harvesting system using neighboring buildings' roofs to establish a public water tap. This strategy could serve as an urban design approach for municipalities with high water consumption patterns, where public space can be created and supported through rainwater harvesting from private properties. Furthermore, this illustrates how ARGS projects could increase social cohesion among neighbors through the development of spaces for resource harvesting, as previously explored by other researchers (Bahers & Giacchè, 2019; Berigüete et al., 2023). Most of the projects, located in publicly accessible spaces, implemented diverse solutions to delimitate their spaces and attract new users while incorporating resource management components (e.g., barriers and access points composed of urban furniture, compost bins). These cases also showcase the diverse solutions employed by ARGS to prevent equipment degradation during periods of non-occupancy by its users; in some instances, inadvertently making the initiatives inaccessible to neighboring residents or visitors. Cooperation among neighbors is common among all projects and their users, often enhancing its resource efficiency and social cohesion. For example, some ARGS use grazing animals from neighboring farms to maintain common water infiltration gardens instead of expending energy on mowing equipment (*CI01*, *CI02*, *OG05).* At the city scale, green spaces managed by regional governments could benefit from this type of symbiosis, thereby reducing both economic and energy costs associated with their maintenance. Likewise, the establishment of carpentry and repair workshops by ARGS has strengthened the bonds within their respective communities (*CI04*, *CI05*, *CI06)*. This is achieved by facilitating symbiotic relationships between neighbors seeking to reduce living costs and professional designers with a keen interest in innovation, an objective pursued by many of these initiatives. In addition to community exchanges, the municipal and regional government annually funds the design and construction of temporary playground furniture to be placed on streets closed to vehicular access during the summer vacation period. This strategy of collaboration could be explored in other contexts to leverage collective efforts in resource management, as previously explored by Toboso-Chavero et al. (2021), that quantified shared resource harvesting scenarios using the roofs of a residential complex in Barcelona, Spain, achieving 42–53% of vegetable consumption, 9–35% of electricity use, and 38–200% of water needs depending on the scenario.

ARGS participants interviewed emphasized the significance of involving design practitioners in advancing their initiatives. In particular, by using spatial representation techniques (e.g., drawings, 3D spatial models, and GIS mapping) to locate infrastructure and key stakeholders, perform spatial analyses, enhance community inclusion, and actively participate in co-creation design processes. Results of the ARGS analysis showed that the involvement of design practitioners can occur in three possible ways. Firstly, they may participate as organized citizens (*OG02*), where their professional experience indirectly supports their voluntary efforts toward social innovation in the management of local resources. Secondly, they can contribute as members of an NGO (*CI04, NP1, RS01*), where their expertise directly applies to volunteer work or is funded by public or private funding. Thirdly, they may be selected for their professional services as a result of public bidding, e.g. in the frame of urban regeneration processes, and remunerated with specific objectives and time frames (*CI03, OG05*). In all cases, the involvement of design practitioners plays a crucial role in spatializing the objectives of resource efficiency and community involvement across multiple urban scales, ranging from the city and municipality to the neighborhood and street levels.

The catalogue of spatial configurations provides examples of existing practices and their spatial layouts, while illustrating urban design ideas based on specific objectives related to resource efficiency and community involvement. Furthermore, by informing design practitioners about spatially explicit strategies for designing publicly accessible spaces with a focus on resource management. Nevertheless, gathering additional local case studies from diverse urban contexts remains imperative to fortify our efforts in formulating urban design strategies that can be universally applicable across various scenarios and urban contexts. Previous research by Cortesão et al. (2020) demonstrated the application of 3D spatial modeling techniques to understand the physical mechanisms underlying the effective cooling capacity of urban water bodies. The outcomes of their study have played a key role in formulating design prototypes, which can be valuable conceptual tools for design professionals. These prototypes contribute to establishing design guidelines and pave the way for developing an innovative design framework tailored to urban water bodies. The use of maps and drawings for feasibility studies, permit acquisition, and temporary project renewal was another aspect highlighted in the interviews. Participatory mapping and co-creation design processes (i.e., creation of maps or projects with all stakeholders involved) are prominent issues to consider in future ARGS projects due to the community's inclusion in the project design processes and the importance of these processes and activities in fostering community belonging and streamlining administrative procedures (De Muynck & Nalpas, 2021; Fox-Kämper et al., 2018).

#### *4.4.2 Scale matters? Upscaling finer grain data*

*Figure 4.13* illustrates the local-scale impact of all ARGS analyzed on creating new publicly accessible spaces per capita across all scales studied (core group, network, and street scale, as detailed in the Methodology section). For instance, eight out of twelve ARGS increased the per capita space area for street residents by at least 20%. This is particularly relevant when considering that urban space can enhance resource efficiency through nature-based solutions, foster synergies between stakeholders, and decentralize resource management; especially when the development of ARGS is focused on objectives primarily centered on resource management, such as urban farms, water harvesting canopies, and recycling centers. Based on this, design practitioners could estimate the potential amount of resource-sensitive public spaces needed to help reduce resource consumption in municipalities with high consumption levels. At the scale of the core users directly managing the ARGS, these projects could cover almost all the water and solid waste management requirements based on per capita values (especially for organic solid waste). In some cases (*OG01*, *OG03*, *OG04*, *CI02*), they represent up to one-third of the average organic solid waste treated by all the street residents where it is located. Considering these results and taking into account some of the opportunities found previously (see *Figure 4.12*), which highlighted the idea of seeking new designs for resource recovery and expansion into other areas, design practitioners engaged in shaping future urban design strategies to improve resource accessibility might contemplate the integration of ARGS with adapted design features. This consideration becomes particularly relevant in municipalities with restricted per capita public open space and elevated resource consumption patterns. Nevertheless, new urban planning models including citizen participation, such as *contrats de quartiers durables* in BCR, should be further explored as there exist still limitations concerning the timing and scale of interventions, regarding the desired social cohesion objectives and the projects' continuity after program support ends (Berger, 2018).

To better understand the diversity of ARGS in terms of resource efficiency and community involvement, we calculated the resource harvesting and the number of people involved per square meter (see *Figure 4.26*). This approach enabled us to identify the types of ARGS suitable for implementation in specific local contexts, facilitating decision-making when devising open space development strategies to promote communal identity and a sense of well-being (Perrotti & Iuorio, 2019).  On the other hand, it provides insights into values per square meter related to resource management, which can be applied at the city scale to estimate the number of square meters required to increase resource supply in areas with high consumption patterns. For example, *OG04*, a 28$m^2$ collective compost located in a recently renovated abandoned site of a communal school in *Uccle,* has installed a rainwater harvesting system that collects water from its roof, making it a highly resource-efficient practice. It has the capacity to collect 475 l/year/$m^2$ of rainwater, process 13 kg/year/$m^2$ of organic waste, and infiltrate 325 l/year/$m^2$ of rainwater. Nevertheless, with only 22 users in its network, it exhibits a low index of community involvement compared to other analyzed ARGS (0.38 people/$m^2$), as illustrated in Table 3. On the other hand, *CI07,* with similar water management capabilities (340 l/year/$m^2$ for rainwater harvesting and 310 l/year/$m^2$ for water infiltration), boasts a higher index of community involvement with 1.37 people/$m^2$. This collective garden is located within a communal equipment in a low-income neighborhood of *Forest*, making it more accessible and visible to new users, with support from the facility's services. If similar rainwater harvesting values were achieved across all public green spaces in the BCR, it could potentially supply approximately 10% of the city's total drinkable water consumption. However, this scenario serves as an illustrative principle, as demonstrating its feasibility would require more precise calculation models, which are beyond the scope of this research. As a reference, BCR consumes 351 l/year/$m^2$ of drinkable water, 25 kWh/year/$m^2$ of electricity, 58 kWh/year/$m^2$ of natural gas, and generates 2.80 kg/year/$m^2$ of solid waste, in addition to having a population density of 133 inhabitants/$m^2$ and more than 15 $km^2$ of public green spaces (parks and gardens).

Using per-square meter ratios as a basis could be of great value to design practitioners when estimating space requirements based on resource efficiency or community involvement in future projects. While top-down UM studies often rely on aggregated city-level data, integrating detailed per-square-meter assessments of ARGS can support the strategic identification of underdeveloped areas and optimize their potential use for resource management and the creation of publicly accessible spaces based on their specific dimensions. This fine-grained approach could be particularly valuable in cities with fragmented land use patterns (e.g., highly dense areas or informal settlements), where smaller-scale interventions, when considered collectively, can generate significant environmental and sustainability benefits. However, while we acknowledge that additional case studies are necessary to enhance the current catalogue of spatial configurations, this approach can serve as a means to upscale the ARGS fine-grained data into a larger-scale UM analysis.

#### *4.4.3 Challenges for design practitioners*

Considering the opportunities and barriers highlighted by the interviewees (see *Figure 4.12*), there are specific challenges to consider for future ARGS development by design practitioners. Firstly, it is crucial to recognize the significance of urban design within citizen-led public open space projects. As described by de Waal and de Lange (2019), design practitioners can act as urban change agents by aiming to bring out the local knowledge of stakeholders while leveraging their professional expertise in open innovation processes. For instance, this can be exemplified by the production of plans and drawings to translate ideas into spatially explicit proposals, facilitating presentations to authorities for funding and permits. This approach was demonstrated in case study *OG02*, where approximately 60 $m^2$ of an urban street surface was transformed into a collective garden, directly involving 14 people and including 80 registered members. In the process of obtaining municipal permits, architects (who were part of the organized group of citizens) assisted in the preparation of detailed plans to visualize the various proposals discussed by the group and based on negotiations with the local authorities regarding the number of parking spaces to be preserved and sections of the street to be made only accessible by pedestrians. This type of collaboration, between a city's municipal or regional authorities, design practitioners, and the community, could contribute to the development of urban policies where public space is designed with resource efficiency principles (such as water, energy, and waste management), with a particular focus on the planning and design of existing street networks and underdeveloped areas. In the case of *OG07*, design practitioners became involved in the project after winning a public competition to create pocket parks using participatory design methods to involve the community in designing the urban space and plan activities to facilitate its use. By the end of their designated mission, they had successfully developed a large public open space and a smaller publicly accessible meeting space for neighbors. However, after the design practitioners gradually disengaged themselves from the project, the small park gradually fell into neglect. This underlined the crucial need for establishing community ambassadors for future projects or public bidding, i.e., local community members who can work alongside design practitioners during the participatory design phases and take shared responsibility with new members once the professionals' involvement ends. These ambassadors could ensure the sustainability and continued maintenance of the projects.

Secondly, it is essential to identify and revitalize neglected sites in collaboration with neighboring communities through participatory workshops involving all relevant stakeholders. For example, case studies *OG01* and *OG05* transformed urban brownfields with support from various public entities into collective gardens and community meeting spaces. Despite their success in creating new public open spaces and increasing local political engagement, like previously studied cases, many members often found it challenging to sustain motivation and the project's momentum (Fox-Kämper et al., 2018). Similarly, case studies *CI03*, *CI04*, and *CI05* capitalized on temporary opportunities by implementing social inclusion and resource management projects on sites awaiting construction permits. Design, in this context, involved exploring, questioning, and reimagining how materials, goods, and services were produced, marketed, managed, used, and valued, to ensure a harmonious coexistence between stakeholders. This approach enabled design practitioners to move beyond generic, city-wide sustainability goals and instead focus on specific neighborhoods where targeted interventions could generate the most significant impact. By aligning strategies with localized consumption and waste production patterns, urban design efforts can become more precise, context-sensitive, and effective in addressing sustainability challenges.

Thirdly, even though half of the selected ARGS for interviews have design practitioners among their stakeholders, there is still room for innovation, particularly concerning the use of recycled materials and the aesthetics of their projects. For example, *CI05* is a community-driven center that accommodates many NGOs and is temporarily located in a residential building to be demolished to make way for a residential complex. This type of initiative fosters grassroots do-it-yourself urban design on abandoned sites and vacant lots in the city, strengthening local urban resilience (Brand & Nicholson, 2016). The core group and volunteer participation have arranged all interior spaces using recycled and donated materials (e.g., pallet wood, zinc sheets, fabric). However, the aesthetics of reused materials have influenced the type of users participating in their activities, including their socio-economic profile and age group, due to preconceived notions about the intended space aesthetics. This lack of inclusivity hinders community members' involvement in managing their resources, impacting the city's metabolism and its overall functionality. Due to the success of the activities carried out, particularly in promoting social inclusion, the municipality invited the responsible NGO to collaborate on the new real-estate development project together with private developers, design practitioners, and the community. During discussions, the idea arose to create a permanent physical space in the upcoming development that would aim serving the local communities and NGO initiatives that had achieved great community inclusion and social cohesion in previous years through resource management activities and practices (i.e., preparing meals using food at risk of perishing, organizing activities to repair and recycle objects, among other initiatives).

#### *4.4.4 Limitations of the methodology*

Given its multi-scale nature involving qualitative (semi-structured interviews), quantitative (resource flows), and spatial (GIS and 3D models) methods, our methodology requires interdisciplinary teams capable of developing various aspects of the study. In addition, we acknowledge the existence of similar ARGS projects within private spaces that fall beyond the scope of this study that deal with urban commons and topics of governance, accessibility, and type of ownership that may be interesting to consider and integrate into future research.

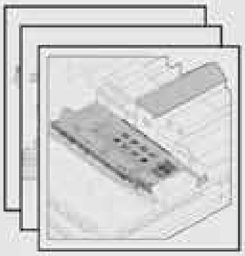
While the method has been tested in BCR, its effectiveness has not yet been validated in other cities with socioeconomic, geographic, and governance differences. Depending on the case study, ARGS may vary in their governance and legal status, and may introduce other aspects related to urban life and urban space, such as informality, which were not addressed in this research. Moreover, there is a need to establish clear parameters for the quantification of the community involved in ARGS to understand its impact at different scales and potentially enhance its applicability and interest for design practitioners at the city scale.

### *4.5 Conclusions*

This article has provided a bottom-up complementary assessment to combine with more widely-used top-down city-scale assessment to achieve a fine-grained UM analysis with the aim to inform urban design. It highlights the role of socio-ecological activities and practices as key drivers of enhanced resource efficiency and increased community involvement. The method is tested in BCR, highlighting potential and limitations of the approach. Through site visits, interviews, and 3D spatial modeling of ARGS involved in citizen-led resource management practices within publicly accessible spaces, distinct local dynamics have emerged, resulting from collaborative efforts among various stakeholders, supported by a strong sense of solidarity, commitment, and activism within the neighborhood. The GIS-based mapping of resource flows, open spaces, vulnerable communities, and ARGS reveals that despite many proposals and initiatives at the regional level, only one-third of the ARGS are located in areas with vulnerable communities and municipalities with high resource consumption.

The catalogue of spatial configurations allowed the addition of the spatial dimension to a fine-grained UM analysis. Furthermore, it has facilitated data collection on resource harvesting, publicly accessible spaces created, and community involvement at a local scale, data that is often missing from local authorities' datasets. Beyond their immediate impact on local resource management, these projects offer replicable models that can inform future research on the cumulative effects of decentralized interventions within broader city-scale UM assessments. This methodological approach has also enabled the identification of spatial typologies (e.g., work, pleasure, energy production, rainwater harvesting, composting) and locally crafted artifacts (e.g., small-scale rainwater harvesting devices, collective garden beds, compost bins), which could be implemented in future urban design projects.

Future research, considering the previously discussed methodological limitations, should extend to the study of ARGS in other cities across the Global South and Global North. This broader exploration would enable the identification of emerging spatial typologies, artifacts, and services within both public and private spaces that can be used by design practitioners. Additionally, these studies could offer valuable insights into potential synergies between design and social innovation strategies within UM frameworks. They may also contribute to refining calculations of the impact of upscaling local data on the overall urban metabolism of the cities analyzed, thereby enhancing the integration of bottom-up initiatives into broader sustainability planning. Building upon new case studies combining this top-down and bottom-up approach, resource-sensitive urban design strategies could be developed at a regional scale, envisioning a network of ARGS in vacant lots, street networks, and open spaces, ultimately contributing to the decentralization of resource management and promoting social cohesion.



***Supporting Material***

*Chapter 4 Community Involvement*

*Alternative resource governance systems and fine-grained data.*

*Summary*

This supporting material provides supplementary information that complements the methods and findings included in *Chapter 4*, including the compiled GIS datasets used in the study, the criteria and sub-criteria used to classify the municipalities, and the main characteristics and stakeholders involved in selected ARGS.

*This section has been submitted and is currently under revision for publication as an original research article in the journal Cities as Supporting Material of Chapter 4: Otero Peña, D., Perrotti, D., & Vanderstraeten, P. (202*). A spatially explicit and fine-grained urban metabolism assessment to inform urban planning and design: alternative resource governance systems in the Brussels Capital Region (manusript submitted for publication). Compared to the published version, the formatting was changed.*

| * Criteria | Type | Indicator | Year | Units |
|---|---|---|---|---|
| W | Flows | Water consumtion | 2020 | l/day/cap |
| W | Infrastructure | Extraction wells | 2018 | l/day/cap |
| W | Infrastructure | Water springs | 2018 | Units |
| W | Infrastructure | Water tanks | 2018 | m3/cap |
| W | Infrastructure | Sewage treatment plants | 2018 | l/day/cap |
| W | Infrastructure | Retention basins | 2018 | m3/cap |
| E | Flows | Electricity consumption | 2020 | kWh/year/cap |
| E | Flows | Natural gas consumption | 2020 | kWh/year/cap |
| E | Infrastructure | Waste-to-energy electrical power plant | 2021 | kWh/year/cap |
| E | Infrastructure | Electrical substations | 2022 | Units |
| SW | Flows | Municipal solid waste (MSW) generation | 2017 | kg/day/cap |
| SW | Infrastructure | Transfer stations | 2021 | kg/day/cap |
| SW | Infrastructure | Recycling plants | 2021 | kg/day/cap |
| SW | Infrastructure | Compost plants | 2021 | kg/day/cap |
| SW | Infrastructure | Glass containers | 2021 | kg/day/cap |
| SW | Infrastructure | Waste-to-Energy incineration plant | 2021 | kg/day/cap |
| OSN | - | Topography | - | m |
| OSN | - | Satellite image | 2021 | - |
| OSN | Infrastructure | Public green spaces | 2018 | $m^2$/inhab |
| OSN | Infrastructure | Public blue spaces | 2018 | $m^2$/inhab |
| OSN | Infrastructure | Public gray spaces | 2018 | $m^2$/inhab |
| OSN | Infrastructure | Private green spaces | 2018 | $m^2$/inhab |
| OSN | Infrastructure | Nature reserves | 2018 | $m^2$/inhab |
| OSN | Infrastructure | Streets | 2022 | km |
| VC | Areas | Low income neighborhoods | 2010 | $m^2$/inhab |
| VC | Areas | High percentage of social housing units | 2015 | $m^2$/inhab |
| ARGS | Areas | Sustainable municipal initiatives | 2022 | $m^2$ |
| ARGS | Areas | Sustainable neighborhood initiatives | 2022 | $m^2$ |
| ARGS | Areas | Facilities with open spaces | 2022 | $m^2$ |
| ARGS | Infrastructure | Reusable material stores | 2022 | Units |
| ARGS | Infrastructure | NGO headquarters | 2022 | Units |
| ARGS | Infrastructure | Compost sites | 2022 | Units |
| ARGS | Areas | Co-creation research studies | 2022 | $m^2$ |

*Table S4.1: Brussels Capital Region compiled datasets and new data plotted on maps (highlighted in gray) used in the study and classified by criteria, type of information, data elements, year, units, source, scale, performed analysis (GIS mapping, interviews, and 3D spatial modelling), and description of the dataset are included. * W: Water, E: Energy, SW: Solid Waste, OSN: Open Space Networks, VC: Vulnerable Communities, ARGS: Alternative Resource Governance Systems.*

| *Source* | *Scale* | *GIS Mapping* | *Interviews* | *3D Spatial analysis* | *Description* |
|---|---|---|---|---|---|
| Brussels Institute for Statistics and Analysis (*IBSA*) | Municipality | x | - | - | Drinkable water consumption of households, public services, industries, agriculture, and the commercial sector. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Groundwater abstraction infrastructure. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Groundwater natural exit points. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Drinkable water reservoirs. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Wastewater and rainwater treatment plants. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Rainwater retention and storage infrastructure. |
| Brussels Institute for Statistics and Analysis (*IBSA*) | Municipality | x | - | - | Electricity consumption of households, public services, industry, agriculture, and the commercial and transportation sectors. |
| Brussels Institute for Statistics and Analysis (*IBSA*) | Municipality | x | - | - | Natural gas consumption of households, public services, industry, agriculture, and the commercial and transportation sectors. |
| Bruxelles Energie (waste-to-energy plant) | Region | x | - | - | Electricity and heat production facility for non-recyclable household waste. |
| BCR Brussels-Capital Region Government | Region | x | - | - | Electrical generation, transmission, and distribution system infrastructure. |
| BCR Waste Agency (*Bruxelles Propreté*) | Region | x | - | - | MSW data are classified by source and type of waste (e.g. organic, inorganic including recycling options). |
| BCR Waste Agency (*Bruxelles Propreté*) | Municipality | x | - | - | Separation and waste collection facilities. |
| BCR Waste Agency (*Bruxelles Propreté*) | Municipality | x | - | - | Recyclable waste (paper, cardboard, plastic, glass, electronics, construction) treatment plants. |
| BCR Waste Agency (*Bruxelles Propreté*) | Municipality | x | - | - | Organic waste (food and garden) treatment plants. |
| BCR Waste Agency (*Bruxelles Propreté*) | Municipality | x | - | - | Glass collection infrastructure. |
| BCR Waste Agency (*Bruxelles Propreté*) | Municipality | x | - | - | Electricity and heat production facility for non-recyclable household waste. |
| BCR Brussels-Capital Region Government | Region | x | - | - | Contour lines every 5 m |
| Google Maps | Region | x | - | - | - |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Parks and gardens. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Rivers, streams, channels, and lakes. Not included culverted rivers and streams. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Squares and pedestrian walkways. Not included the street network. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Residential and commercial gardens and parks. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Municipality | x | - | - | Forests, marshes, and wetlands. |
| BCR Brussels-Capital Region Government | Municipality | x | - | - | Streets, roads, and highways. |
| BCR Environmental Agency (*Bruxelles Environnement*) | Neighborhood | x | - | - | Areas with most of the population living with precarious access to basic services, public space, and housing quality conditions due to their socio-economic status or irregular land occupation. |
| *Monitoring des Quartiers* (Brussels Institute for Statistics and Analysis) | Neighborhood | x | - | - | Neighborhoods with higher share of social housing units (number of social housing units per 100 households) than the average in the region. |
| *Contrats de quartiers durables* (BCR Action Plans) | Municipality | x | x | x | Initiatives focusing on publicly accessible spaces, co-led by citizens, and managing one of the 3 resources studied (water, waste, energy). |
| *Quartiers durables citoyens* (BCR Environmental Agency) | Neighborhood | x | x | x | |
| - | Neighborhood | x | x | x | Urban farms and public buildings. |
| *Fédération des Récupérathèques* (NGO) | Neighborhood | x | x | x | Recycling centers, materials storage, and workshops. |
| - | Neighborhood | x | x | x | NGO with physical facilities open to the public. |
| *Worms* (NGO) | Neighborhood | x | x | x | Community composting sites. |
| *INNOVIRIS* BCR Research and Innovation Institute | Neighborhood | x | x | - | Research projects focusing on publicly accessible spaces, co-led by citizens, and managing one of the 3 resources studied (water, waste, energy). |

| Administrative Limit | | | |
|---|---|---|---|
| *Municipalities* | *Poulation (habitants)* | *Area (Km2)* | *Density (inhab/km2)* |
| Anderlecht | 120,887 | 17.9 | 6,750 |
| Auderghem | 34,404 | 9.0 | 3,835 |
| Berchem Sainte-Agathe | 25,502 | 2.9 | 8,674 |
| Bruxelles w e g | 185,103 | 33.1 | 5,594 |
| Etterbeek | 48,473 | 3.2 | 15,291 |
| Evere e | 42,656 | 5.1 | 8,331 |
| Forest | 56,581 | 6.3 | 8,981 |
| Ganshoren | 25,234 | 2.4 | 10,384 |
| Ixelles w g | 87,632 | 6.4 | 13,693 |
| Jette | 52,728 | 5.2 | 10,160 |
| Koekelberg | 21,959 | 1.2 | 18,609 |
| Molenbeek Saint-Jean | 97,979 | 6.0 | 16,303 |
| Saint-Gilles w | 49,678 | 2.5 | 19,713 |
| Saint-Josse-ten-Noode w e | 27,497 | 1.2 | 23,704 |
| Schaerbeek | 132,799 | 7.9 | 16,831 |
| Uccle g | 83,980 | 22.9 | 3,672 |
| Watermael-Boitsfort g s | 25,332 | 13.0 | 1,953 |
| Woluwe Saint-Lambert | 57,712 | 7.3 | 7,906 |
| Woluwe Saint-Pierre s | 42,119 | 8.9 | 4,711 |
| *Total* | *1,218,255* | *162* | - |
| *Average* | *64,119* | *8.55* | *7503.42* |

*Table S4.2: Population and density. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| Administrative Limit | W Flows | W Infrastructure | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Municipalities | Water Consumtion (l/day/cap) | Extraction wells (l/day/cap) | | Water springs ( units) (l/day/cap) | | Water tanks capacity (units) (m3/cap) | | Sewage treatment plants (units) (l/day/cap) | | Retension basins (units) (m3/cap) | |
| Anderlecht | 115 | (108) | 3.09 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Auderghem | 115 | (13) | 1.31 | (4) | N/A | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Berchem Sainte-Agathe | 104 | (9) | 1.22 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (2) | 1.21 |
| Bruxelles | 163 | (85) | 6.36 | (2) | N/A | (1) | 0.04 | (1) | 1,465 | (4) | 1.12 |
| Etterbeek | 129 | (19) | 1.36 | (1) | N/A | (1) | 3.82 | (0) | 0.00 | (1) | 0.20 |
| Evere | 115 | (17) | 1.38 | (1) | N/A | (0) | 0 | (0) | 0.00 | (1) | 1.93 |
| Forest | 111 | (36) | 2.20 | (1) | N/A | (0) | 0 | (1) | 2,397 | (1) | 0.05 |
| Ganshoren | 100 | (9) | 1.23 | (0) | 0.00 | (0) | 0 | (0) | 0.00 | (1) | 1.09 |
| Ixelles | 161 | (24) | 0.95 | (1) | N/A | (1) | 0.22 | (0) | 0.00 | (0) | 0.00 |
| Jette | 107 | (5) | 0.33 | (1) | N/A | (0) | 0.00 | (0) | 0.00 | (2) | 0.06 |
| Koekelberg | 103 | (5) | 0.79 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Molenbeek Saint-Jean | 111 | (37) | 1.31 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (1) | 0.06 |
| Saint-Gilles | 148 | (12) | 0.84 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (1) | 0.28 |
| Saint-Josse-ten-Noode | 143 | (4) | 0.50 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (1) | 0.75 |
| Schaerbeek | 116 | (26) | 0.68 | (1) | N/A | (0) | 0.00 | (0) | 0.00 | (1) | 0.12 |
| Uccle | 130 | (29) | 1.19 | (4) | N/A | (1) | 0.60 | (0) | 0.00 | (3) | 1.09 |
| Watermael-Boitsfort | 92 | (9) | 1.23 | (3) | N/A | (1) | 1.97 | (0) | 0.00 | (3) | 0.87 |
| Woluwe Saint-Lambert | 130 | (22) | 1.32 | (2) | N/A | (0) | 0.00 | (0) | 0.00 | (3) | 0.17 |
| Woluwe Saint-Pierre | 121 | (12) | 0.99 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 | (5) | 1.49 |
| *Total* | - | *(481)* | *28* | (21) | - | (5) | *7* | *2* | *3,862* | *(30)* | *10* |
| *Average* | 128 | *(25)* | 1.49 | (1) | - | (0) | *0.35* | *0.11* | *203.27* | *(2)* | *0.55* |

*Table S4.3: Water consumption and infrastructure. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| Administrative Limit | E Flows | | E Infrastructure | | | | | |
|---|---|---|---|---|---|---|---|---|
| Municipalities | Electricity consumption (kWh/year/cap) | Natural gas consumption (kWh/year/cap) | Waste-to-Energy Electrical power plant generation (kWh/cap) | | Electrical power plant (turbojet) (kWh/cap) | | Electrical substations (units) (kVA/capita) | |
| Anderlecht | 2,945 | 6,703 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Auderghem | 2,995 | 8,294 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Berchem Sainte-Agathe | 2,417 | 6,046 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Bruxelles | 7,423 | 11,678 | (1) | 931.57 | (0) | 0.00 | (2) | N/A |
| Etterbeek | 3,017 | 7,276 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Evere | 3,797 | 5,949 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Forest | 2,235 | 7,892 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Ganshoren | 1,751 | 5,953 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Ixelles | 3,297 | 8,695 | (0) | 0.00 | (1) | N/A | (0) | 0.00 |
| Jette | 2,066 | 6,508 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Koekelberg | 1,892 | 4,918 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Molenbeek Saint-Jean | 1,820 | 4,506 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Saint-Gilles | 2,833 | 7,290 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Saint-Josse-ten-Noode | 4,661 | 7,441 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Schaerbeek | 2,157 | 5,682 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Uccle | 2,728 | 9,019 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Watermael-Boitsfort | 2,388 | 8,760 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| Woluwe Saint-Lambert | 3,366 | 8,056 | (0) | 0.00 | (0) | 0.00 | (1) | N/A |
| Woluwe Saint-Pierre | 2,357 | 8,404 | (0) | 0.00 | (0) | 0.00 | (0) | 0.00 |
| *Total* | - | - | *(1)* | *931.57* | *(1)* | *0.00* | *(10)* | - |
| *Average* | #REF! | #REF! | *(0)* | *58.22* | *(0)* | *0.00* | *(1)* | - |

*Table S4.4: Energy consumption and infrastructure. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| *Administrative Limit* | *SW Flows* | *SW Infrastructure* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Municipalities* | *Municipal Solid Waste Generation (kg/day/cap)* | *Transfer stations (units) (kg/day/cap)* | | *Recycling plants (units) (kg/day/cap)* | | *Compost plants (units) (kg/day/cap)* | | *Glass containers (units) (k g/day/cap)* | | *Waste-to-Energy incineration plant (units) (kg/day/cap)* | |
| Anderlecht | 1.10 | (3) | N/A | (3) | N/A | (1) | N/A | (66) | 0.00 | (0) | 0.00 |
| Auderghem | 1.06 | (1) | 0.35 | (0) | 0.00 | (0) | 0.00 | (19) | 0.00 | (0) | 0.00 |
| Berchem Sainte-Agathe | 0.97 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (8) | 0.00 | (0) | 0.00 |
| Bruxelles | 1.16 | (14) | 0.09 | (11) | N/A | (1) | N/A | (79) | 0.00 | (1) | 496,443 |
| Etterbeek | 0.85 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (17) | 0.00 | (0) | 0.00 |
| Evere | 1.05 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (29) | 0.00 | (0) | 0.00 |
| Forest | 1.04 | (6) | 0.79 | (4) | 15.77 | (1) | 0.80 | (19) | 0.00 | (0) | 0.00 |
| Ganshoren | 0.93 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (13) | 0.00 | (0) | 0.00 |
| Ixelles | 0.90 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (34) | 0.00 | (0) | 0.00 |
| Jette | 0.95 | (1) | N/A | (1) | N/A | (0) | 0.00 | (15) | 0.00 | (0) | 0.00 |
| Koekelberg | 0.84 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (9) | 0.00 | (0) | 0.00 |
| Molenbeek Saint-Jean | 0.87 | (2) | N/A | (3) | N/A | (0) | 0.00 | (35) | 0.00 | (0) | 0.00 |
| Saint-Gilles | 0.82 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (14) | 0.00 | (0) | 0.00 |
| Saint-Josse-ten-Noode | 0.84 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (5) | 0.00 | (0) | 0.00 |
| Schaerbeek | 0.86 | (1) | N/A | (1) | N/A | (0) | 0.00 | (60) | 0.00 | (0) | 0.00 |
| Uccle | 1.23 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (27) | 0.00 | (0) | 0.00 |
| Watermael-Boitsfort | 1.39 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (15) | 0.00 | (0) | 0.00 |
| Woluwe Saint-Lambert | 1.05 | (0) | 0 | (0) | 0.00 | (0) | 0.00 | (30) | 0.00 | (0) | 0.00 |
| Woluwe Saint-Pierre | 1.39 | (1) | 0.19 | (0) | 0.00 | (0) | 0.00 | (22) | 0.00 | (0) | 0.00 |
| *Total* | *19.30* | *(29)* | *1.42* | *(23)* | *16* | *(3)* | *1* | *(516)* | *0.00* | | *496,443* |
| *Average* | *0.00* | *(2)* | *0.09* | *(1)* | *0.99* | *(0)* | *0.05* | *(32)* | *0.00* | | *31027.69* |

*Table S4.5: Solid waste generation and infrastructure. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| *Administrative Limit* | *Open Space Network (OSN)* | | | | |
|---|---|---|---|---|---|
| *Municipalities* | *Public green spaces (m²/inhab)* | *Public blue spaces (m²/inhab)* | *Public grey spaces (m²/inhab)* | *Private green spaces (m²/inhab)* | *Nature reserves (m²/inhab)* |
| Anderlecht | 10.92 | 3.79 | 0.34 | 56.29 | 0.00 |
| Auderghem | 51.24 | 5.52 | 0.21 | 67.31 | 102.43 |
| Berchem Sainte-Agathe | 11.31 | 0.20 | 0.07 | 55.29 | 2.44 |
| Bruxelles | 20.04 | 5.45 | 0.49 | 62.51 | 1.29 |
| Etterbeek | 1.69 | 0.04 | 0.30 | 19.73 | 0.00 |
| Evere | 11.37 | 0.18 | 0.00 | 61.74 | 0.00 |
| Forest | 9.00 | 0.11 | 0.24 | 44.34 | 0.00 |
| Ganshoren | 7.61 | 0.81 | 0.14 | 36.96 | 7.70 |
| Ixelles | 2.07 | 0.39 | 0.46 | 26.32 | 0.00 |
| Jette | 13.37 | 0.61 | 0.18 | 33.08 | 13.02 |
| Koekelberg | 4.12 | 0.00 | 0.10 | 12.45 | 0.00 |
| Molenbeek Saint-Jean | 6.93 | 0.41 | 0.08 | 20.37 | 0.00 |
| Saint-Gilles | 1.09 | 0.01 | 0.25 | 9.86 | 0.00 |
| Saint-Josse-ten-Noode | 1.94 | 0.08 | 0.19 | 7.70 | 0.00 |
| Schaerbeek | 3.43 | 0.07 | 0.16 | 18.41 | 0.00 |
| Uccle | 15.77 | 0.78 | 0.15 | 122.57 | 66.92 |
| Watermael-Boitsfort | 22.18 | 6.99 | 1.07 | 108.27 | 307.56 |
| Woluwe Saint-Lambert | 14.02 | 0.89 | 0.31 | 59.62 | 0.00 |
| Woluwe Saint-Pierre | 60.02 | 3.06 | 0.43 | 103.46 | 14.61 |
| *Total* | - | - | - | - | - |
| *Average* | *12.83* | *1.81* | *0.28* | *48.29* | *15.22* |

*Table S4.6: Open space networks. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| *Administrative Limit* | *Vulnerable Communities (VC)* | |
|---|---|---|
| *Municipalities* | *Low income neighborhoods (m²/inhab)* | *High percentage of social housing units (m²/inhab)* |
| Anderlecht | 19.80 | 51.81 |
| Auderghem | 0.00 | 35.47 |
| Berchem Sainte-Agathe | 0.00 | 70.53 |
| Bruxelles | 24.95 | 50.73 |
| Etterbeek | 0.00 | 21.88 |
| Evere | 0.00 | 55.86 |
| Forest | 12.92 | 24.46 |
| Ganshoren | 0.00 | 30.50 |
| Ixelles | 0.00 | 10.32 |
| Jette | 0.00 | 20.10 |
| Koekelberg | 16.80 | 16.80 |
| Molenbeek Saint-Jean | 33.91 | 20.73 |
| Saint-Gilles | 18.22 | 14.76 |
| Saint-Josse-ten-Noode | 39.87 | 6.06 |
| Schaerbeek | 17.43 | 15.01 |
| Uccle | 0.00 | 53.07 |
| Watermael-Boitsfort | 0.00 | 70.25 |
| Woluwe Saint-Lambert | 0.00 | 64.72 |
| Woluwe Saint-Pierre | 0.00 | 40.91 |
| *Total* | - | - |
| *Average* | *11.50* | *42.12* |

*Table S4.7: Vulnerable communities. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| *Administrative Limit* | *Alternative Resource Governance Systems (ARGS)* | | | | | |
|---|---|---|---|---|---|---|
| *Municipalities* | *Sustainable neighborhood initiatives (units)* | *Facilities with open spaces (units)* | *Reusable material stores (units)* | *NGO headquarters (units)* | *Compost sites (units)* | *Co-creation research studies (units)* |
| Anderlecht | 2 | 1 | 1 | 0 | 8 | 0 |
| Auderghem | 3 | 0 | 0 | 0 | 6 | 0 |
| Berchem Sainte-Agathe | 1 | 0 | 0 | 0 | 3 | 0 |
| Bruxelles | 2 | 4 | 4 | 1 | 21 | 0 |
| Etterbeek | 1 | 0 | 0 | 0 | 5 | 0 |
| Evere | 2 | 0 | 0 | 0 | 1 | 0 |
| Forest | 2 | 1 | 0 | 0 | 8 | 1 |
| Ganshoren | 0 | 1 | 0 | 0 | 2 | 1 |
| Ixelles | 1 | 1 | 3 | 0 | 13 | 1 |
| Jette | 2 | 0 | 0 | 0 | 4 | 1 |
| Koekelberg | 1 | 0 | 0 | 0 | 3 | 0 |
| Molenbeek Saint-Jean | 2 | 3 | 0 | 0 | 3 | 1 |
| Saint-Gilles | 2 | 2 | 1 | 1 | 5 | 1 |
| Saint-Josse-ten-Noode | 1 | 0 | 0 | 0 | 5 | 0 |
| Schaerbeek | 5 | 0 | 0 | 0 | 11 | 0 |
| Uccle | 2 | 0 | 0 | 0 | 9 | 0 |
| Watermael-Boitsfort | 2 | 1 | 0 | 0 | 10 | 1 |
| Woluwe Saint-Lambert | 1 | 0 | 0 | 0 | 5 | 0 |
| Woluwe Saint-Pierre | 2 | 0 | 0 | 0 | 3 | 0 |
| *Total* | *34* | *14* | *9* | *2* | *125* | *7* |
| *Average* | *2* | *1* | *1* | *0* | *8* | *0* |

*Table S4.8: Alternative resource governance systems. Evaluation and classification of all criteria and subcriteria used in the analysis by municipality. Highlighted in red are values 10% above the average, in orange the average values, and in gray the values 10% below the average.*

| | | CI01 | CI02 | CI03 | CI04 | CI05 | CI06 | CI07 | NP01 | OG01 | OG02 | OG03 | OG04 | OG05 | RS01 | RS02 | RS03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Scale of intervention* | *Individual* | x | x | - | x | - | x | - | x | x | x | x | x | x | x | - | - |
| | *Household* | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | - |
| | *Neighborhood* | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | *Municipality* | x | - | x | x | x | x | x | x | - | - | - | x | - | x | x | x |
| | *Region* | x | - | - | - | - | - | - | x | - | - | - | - | - | x | x | x |
| *Stakeholders* | *Government* | x | - | - | - | - | - | - | x | - | - | - | - | - | x | - | x |
| | *Academia* | - | - | - | - | - | x | - | x | - | - | - | - | - | x | x | x |
| | *Design practitioners* | - | - | x | x | - | - | - | x | - | x | - | - | x | x | - | - |
| | *NGO* | x | x | x | - | x | x | x | x | x | x | x | x | x | x | x | x |
| | *Organized community* | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Location* | *Woluwe-Saint-Pierre* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| | *Woluwe-Saint-Lambert* | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - |
| | *Wtaermael-Boitsfort* | - | x | - | - | - | - | - | - | - | - | - | - | - | - | x | - |
| | *Uccle* | - | - | - | - | - | - | - | - | - | - | - | x | - | - | - | x |
| | *Schaerbeek* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| | *Saint-Gilles* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| | *Molenbeek-Saint-Jean* | - | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | *Jette* | - | - | - | - | - | - | - | - | - | - | x | - | - | x | - | - |
| | *Ixelles* | - | - | - | - | x | - | - | - | - | - | - | - | - | - | x | - |
| | *Ganshoren* | - | - | - | - | - | - | - | - | - | - | - | - | - | x | - | - |
| | *Forest* | - | - | - | - | - | - | x | - | - | - | - | - | - | x | - | - |
| | *Bruxelles* | x | - | - | - | - | - | - | - | - | x | - | - | x | - | x | - |
| | *Anderlecht* | - | - | - | x | - | x | - | - | - | - | - | - | - | - | - | x |
| | *All municipalities* | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - |
| *People involved* | *More than 50* | - | x | - | - | - | - | - | x | - | - | - | - | - | - | - | - |
| | *21 to 50* | - | - | x | - | - | x | - | - | - | - | - | x | - | - | - | - |
| | *11 to 20* | x | - | - | x | - | - | - | - | - | x | x | - | - | x | - | x |
| | *6 to 10* | - | - | - | - | - | - | - | - | x | - | - | - | x | - | - | - |
| | *1 to 5* | - | - | - | - | x | - | x | - | - | - | - | - | - | - | x | - |
| *Urban space use* | *Banks of water bodies* | - | - | - | - | - | x | - | - | - | - | - | - | - | x | - | - |
| | *Nature reserves* | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - |
| | *Gardens* | - | - | - | - | - | - | x | x | - | - | - | - | - | x | - | - |
| | *Parks* | x | - | - | - | - | x | - | x | - | - | - | - | - | x | - | - |
| | *Built facilities* | - | - | - | x | x | - | - | - | - | - | - | x | - | - | x | x |
| | *Underdeveloped spaces* | - | x | x | - | - | - | - | x | x | - | x | x | x | x | - | - |
| | *Pedestrian walkways* | - | - | - | - | - | - | - | x | - | - | - | - | - | x | - | - |
| | *Squares* | - | - | - | x | - | - | - | x | - | - | - | - | - | x | - | - |
| | *Streets* | - | - | - | x | - | - | - | x | x | x | - | x | - | x | - | - |
| *Activities* | *Self-organization* | x | x | x | - | x | - | - | x | - | - | x | x | x | x | x | x |
| | *Networking* | x | x | x | x | x | - | x | x | - | - | - | - | - | x | x | x |
| | *Working* | x | x | x | x | - | x | - | x | x | x | x | x | x | - | - | - |
| | *Meeting and sharing* | x | x | x | x | x | x | x | x | x | x | x | x | x | - | - | - |
| | *Knowledge sharing* | x | x | x | - | x | x | x | x | - | x | x | x | - | x | x | x |
| | *Resource harvesting* | x | x | x | x | x | x | x | x | x | x | x | x | - | - | x | - |
| *Resources* | *Solid waste* | x | x | x | x | x | - | x | x | - | x | x | x | - | - | - | x |
| | *Energy* | x | - | x | - | - | x | - | - | x | - | - | - | - | - | x | - |
| | *Water* | x | x | x | - | x | x | x | - | x | x | x | x | x | x | - | - |

*Table S4.9: Main characteristics and stakeholders involved in selected ARGS.*

Collective infrastructures **CI**
Networking platforms **NP**
Organized groups **OG**
Research studies **RS**

Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)

*Figure S4.1: Main characteristics of selected ARGS (Collective Infrastructures), including scale of intervention, type of stakeholder involved, location, number of people involved, type of urban space used, activities, and key resources managed.*

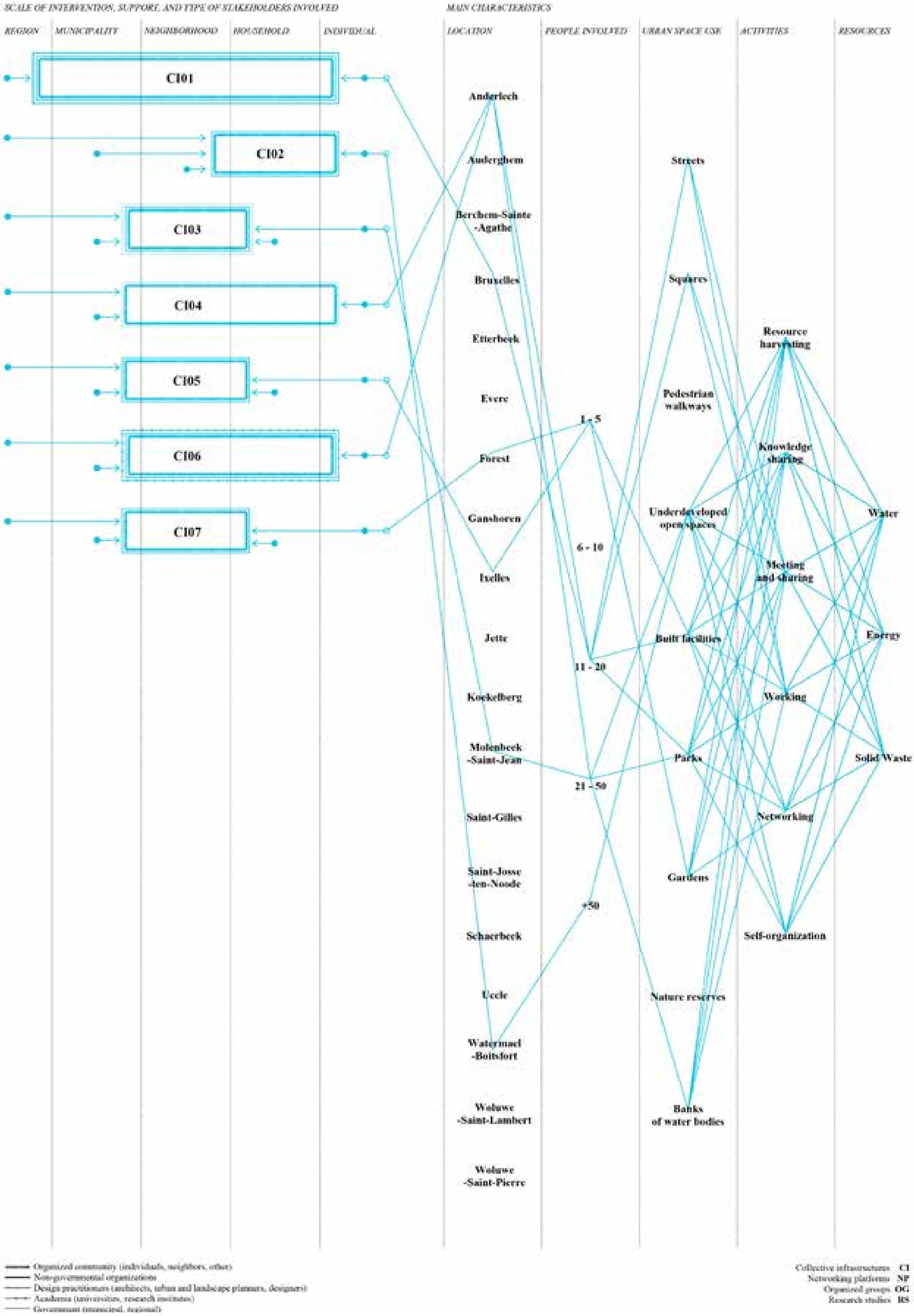

SCALE OF INTERVENTION, SUPPORT, AND TYPE OF STAKEHOLDERS INVOLVED
REGION
MUNICIPALITY
NEIGHBORHOOD
HOUSEHOLD
INDIVIDUAL
CI01
CI02
CI03
CI04
CI05
CI06
CI07
MAIN CHARACTERISTICS
LOCATION
PEOPLE INVOLVED
URBAN SPACE USE
ACTIVITIES
RESOURCES
Anderlech
Auderghem
Berchem-Sainte -Agathe
Bruxelles
Etterbeek
Evere
Forest
Ganshoren
Ixelles
Jette
Koekelberg
Molenbeek -Saint-Jean
Saint-Gilles
Saint-Josse -ten-Noode
Schaerbeek
Uccle
Watermael -Boitsfort
Woluwe -Saint-Lambert
Woluwe -Saint-Pierre
1 - 5
6 - 10
11 - 20
21 - 50
+50
Streets
Squares
Pedestrian walkways
Underdeveloped open spaces
Built facilities
Parks
Gardens
Nature reserves
Banks of water bodies
Resource harvesting
Knowledge sharing
Meeting and sharing
Working
Networking
Self-organization
Water
Energy
Solid Waste
Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)
Collective infrastructures CI
Networking platforms NP
Organized groups OG
Research studies RS

Figure S4.2: Main characteristics of selected ARGS (Networking Platforms), including scale of intervention, type of stakeholder involved, location, number of people involved, type of urban space used, activities, and key resources managed.

Collective infrastructures **CI**
Networking platforms **NP**
Organized groups **OG**
Research studies **RS**

Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)

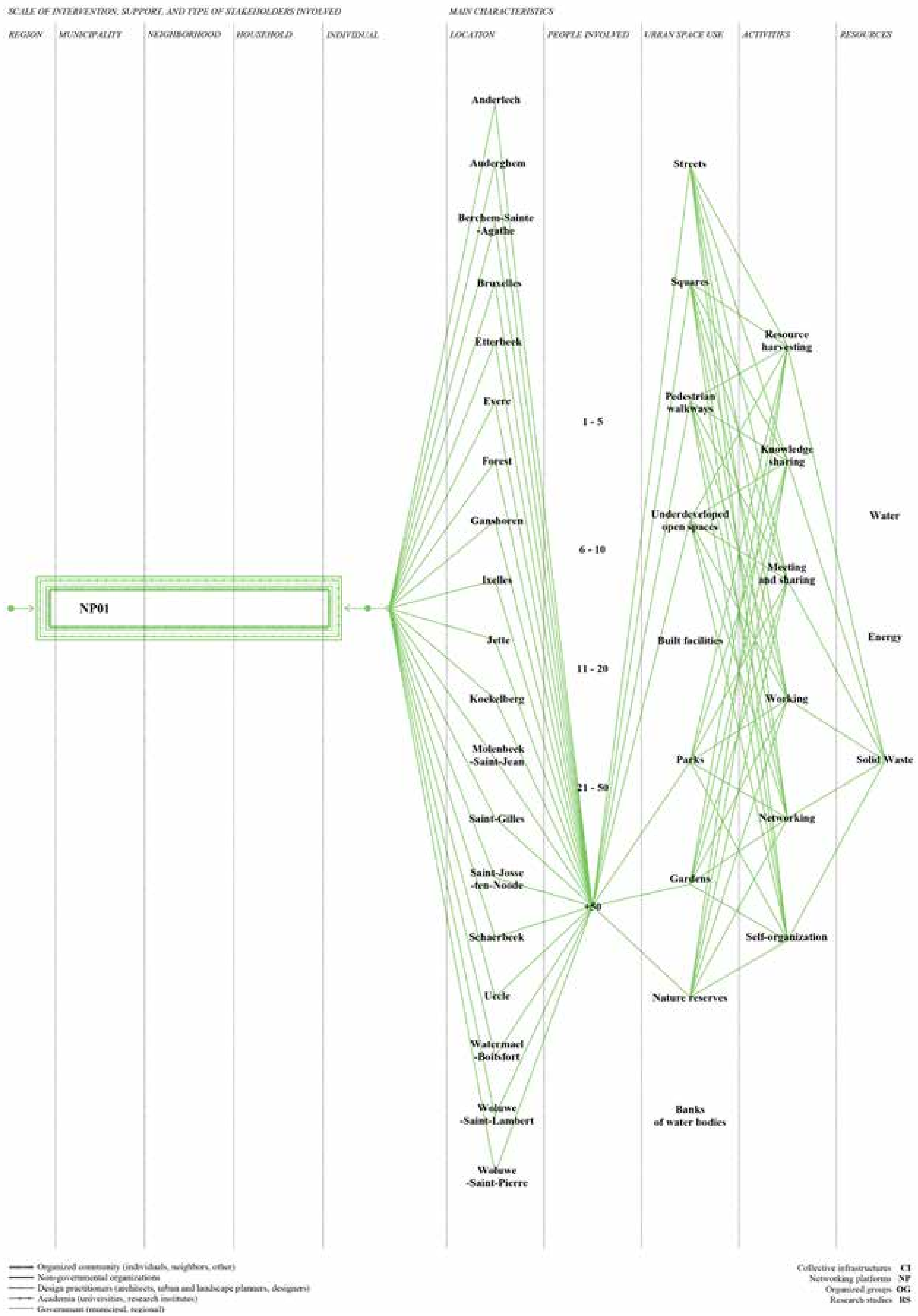

SCALE OF INTERVENTION, SUPPORT, AND TYPE OF STAKEHOLDERS INVOLVED
MAIN CHARACTERISTICS
REGION
MUNICIPALITY
NEIGHBORHOOD
HOUSEHOLD
INDIVIDUAL
LOCATION
PEOPLE INVOLVED
URBAN SPACE USE
ACTIVITIES
RESOURCES
NP01
Anderlech
Auderghem
Berchem-Sainte
-Agathe
Bruxelles
Etterbeek
Evere
Forest
Ganshoren
Ixelles
Jette
Koekelberg
Molenbeek
-Saint-Jean
Saint-Gilles
Saint-Josse
-ten-Noode
Schaerbeek
Uccle
Watermael
-Boitsfort
Woluwe
-Saint-Lambert
Woluwe
-Saint-Pierre
1 - 5
6 - 10
11 - 20
21 - 50
+50
Streets
Squares
Pedestrian
walkways
Underdeveloped
open spaces
Built facilities
Parks
Gardens
Nature reserves
Banks
of water bodies
Resource
harvesting
Knowledge
sharing
Meeting
and sharing
Working
Networking
Self-organization
Water
Energy
Solid Waste
Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)
Collective infrastructures CI
Networking platforms NP
Organized groups OG
Research studies RS

*Figure S4.3: Main characteristics of selected ARGS (Organized Groups), including scale of intervention, type of stakeholder involved, location, number of people involved, type of urban space used, activities, and key resources managed.*

Collective infrastructures **CI**
Networking platforms **NP**
Organized groups **OG**
Research studies **RS**

Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)

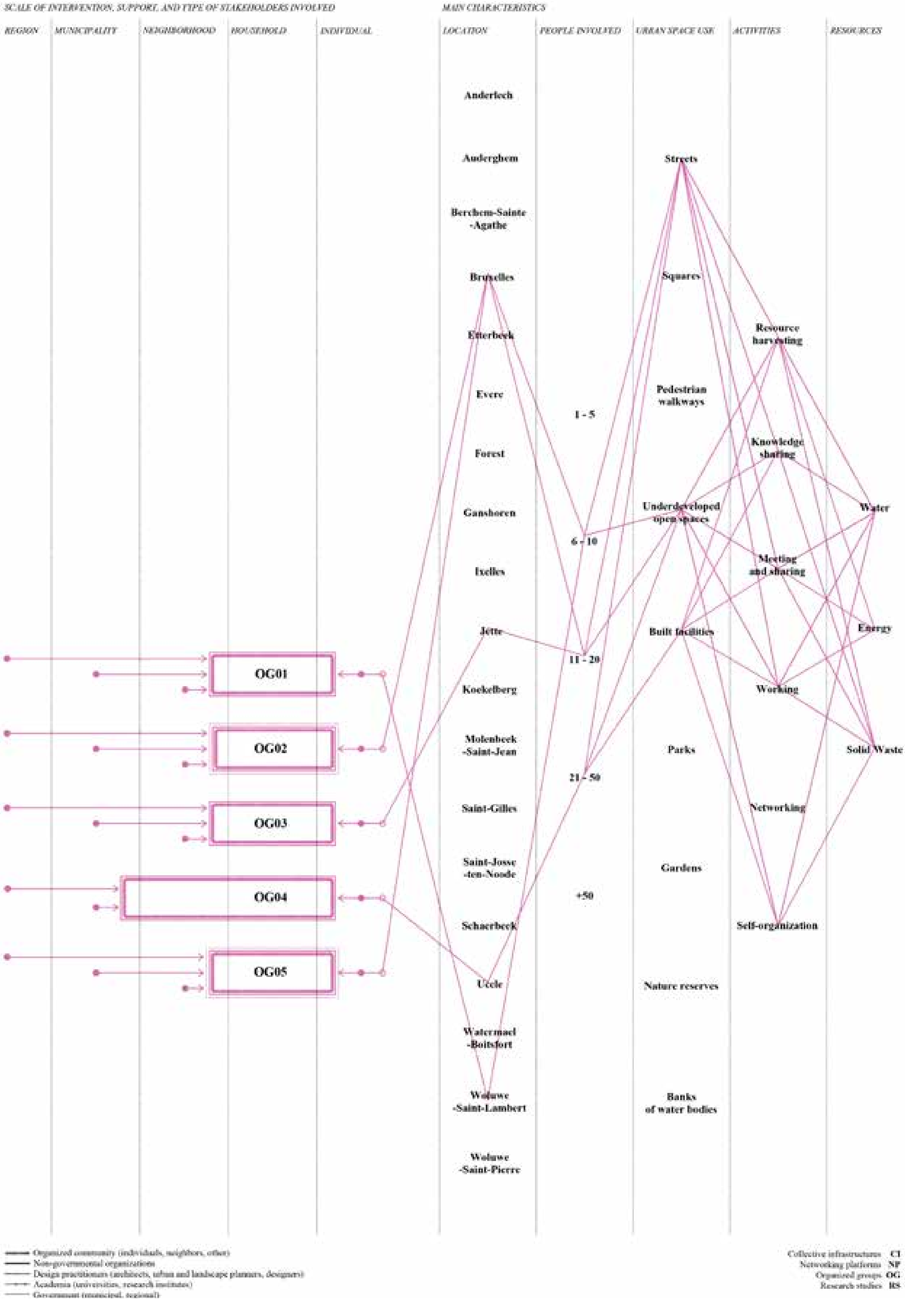
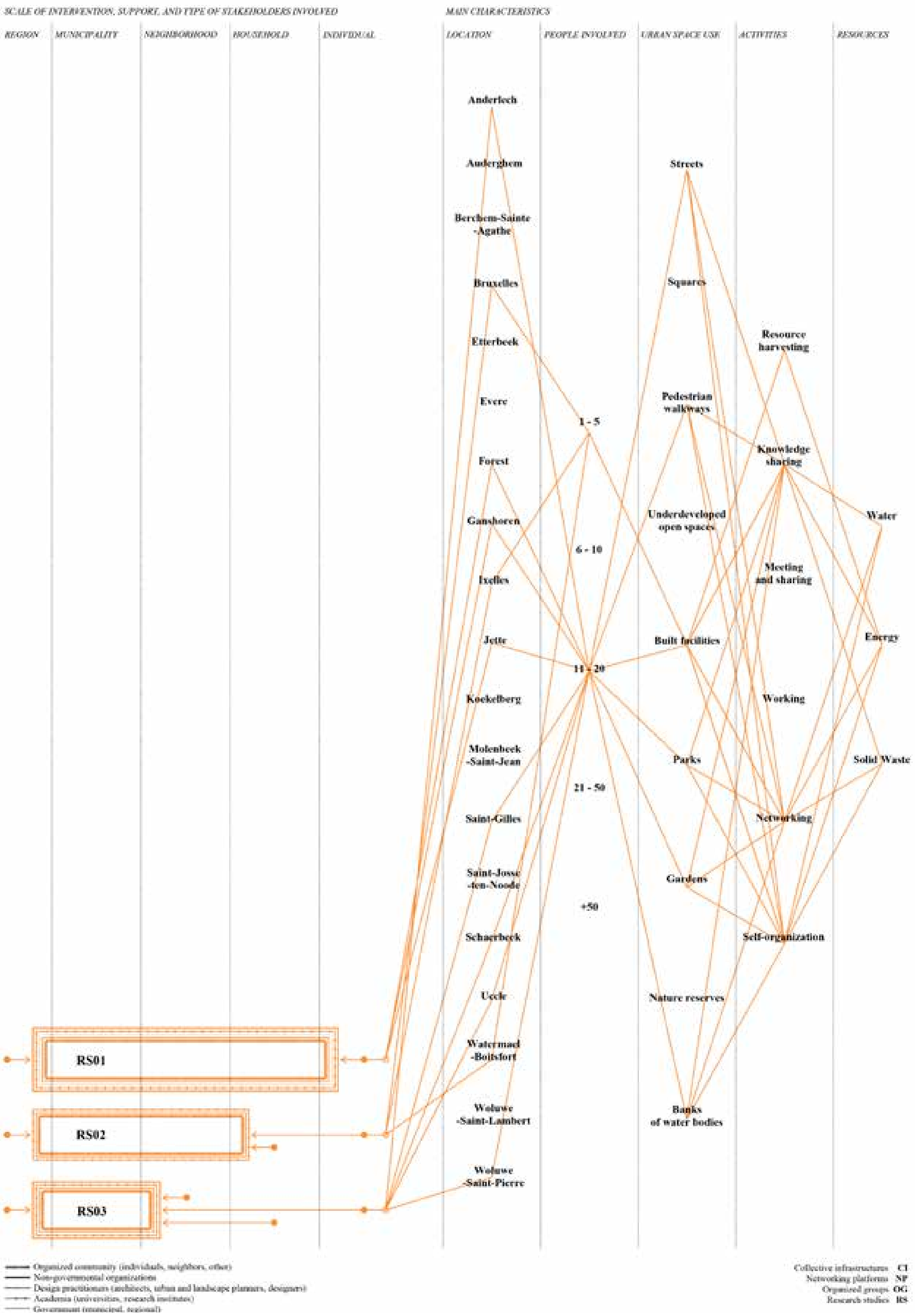

SCALE OF INTERVENTION, SUPPORT, AND TYPE OF STAKEHOLDERS INVOLVED
REGION
MUNICIPALITY
NEIGHBORHOOD
HOUSEHOLD
INDIVIDUAL
MAIN CHARACTERISTICS
LOCATION
PEOPLE INVOLVED
URBAN SPACE USE
ACTIVITIES
RESOURCES
Anderlech
Auderghem
Berchem-Sainte -Agathe
Bruxelles
Etterbeek
Evere
Forest
Ganshoren
Ixelles
Jette
Koekelberg
Molenbeek -Saint-Jean
Saint-Gilles
Saint-Josse -ten-Noode
Schaerbeek
Uccle
Watermael -Boitsfort
Woluwe -Saint-Lambert
Woluwe -Saint-Pierre
1 - 5
6 - 10
11 - 20
21 - 50
+50
Streets
Squares
Pedestrian walkways
Underdeveloped open spaces
Built facilities
Parks
Gardens
Nature reserves
Banks of water bodies
Resource harvesting
Knowledge sharing
Meeting and sharing
Working
Networking
Self-organization
Water
Energy
Solid Waste
OG01
OG02
OG03
OG04
OG05
Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)
Collective infrastructures CI
Networking platforms NP
Organized groups OG
Research studies RS

*Figure S4.4: Main characteristics of selected ARGS (Research Studies), including scale of intervention, type of stakeholder involved, location, number of people involved, type of urban space used, activities, and key resources managed.*

Collective infrastructures **CI**
Networking platforms **NP**
Organized groups **OG**
Research studies **RS**

Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)


SCALE OF INTERVENTION, SUPPORT, AND TYPE OF STAKEHOLDERS INVOLVED
REGION
MUNICIPALITY
NEIGHBORHOOD
HOUSEHOLD
INDIVIDUAL
MAIN CHARACTERISTICS
LOCATION
PEOPLE INVOLVED
URBAN SPACE USE
ACTIVITIES
RESOURCES
Anderlech
Auderghem
Berchem-Sainte -Agathe
Bruxelles
Etterbeek
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Forest
Ganshoren
Ixelles
Jette
Koekelberg
Molenbeek -Saint-Jean
Saint-Gilles
Saint-Josse -ten-Noode
Schaerbeek
Uccle
Watermael -Boitsfort
Woluwe -Saint-Lambert
Woluwe -Saint-Pierre
1 - 5
6 - 10
11 - 20
21 - 50
+50
Streets
Squares
Pedestrian walkways
Underdeveloped open spaces
Built facilities
Parks
Gardens
Nature reserves
Banks of water bodies
Resource harvesting
Knowledge sharing
Meeting and sharing
Working
Networking
Self-organization
Water
Energy
Solid Waste
RS01
RS02
RS03
Organized community (individuals, neighbors, other)
Non-governmental organizations
Design practitioners (architects, urban and landscape planners, designers)
Academia (universities, research institutes)
Government (municipal, regional)
Collective infrastructures CI
Networking platforms NP
Organized groups OG
Research studies RS

*Detachable metal structure and nature in the Botanical Park of Caracas, Venezuela. Photo by author, 2017.*

## *5 Urban Archetypes*

*Methods and tools to enhance UM applicability by design practitioners.*

*Abstract*

Recent studies demonstrate the value of applying urban metabolism (UM) approaches in urban design across various scales. However, the development of actionable design tools and guidelines based on these approaches remains limited, particularly for first-hand use by design practitioners, i.e. urban planners and designers, architects, researchers and activists, among others. This study aims to bridge this gap by introducing nine resource-sensitive and community-inclusive urban archetypes, supported by a UM analytical framework. These urban archetypes are based on the spatial characteristics of an inventory of alternative resource governance systems in both the Global South and Global North. The versatility of these urban archetypes is evident in their adaptability to diverse sites, geographical settings, and socio-economic contexts, as demonstrated by the selected projects. Furthermore, identifying the design tools used in these projects offers practitioners a tangible set of options that can be customized to meet the specific spatial and programmatic needs of future developments focused on resource efficiency and community involvement. The testing of three urban archetypes in a case study in Caracas, Venezuela, showcases their capacity for resource harvesting and their flexibility in creating functional meeting and working spaces within a real-world setting. This also highlights the potential spatial qualities that can be achieved by applying different configurations in response to specific programmatic scenarios or site conditions. The results of this study contribute to the ever-growing interest in the spatial dimension of UM and its practical application in the design of publicly accessible spaces which can enhance resource management efficiency while strengthening community involvement.

*Keywords*

*Sustainability, architecture, research by design, industrial ecology, informal settlements, circular economy.*

*This chapter is structured as an original research article to be published in a scientific journal. Parts of the research were presented as Otero Peña, D. & Perrotti, D. (2023). The Spatial Dimension of Urban Metabolism: A Design Atlas of Resource-Sensitive Urban Archetypes, at the 11th International Conference on Industrial Ecology (ISIE2023) of the International Society for Industrial Ecology in Leiden, Netherlands, and at EDRA54: Environment and Health: Global/Local Challenges and Actions in Mexico City, Mexico. These presentations highlighted the preliminary findings and insights, which provided the foundation for the more detailed analysis and discussion presented in this chapter.*

## *5.1 Introduction*

### *5.1.1 Spatial dimension of Urban Metabolism in urban design*

Urban centers currently house 55% of the global population, with this figure projected to rise to nearly 70% by 2050 (UN HABITAT, 2022). The rapid growth of urban areas, coupled with a lack of adequate planning, has led to a decline in the quality of life within cities, significantly affecting the public space network, water and energy systems, waste management, transportation, and other essential services (Akhtar et al., 2021; Kopittke et al., 2019; Mouratidis, 2021). These challenges contribute to the emergence of severe environmental issues, including global warming, the intensification of extreme weather events, water scarcity, air quality degradation, and biodiversity loss (IPCC, 2023). An urban metabolism (UM) framework for urban planning and design can be instrumental in helping decision-makers understand and evaluate the sociotechnical processes related to the collection and use of resources in urban environments (Kennedy et al., 2011; Perrotti & Stremke, 2018). By providing insights into the scale and dynamics of resource flows, this framework can facilitate more resource-efficient urban planning, the development of effective waste minimization strategies, and the identification of deficiencies in existing infrastructure, recognition of opportunities within urban spaces to mitigate resource-related vulnerabilities, and enhance local resource harvesting through spatial design strategies (Dijst et al., 2018; Furlan et al., 2022; Galan & Perrotti, 2019; Lanau & Liu, 2020; Otero Peña et al., 2022; Perrotti & Stremke, 2018; Stephan & Athanassiadis, 2018). The spatial dimension of UM has recently gained significant relevance by researchers focusing directly on power relations between stakeholders, organizational economics of supply chains, society-nature interactions, infrastructure governance and planning, and the spatially explicit modeling approach (Bahers et al., 2022). However, few studies have developed practical design tools or design guidelines based on UM frameworks that can be directly applied by design practitioners, i.e., urban planners and designers, architects, researchers, and activists, among others.

In recent years, design practitioners have increasingly adopted UM approaches to analyze and develop projects that integrate resource and waste management across various scales, from territorial to urban and infrastructural levels. A notable example is the *2014 International Architecture Biennial of Rotterdam*, where landscape architect James Corner (*Field Operations*) and urban design practice *FABRICations* led a multidisciplinary workshop involving governmental and other stakeholders to map and quantify resource and waste flows in Rotterdam (Tillie et al., 2014). The workshop produced four spatially explicit design scenarios, including strategies for sourcing raw materials from waste and food, enhancing urban nature through green infrastructure, developing a geothermal energy network for housing, and envisioning local-scale re-industrialization. Inspired by this initiative, *51N4E architects*, in collaboration with *FABRICations*, devised a sustainable strategic plan for Albania based on the nation's metabolic analysis (Brugmans et al., 2015). The study proposed coastal test cases as prototypes for potential projects, emphasizing frameworks for impactful interventions rather than fixed solutions. These initiatives aimed to harness existing resources and avoid reliance on imported models, promoting scalable investments that balance economic, social, and environmental needs.

On a more localized scale, the government of Flanders, Belgium, collaborated with architecture and urban planning firms *Architecture Workroom Brussels* and *1010au* to increase resource circularity in its ports (Tempst et al., 2019). This resulted in detailed urban design strategies that sought industrial synergies to optimize resource and waste management. Additionally, in an architecture renovation project, the socio-cultural organization *Zinneke*, along with the architectural firm *Ouest* and the design cooperative *Rotor*, renovated existing buildings for their headquarters in Brussels, guided by a strategic framework focused on recovering, reusing, and adapting building materials (Stoffen, 2020). The project innovatively treated the existing structure as a primary raw material, emphasizing dynamic design, adaptability, co-creation with stakeholders, and the infusion of local knowledge and craftsmanship. Despite the richness of these spatially explicit initiatives, the design outcomes were often framed within a top-down approach and lacked a clear methodology, which can make it challenging for other design practitioners to replicate them.

Recent UM research focusing on urban design has evaluated the metabolic impact of neighborhood scale renovation projects working with the designers (Doussard et al., 2024), introduced the digital twin interface approach to enhance analysis visualizations results and facilitate real-time modifications (Geremicca & Bilec, 2024), explored the potential decoupling of day-to-day design uses and needs from scientific and quantitative models (Pistoni & Bonin, 2017), emphasized the spatially structuring potential of technical infrastructures in energy transition scenarios (Juwet & Ryckewaert, 2018), and applied metabolic concepts to research by design applications within the framework of academic urban design and architecture studios (Baker-Brown & Brooker, 2024; Bortolotti et al., 2024; Grulois et al., 2018; Grulois et al., 2015; Marin & De Meulder, 2018). These studies demonstrate the value of applying metabolic frameworks in the application of urban design principles at different scales and suggest further research to increase collaboration between scientists and practitioners. However, they did not focus on the applicability of the results in practice or on identifying opportunities to clarify the connection between scientific research and practical aspects of urban planning and design (Perrotti, 2019). Additionally, the challenges in acquiring comprehensive datasets to analyze urban resource flows and stocks, combined with the limited time allocated for integrating metabolic strategies into urban planning and design processes and decision-making, have hindered the widespread adoption of UM by design practitioners (Longato et al., 2019; Wang et al., 2023).

Engaging key stakeholders and understanding their socio-ecological practices and resource-management activities in urban space at the local scale can significantly improve a community's resource use and illustrate to better understand spatial dynamics within vulnerable population groups (Acevedo-De-los-Ríos et al., 2024; Estrada et al., 2023; Guibrunet et al., 2017; Kaviti Musango et al., 2020; Liu & Iossifova, 2023; Nkrumah et al., 2023; Smit et al., 2019). These alternative resource governance systems (ARGS), i.e., publicly accessible spaces subject to a local-scale and community-led approach towards decentralized resource management, can help the development of local design strategies based on the stakeholders involved, socio-ecological practices observed, and resources managed (Perrotti, 2020). Additionally, previous studies have highlighted the crucial role design practitioners can play in creating new conditions for resilient living, emphasizing coexistence, co-production of spaces, collective governance, innovative knowledge forms, and political agency (De Muynck & Nalpas, 2021; Petrescu et al., 2016).

This study proposes that the identification and classification of resource-sensitive and community-inclusive urban archetypes from ARGS projects can guide design practitioners in developing  spatial design strategies for publicly-accessible spaces tailored to specific contexts and communities, ultimately contributing to the resource efficiency and community involvement in cities. In this research, urban archetypes are defined as design models characterized by a unique spatial configuration that can be replicated or adapted (Cerezo et al., 2017; Famuyibo et al., 2012), prioritizing resource-sensitive approaches to both form and function and seeking to improve urban quality and to foster community involvement. The identification and classification of urban archetypes, including typologies, prototypes, categories, and spatial configurations, have been longstanding methods employed by both academics and practitioners within the discipline of urban design (Foroughmand Araabi, 2016). For example, previous research has identified urban mechanisms in maker-space typologies to enhance circular production cycles tangibly (Elwakil et al., 2023), presented results from research by design prototypes and an inventory of existing projects for cool urban water environments (Cortesão et al., 2020; Requena-Ruiz et al., 2023), evaluated neighborhood typologies to assess solar performance indicators (Czachura et al., 2022), developed typologies of incremental design and construction in informal settlements (Kamalipour & Dovey, 2020), categorized public space typologies based on neighborhood park surroundings (Lee, 2019), and classified urban form types at the street level to measure the impact on pedestrian patterns and commercial activities (Thai et al., 2019). In the framework of a research by design project aimed at reducing the urban heat island effect through urban interventions on water bodies in the Netherlands, Cortesão et al. (2020) classified typical spatial configurations to be addressed in workshops with design practitioners. The results underscored the practitioners' acceptance of using testbeds both in this project and in future professional endeavors. The testbeds provided design guidelines that were sufficiently abstract to avoid being tied to a specific location, yet specific enough to clearly identify the type of water body being studied. This balance facilitated the replication and application of the guidelines across various contexts, enhancing their practical utility for urban design. Furthermore, the classification of urban manufacturing spaces at the local scale in seven European cities (Elwakil et al. (2023)) allowed to develop closed-loop scenarios within the city scale, facilitating symbiotic relationships as part of a larger circular urban production system.

Based on the above discussion, the aim of this study is to develop a design catalogue of resource-sensitive and community-inclusive urban design archetypes supported by an UM analytical framework. The design catalogue has been developed to address the following guiding research question: how can design strategies for publicly accessible urban spaces be developed taking into consideration the most common spatial characteristics of ARGS in both the Global South and North? This design catalogue is intended to serve as a practical tool for design practitioners, offering a series of examples that can be applied in the initial phases of urban design projects.

Having explored the relevance (and growing research interest) of incorporating the spatial dimension in UM frameworks and introduced the definition of resource-sensitive and community-inclusive urban archetypes used in this study, the reminder of this section will provide an overview of the selected testbed case study in Caracas, Venezuela. The methodology section details the online sources used for the ARGS projects selection, the approach used to classify these sources according to urban archetypes and the validation process, as well as the practical implementation within the case study. In the results section, the urban archetypes are identified, design tools for practitioners introduced, and their assessment and verification within the case study analyzed. These findings are illustrated through maps, diagrams, tables, and visual representations. The subsequent discussion section analyzes the results, highlighting the key characteristics of urban archetypes, their significant impact at the local scale, and their potential applicability in urban design, as well as the real-world implications they may generate. In the conclusion, directions for future research are provided.

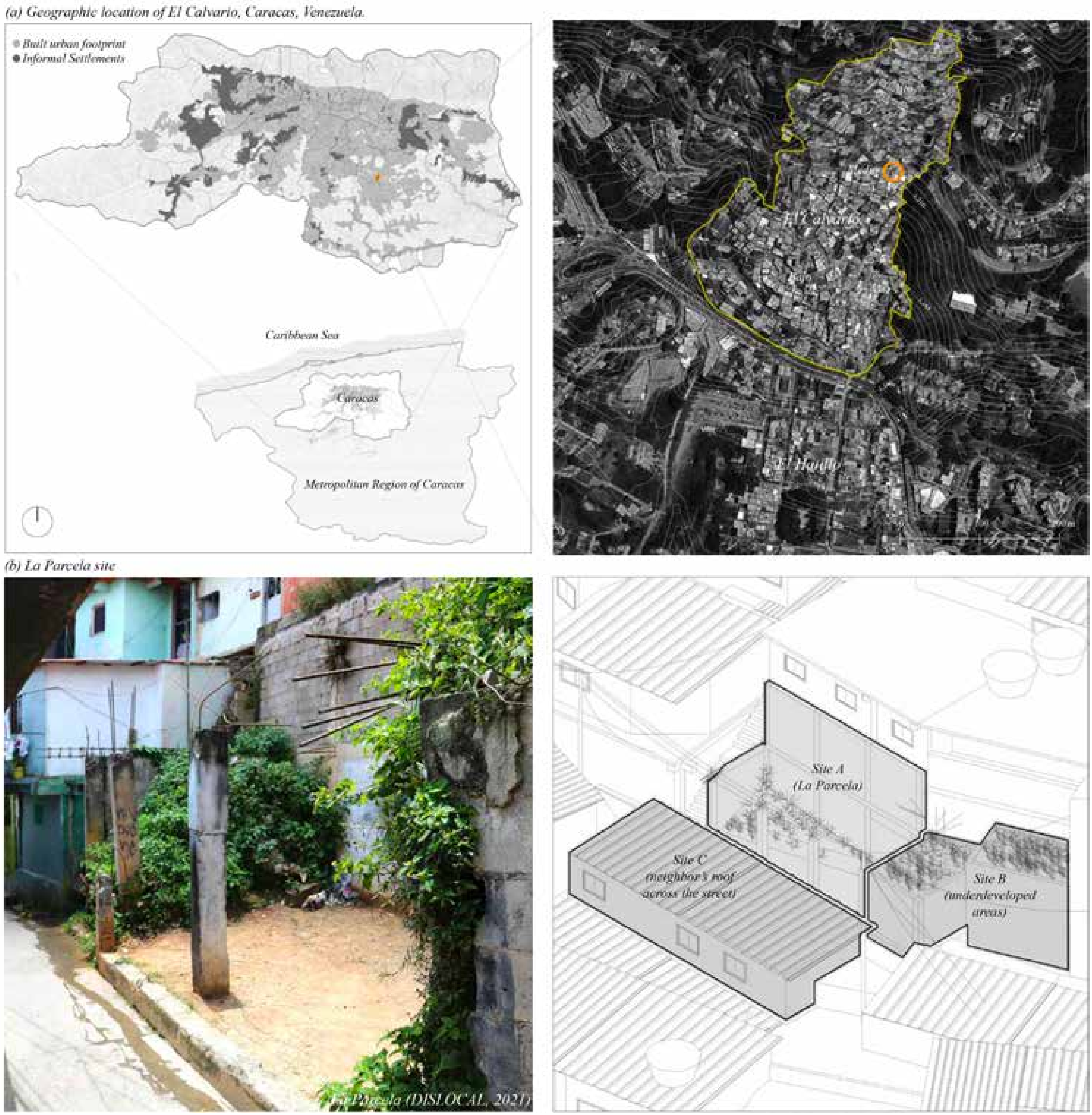



*Figure 5.1: (a) The geographic location of El Calvario informal settlement in Caracas, Venezuela. (b) La Parcela site in El Calvario Medio neighborhood (Site A), neighboring underdeveloped areas (Site B), and the roof of the house across the street, which belongs to the resident owner of La Parcela (Site C).*

#### *5.1.2 El Calvario, Caracas, Venezuela*

The community of *El Calvario* is located over 1100 meters above sea level in the southeastern part of Caracas within the municipality of *El Hatillo* (see *Figure 5.1a*). This informal settlement has a population density of 2,800 inhabitants per square kilometer and despite the steep topography, *El Calvario* is well-connected with the surrounding region by a network of roads and stairways that facilitate its accessibility (CCS city, 2020). The area features a mix of residential housing, stores, and public services, and benefits from its strategic location near the historic center of *El Hatillo*. Although almost all households are connected to drinking water, sewage, and electricity networks, the operating conditions are unreliable and the distribution is not equitable, mainly due to the presence of unplanned informal networks in certain areas which contribute to frequent electricity interruptions and significant potable water losses, among other challenges (Martinez et al., 2013). Waste collection in the community is organized through designated collection points located along the main avenues on the periphery. However, waste collection services are hindered by narrow roads, leading to the accumulation of illegal dumps in certain areas of the community (Bolívar et al., 2012). The climate is tropical, characterized by warm temperatures throughout the year and a rainy season that extends from May to November. The community is renowned for its active and participatory spirit, hosting cultural events that enhance the sense of belonging among its residents (García Alcaraz, 2024). Additionally, *El Calvario* has a vibrant commercial environment due to its proximity to the main avenue connecting the southern and northern parts of the city.

In 2021, the *DISLOCAL* architecture platform organized a workshop for architecture and urban planning students to collaborate with *El Calvario* community, alongside both local and international tutors, including the first author. The workshop focused on urban analysis of the settlement and developing proposals to improve public space and resource management within the neighborhood. The workshop's result highlighted several resource management issues within the community, such as the lack of access to drinking water for some residents, frequent disruptions of the electricity provisioning system, and inadequate waste management infrastructure, among others. Additionally, the workshop identified potential intervention sites and specific spatial programs required by the community for future projects. One of the identified sites, *La Parcela*, is a small, narrow, and elongated plot owned by a resident of *El Calvario Medio* (see Figure 1b).

In early 2024, meetings were held between the community and *DISLOCAL* to discuss the outcomes of the workshop. As a result, both parties agreed to explore funding opportunities for developing together a community center at one of the previously identified sites. The residents collectively decided to use *La Parcela* site for the construction of the facility, with the stipulation that a rental space had to be included for the personal use of the plot owner, either as a residence or commercial space. Additionally, the community emphasized the importance of using local construction materials and incorporating enclosed spaces for community meetings, woodworking workshops, and community gardens for food production as key components of the project. Furthermore, discussions explored the possibility of expanding the project to adjacent underdeveloped areas (i.e., public or private unused urban space such as brownfields, vacant lots, and abandoned buildings), including neighboring vacant lots and the rooftops of nearby buildings. These additional spaces could accommodate alternative programmatic scenarios linked to urban agriculture initiatives and a music school affiliated with *El Sistema*, a nationwide Venezuelan cultural and social program fostering symphonic music education to children in vulnerable communities (Stainova, 2021).

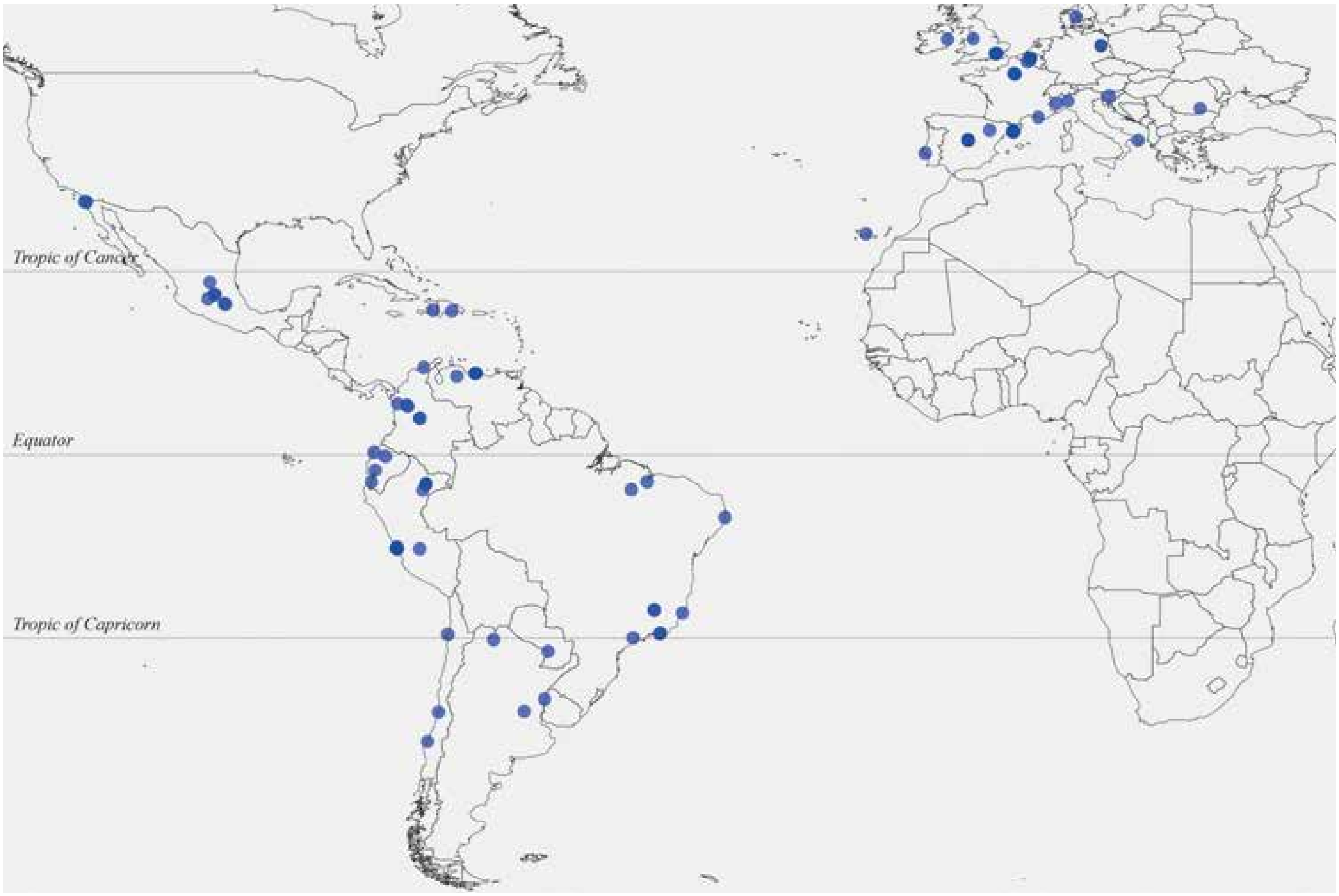
*El Calvario* is an ideal case study for testing and developing the resource-sensitive urban archetypes due to several key factors. The community's challenges with vulnerable accessibility and unreliable infrastructure for drinking water, sewage, and electricity provide a critical context for exploring innovative solutions. Additionally, the active participation of residents in public space demonstrates a high level of community engagement, which is essential for ARGS projects. Moreover, the availability of a site within the area offers a valuable opportunity to experiment with and implement urban design scenarios. Leveraging these factors, *El Calvario* can serve as an ideal testbed for developing and refining approaches to infrastructure and resource management. It also offers an opportunity to analyze potential community center solutions and other programmatic scenarios that could be implemented in *La Parcela* site, while also providing valuable insights and models for other communities facing similar challenges.

## *5.2 Methodology*

### *5.2.1 ARGS projects in Europe and Latin America*

The first stage of the methodology involved the selection of ARGS projects to provide a basis for the creation of a design catalogue of urban archetypes. Building on the identification of ARGS projects by Otero Peña et al. (2025), the study compiled and analyzed ARGS based on the following criteria: projects were designed and implemented by design practitioners, located in publicly accessible spaces, and led or co-led by citizen collectives to manage key resources in a community. To ensure a diversity of spatial configurations shaped by varying socio-economic and geographic contexts, the study focused on two regions representative of the Global South and Global North: Latin America and Europe. Among the selected 104 ARGS projects to assess, 57 were located in Latin America (spanning 37 cities accorss 10 countries) and 47 were situated in Europe (covering 26 cities across 11 countries), thereby ensuring a wide range of geographic and socio-economic contexts in both the Global South and Global North, see *Figure 5.2*. This comprehensive approach enabled the identification of the urban archetypes used within these spaces, a detailed examination of their spatial contexts, and an in-depth analysis of their primary characteristics.

Projects were selected through a systematic review of two types of online sources oriented to architecture, urban design, and landscape architecture professionals: project dissemination platforms and design awards. The selection criteria for these sources included the availability of their virtual catalogs, the number of projects exhibited, and their relevance within the professional community in the regions studied. For project dissemination platforms, the focus was placed on *archdaily.com* and its Spanish and Portuguese versions, *archaaily.cl* and *archaaily.br*, respectively. These platforms were selected since they feature among the most visited online sites for design practitioners, showcasing a continuously updated database on a daily basis, including over one hundred thousand projects each (Fishmotion, 2023; Roudbari, 2018). Regarding the design awards, the focus was placed on the Ibero-American Biennial of Architecture and Urbanism (*bienaliberoamericana.org*), the Pan-American Biennial of Architecture of Quito (*bac-cae.ec*), the Venice Biennial of Architecture (*labiennale.org*), the European Union Prize for Contemporary Architecture (*miesarch.com*), the Mies Crown Hall Americas Prize (*mchap.co*), the European Prize for Public Space (*publicspace.org*), and the Landezine International Landscape Award (*landezine-award.com*). These awards were chosesn because of the availability of their online catalogs and the amount of grassroot type of projects exhibited in recent years within the geographic areas analyzed. *Table S5.1* in the *Supporting Material* provides further details on the data sources. The research process involved analyzing the titles, texts, and figures of projects to ensure their selection in the research. Additionally, the websites of the design practitioners involved with the selected ARGS projects were reviewed to identify other relevant projects in addition to those found in the initial systematic review. Data collection was conducted between September and November 2023, and July and August 2024.




***ARGS projects distribution. Total number of projects (104).***
***Latin America (57):*** *Argentina: Caimancito (1), Concordia (1), Rosario (1). Brazil: Belo Horizonte (2), Bom Jesus das Selvas (1), Recife (1), Rio de Janeiro (2), Sao Paolo (1), Vitoria (1), Vitória do Mearim(1). Chile: Concepción (1), Mejillones (1), Valparaiso (1). Colombia: Bogotá (2), San Jerónimo (1), Medellin (1), Vigia del Fuerte (1), Guajira (1). Dominican Republic: Sto. Domingo (1). Ecuador: Samborondón (1), San José de Chamanga (1), Huaquillas (1), Quito (1). Haiti: Port au Prince (1). Mexico: Mexico City (2), Piñicuaro (1), Querétaro (2), San Luis de Potosi (1), Tijuana (2). Paraguay: Asunción (1). Peru: Iquitos (3), Lima (8), Loreto (1), Tanquin (1). Venezuela: Caracas (7), Barquisimeto (1).*
***Europe (47):*** *Belgium: Brussels (11), Mons (1). Denmark: Aarhus (1). France: Colombes (1), Courbevoie (1), Marseille (1), Paris (2). Germany: Berlin (2). Ireland: Dublin (1). Portugal: Lisboa (1). Italy: Lecce (1), Milano (1), Turin (1). Romania: Bucharest (1). Spain: Barcelona (2), Caldes de Montbui (1), Madrid (6), Rubi (1), Santa Cruz de Tenerife (1), Zaragoza (1).Slovenia: Ljubljana (1). United Kingdom: Westminster (1), Liverpool (1), London (6).*

*Figure 5.2: Distribution the selected 104 ARGS projects in Latin-America and Europe.*

### *5.2.2 A design catalogue of Urban Archetypes (classification and definition)*

Based on the results from the analysis of ARGS projects, a classification system was developed to define urban archetypes and their potential spatial variations, culminating in the development of a design catalogue. Each urban archetype was examined in relation to its main spatial and programmatic characteristics: location, type of context and urban space used, scale, type of access, stakeholders involved, governance structures, resource management practices, activities and practices held by the community, and type of community involvement. The context and type of urban space in which the archetypes can be implemented encompass a diverse range of physical environments, including urban city centers, urban and rural peripheries, and informal settlements. Within these contexts, the urban space used by the archetypes include both underdeveloped areas, such as vacant lots, grass fields, commons, brownfields, and abandoned buildings, and established open spaces, such as parks, gardens, squares, and streets. To assess their spatial impact, projects were classified according to their scale into small (less than 100 m²), medium (101 to 400 m²), large (400 to 6,000 m²), and extra-large (more than 6,000 m²). The level of accessibility was classified with distinctions made between public spaces (e.g., squares and parks), semi-public spaces (e.g., community gardens with scheduled open hours), and semi-private spaces (e.g., publicly accessible areas within private and institutional buildings, also regulated by specific opening hours). Stakeholders involved include individuals, NGOs, academic institutions, public agencies, private sector actors, municipal and regional governments, international organizations, and design practitioners. The governance structures guiding these initiatives include organized groups managing public space interventions, collective infrastructures providing publicly accessible areas, academic research studies adopting multi-scale and multi-disciplinary approaches, and networking platforms that operate as virtual spaces to facilitates the clustering of resource management activities. Resource management strategies implemented within the archetypes focus on the harvesting, storage, and treatment of water (rainwater harvesting, infiltration systems, and treatment processes), energy (electricity generation through photovoltaic panels and biogas production), and solid waste (community composting systems and recycling centers). Community involvement takes various forms, including direct participation in resource management initiatives (e.g., community composting, collective laundries), social engagement practices (e.g., meal preparation using anti-waste techniques, barter-based material warehouses), educational programs (e.g., environmental workshops for children, gardening training sessions), recreational opportunities (e.g., play libraries, playgrounds), cultural initiatives (e.g., local exhibitions, documentation of folkloric traditions), and activist practices (e.g., political participation guerrilla gardening). These characteristics of urban archetypes are intended to define design principles based on the degree of resource efficiency and community involvement required in future projects. For instance, projects prioritizing resource efficiency can incorporate archetypes variants with a higher proportion of resource-harvesting areas and working spaces relative to meeting spaces for recreation. Conversely, projects emphasizing community involvement can feature archetype variants with a greater proportion of spaces dedicated to meeting, recreation, knowledge exchange, and cultural dissemination in relation to resource management functions.

#### *5.2.3 Practical implementation and testing of urban archetypes*

The adaptability and applicability of the design catalog was assessed through its implementation in the case study at *La Parcela* in *El Calvario*. This process was informed by previous meetings between *DISLOCAL* and the local community, which led to the definition of three programmatic scenarios, three site boundaries, and the architectural construction material principles. Additionally, three urban archetypes were selected based on their compatibility with the specific urban conditions of the site, namely, its narrow configuration with two blindsides and adjoining access pathways without any direct contact or support with any public or private equipment. This evaluation aimed to determine the qualitative and quantitative potential of each urban archetype in terms of resource efficiency and community involvement. To achieve this, the following key metrics were analyzed: *i*) total new urban space created was calculated (differentiating among meeting spaces, workspaces, harvesting spaces, rental spaces, technical spaces, and circulation), *ii*) total value of rainwater that could be collected and stored from roofs and overhead surfaces , *iii*) estimated electricity generation from installed solar panels, *iv*) total mass of organic waste treated based on composting capacity, *v*) and maximum number of users and visitors was estimated based on the architectural program developed.

The programmatic scenarios explore how the urban archetypes could be effectively applied and integrated into the local environment based on the community requirements and the design principle of resource efficiency and community involvement desired. The first programmatic scenario corresponds to a more resource-efficient program, for this purpose it was planned to develop an urban farm that maximizes resource harvesting capacity by integrating collective gardens, indoor farming, and a polyvalent space for markets. The second programmatic scenario addresses the need for a community center with polyvalent spaces, workshops, collective gardens, and a rental space, seeking a balance between resource efficiency and community involvement. The third programmatic scenario corresponds to a program aimed at integrating a larger number of people from the community and specific spatial requirements. To this end, a music school for children was envisioned to include a multi-purpose meeting space, workshops, and rehearsal rooms. *Tables S5.2* in the *Supporting Material* provides details of all spatial requirement for each programmatic scenario, including the most suitable square meters per space and per user type. The defined site boundaries include three variations: the vacant *La Parcela* site on its own, an expanded version that incorporates the adjacent undeveloped areas, and a third option that adds the use of the roof of the house across the street, which is owned by the resident owner of the plot (see *Figure 5.1b*). The architectural and constructive principles to be used for the spatial configurations resulted from continued discussion between the community and *DISLOCAL*, including decision upon the optimal use of local materials and construction techniques. This involved proposing steel and reinforced concrete for structural elements, corrugated steel and polished cement finishes for floors, clay blocks with frieze for partition walls, and metal carpentry for stairs and façades, among other construction components. This approach allowed us to test the feasibility, effectiveness, and spatial quality of twenty-seven spatial configurations to guide urban development in a real environment.

### *5.3 Results*

#### *5.3.1 Nine Urban Archetypes: a design catalogue*

An analysis of the design schemes of the selected 104 ARGS projects led to the identification of nine urban archetypes that respond to the different spatial configurations used by design practitioners: *Adaptive Grounds*, *Covered Surfaces*, *Shaped Volumes*, *Modular Units*, *Vertical Stackings*, *Mobile Artifacts*, *Networking Systems*, and *Hybrid Spaces* (see *Figures 5.3a, 5.3b, and 5.3c*). Each analyzed ARGS project was then associated to one or more archetypes, which allowed to recognize common spatial patterns and, in some cases, resource-sensitive forms and functions as a means to enhance urban quality and community involvement. All ARGS projects were systematically classified in an inventory according to their urban archetype and corresponding variant. Each entry includes key details such as the name of the project, description, year of construction, location, urban space used, access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved (see *Figure 5.4*). See *Tables S5.3a-S5.3D* in the *Supporting Material* for the complete detailed tables.

*Adaptative Grounds* (25 projects) are spaces where the horizontal surfaces and topography are used as the main architectural tools to generate inhabited spaces or to delimit spatial functions. The floor limits are managed to create spaces that adapt to the height differences proposing a variety of programs (e.g., collective gardens, urban farms, slope stabilization infrastructure, and water retention parks). *Covered Surfaces* (8 projects) are open spaces that are largely covered by a temporary or permanent canopy, including enclosed spaces within them (e.g., covered community spaces, collective gardens, and recycling centers). *Shaped Volumes* (16 projects) are temporary or permanent structures, with a wide variety of shapes and sizes that protect from climatic elements (e.g., pavilions, winter gardens, and greenhouses). *Modular Units* (12 projects) are spaces created from construction systems composed of separate elements that can be connected while preserving proportional and dimensional relationships. The small-scale spaces can vary in their dimensions and shapes as long as they comply with a series of rules that are incorporated from the very beginning of the design process (e.g., community equipment such as kitchens and gardens). *Vertical Stackings* (12 projects) are superimposed volumes one on top of the other to generate vertical spatial relationships and maximize the density of the parcel (e.g., cultural facilities, workshops, and recycling centers). *Symbiotic Structures* are open or closed spaces that are attached to an existing building or structure. These spaces are often dependent or interdependent on pre-existing structures and may be located on the sides, above, or below the existing construction (e.g., community spaces inside abandoned buildings and rooftop gardens). *Mobile Artifacts* (6) are small-scale structures on wheels or floatable structures, which allow movement within a given territory (e.g., floatable greenhouses and wood workshop trailers). *Network Systems* (6) are spaces created by the merging of a set of built spaces that are interdependent between them, clearly delimiting the area of intervention and hierarchizing the spaces (e.g., constructed wetlands, urban parks, and cultural complexes). *Hybrid Spaces* (9) are spatial structures combining multiple types of urban archetypes (e.g., urban farms and cultural facilities).

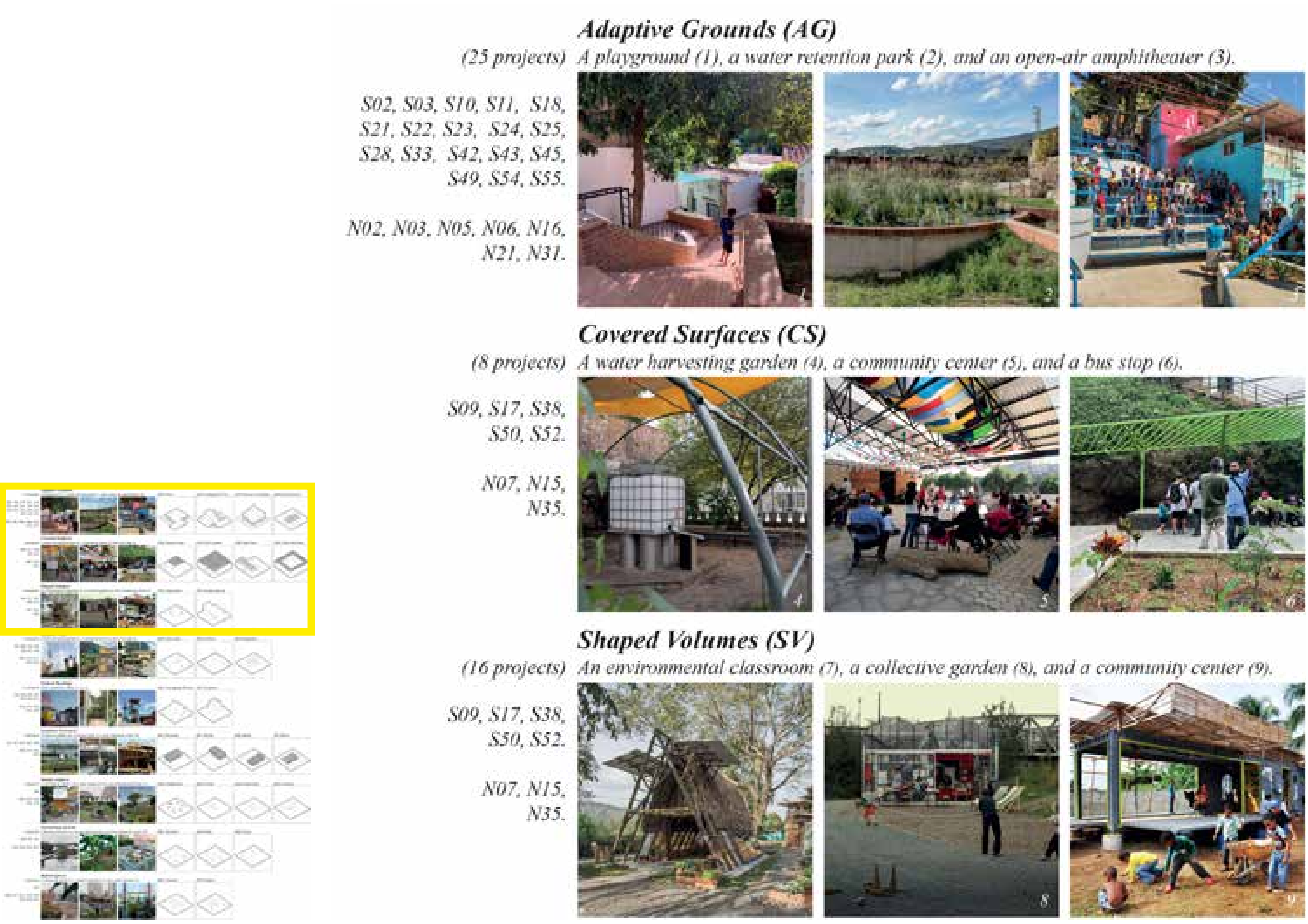
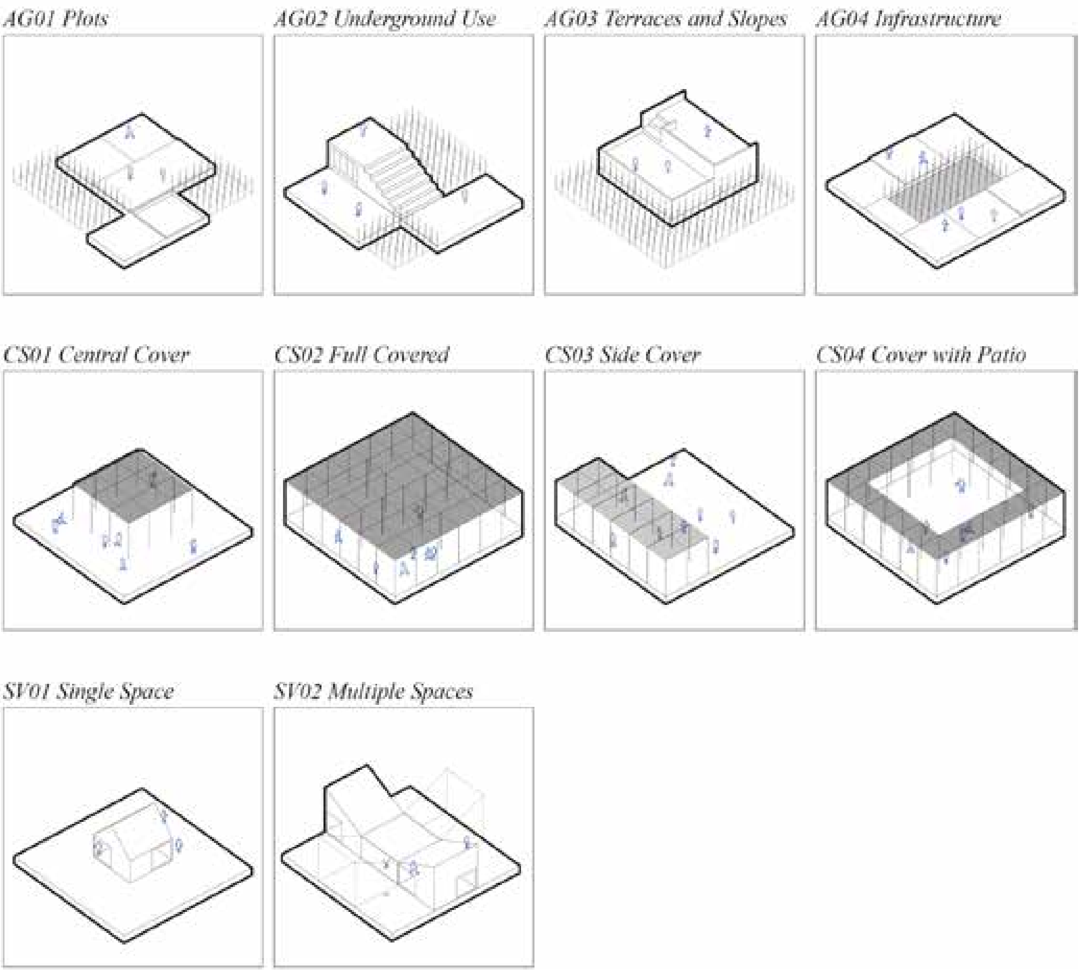



*Figure 5.3a: Nine urban archetypes including the number of identified ARGS projects, a selection of references, and their spatial variations (see Table S5.7 in the Supporting Material for the sources of the photos used as references.*


AG01 Plots
AG02 Underground Use
AG03 Terraces and Slopes
AG04 Infrastructure
CS01 Central Cover
CS02 Full Covered
CS03 Side Cover
CS04 Cover with Patio
SV01 Single Space
SV02 Multiple Spaces

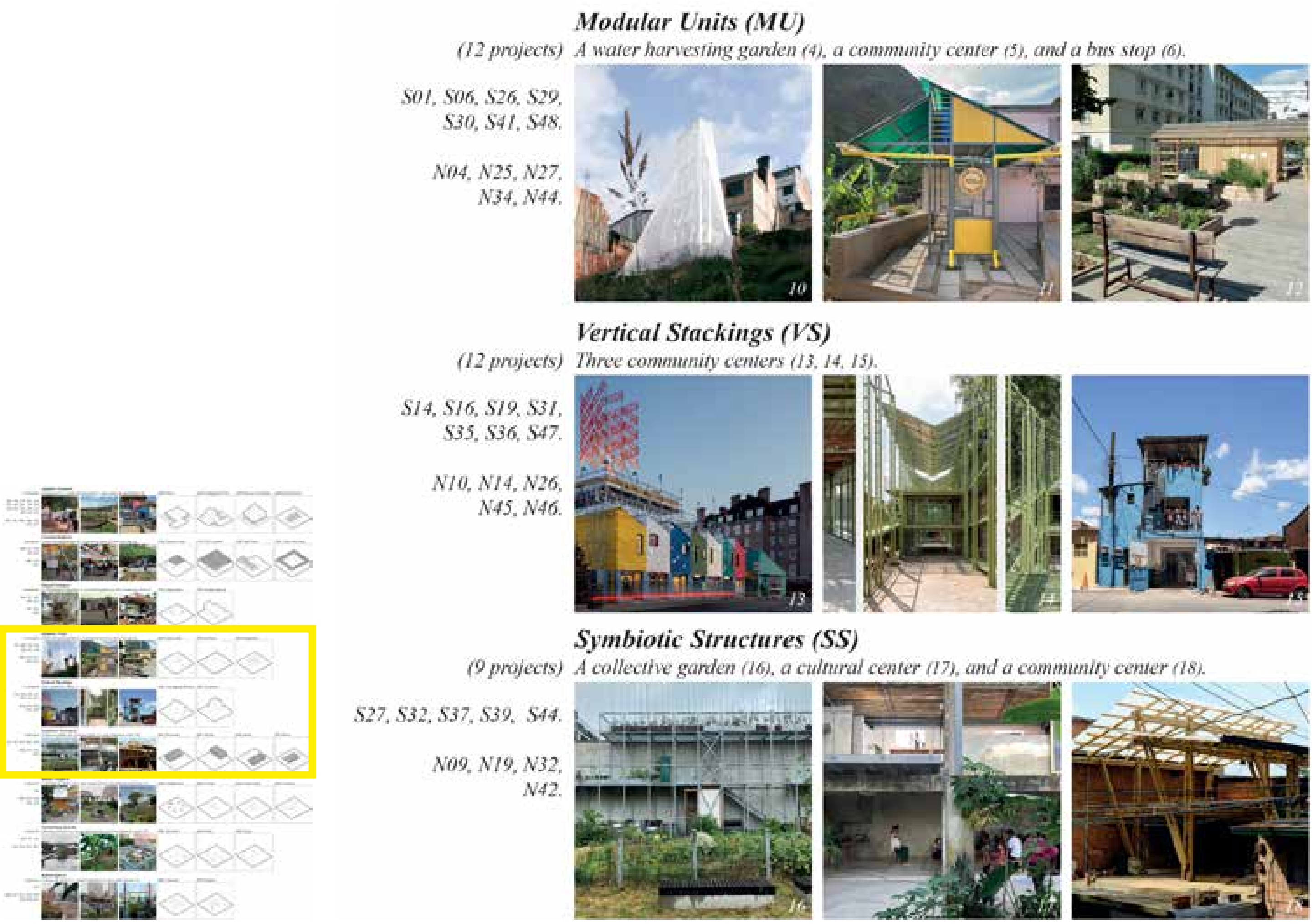
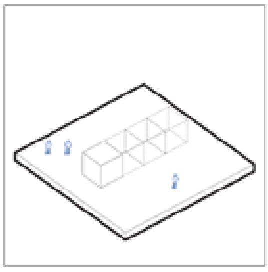
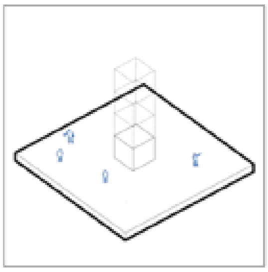



*Figure 5.3b: Nine urban archetypes including the number of identified ARGS projects, a selection of references, and their spatial variations (see Table S5.7 in the Supporting Material for the sources of the photos used as references.*

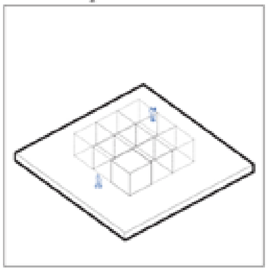
*MU01 Horizontal*



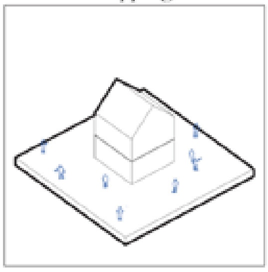
*MU02 Vertical*



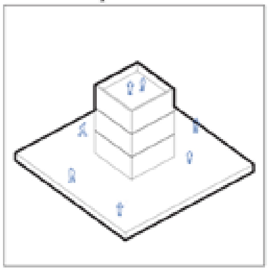
*MU03 Repetitive*



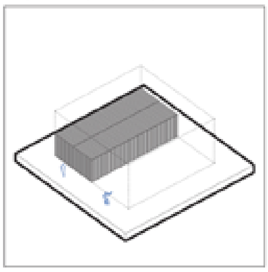
*VS01 Overlapping Volumes*



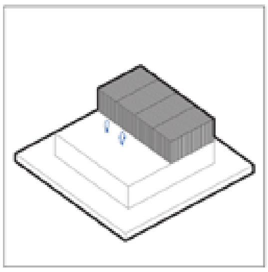
*VS02 Viewpoint*



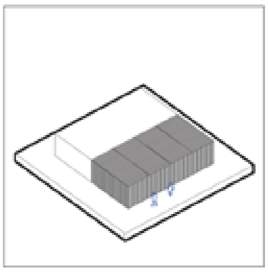
*SS01 Horizontal*



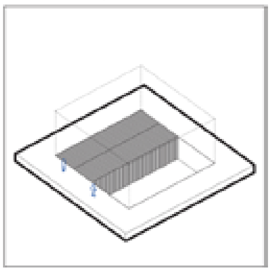
*SS02 Vertical*



*SS03 Beside*



*SS04 Below*



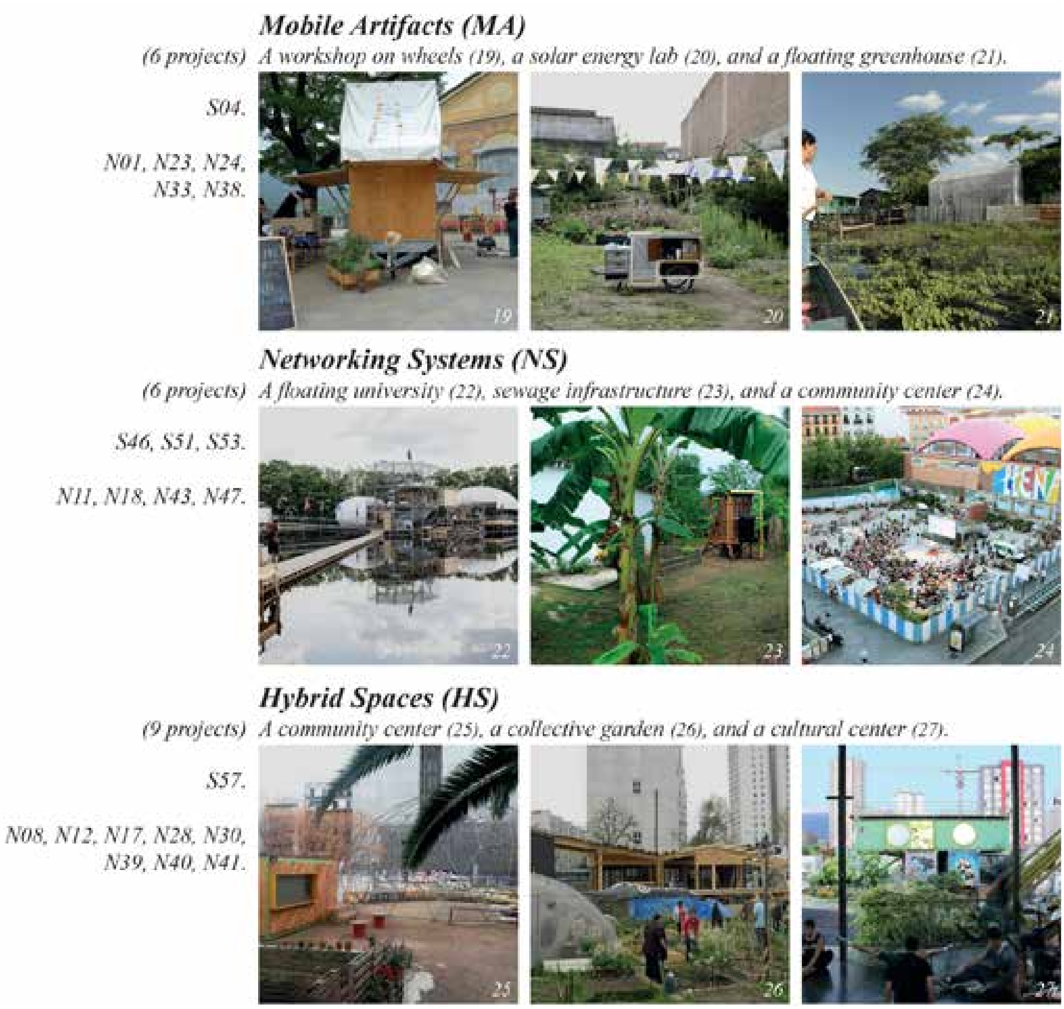
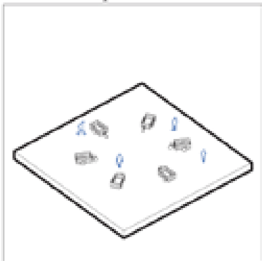
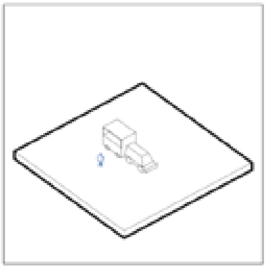



*Figure 5.3c: Nine urban archetypes including the number of identified ARGS projects, a selection of references, and their spatial variations (see Table S5.7 in the Supporting Material for the sources of the photos used as references.*

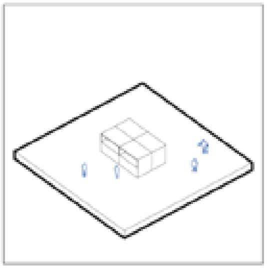
*MA01 Independant*



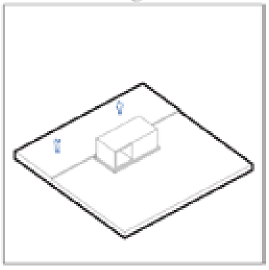
*MA02 Trailer*



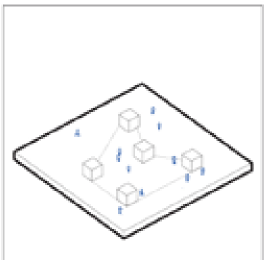
*MA03 Detachable*



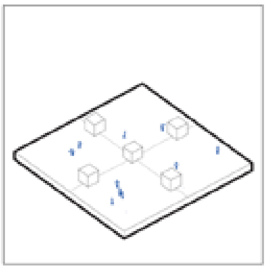
*MA02 Floating*



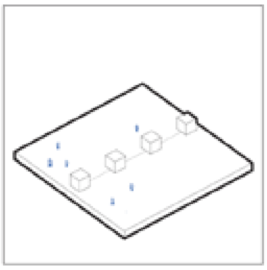
*NS01 Perimeter*



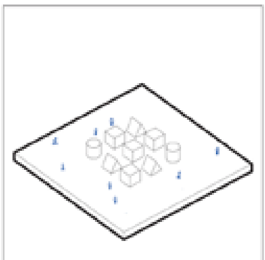
*NS02 Nodal*



*NS03 Linear*



*HS01 Scattered*



*HS02 Merged*

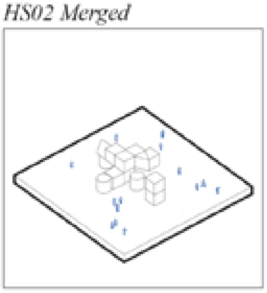
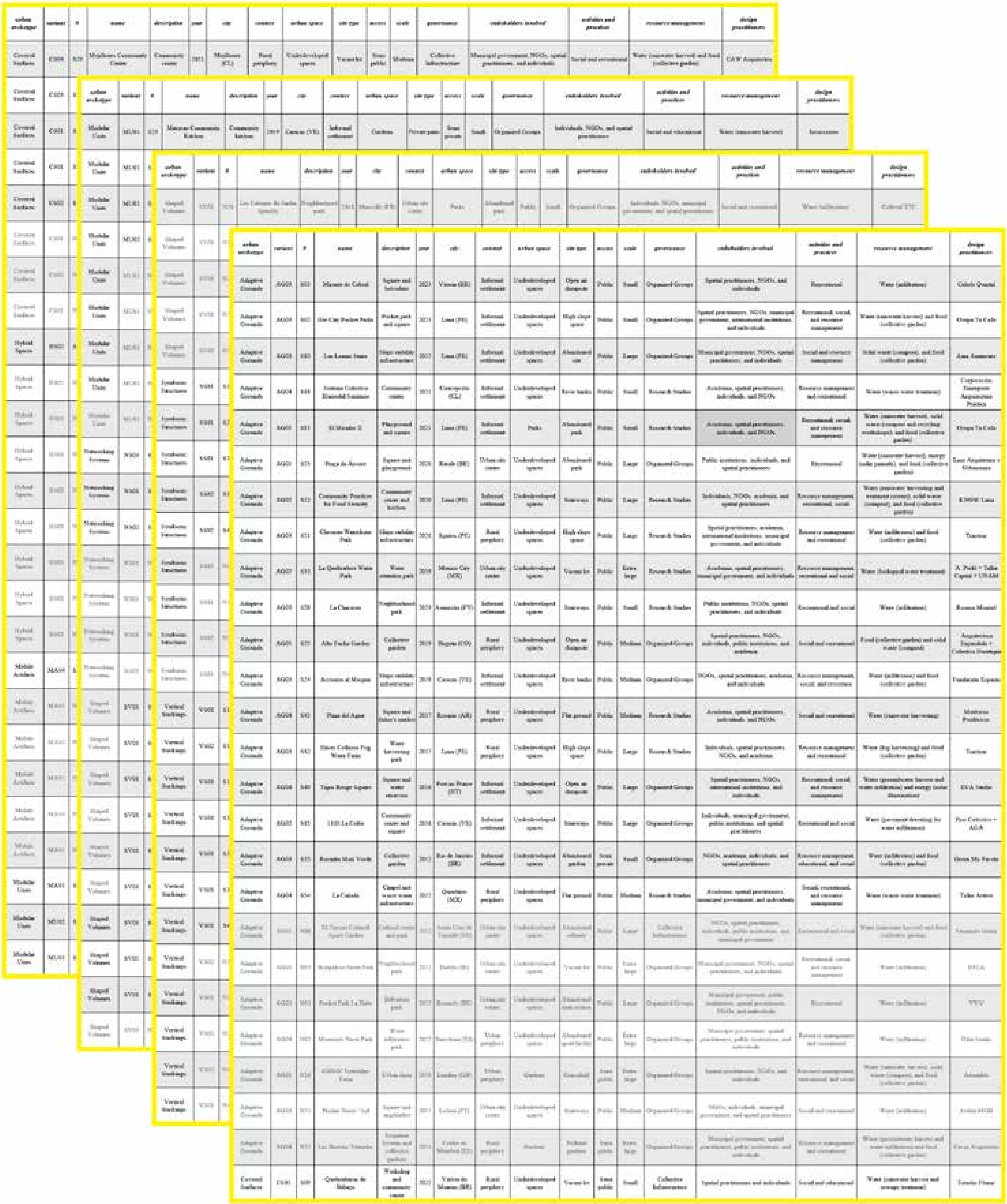


*Figure 5.4: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. See Tables S5.3a—S5.3h in the Supporting Material for the complete detailed tables.*



### *5.3.2 Main characteristics and design tools of Urban Archetypes*

*Figure 5.5* provides some grounding and key characteristics of the nine urban archetypes as represented by the analyzed 104 ARGS projects. Overall, the nine urban archetypes are spread out in similar proportions in Europe and Latin America. However, more than three-quarters of the *Mobile Artifacts* and *Hybrid Spaces* are concentrated in the Global North and more than two-thirds of the *Covered Surfaces* and *Adaptive Grounds* are in the Global South. 75% of the projects are located in cities (and one third of these are located in informal settlements). More than three quarters of all urban archetypes represented were developed in underdeveloped areas. *Shaped Volumes* and *Covered Squares* have almost half and one-third of their projects located in public open spaces, respectively. More than 75% of *Vertical Stackings* and *Symbiotic Structures* have controlled access (e.g., spaces with opening hours or spaces intended for specific users), while all *Network Systems* and almost all *Adaptive Grounds* and *Hybrid Spaces* have public access. 40% of all ARGS projects include rainwater harvesting and storage systems, 24% include solid waste treatment systems, and 20% include both. However, only 13% include energy production systems. Two thirds of the urban archetypes represented are medium and small scale and are mostly concentrated in *Vertical Stackings*, *Shaped Volumes*, *Modular Units*, *Mobile Artifacts* and *Covered Surfaces* classifications. The urban archetypes that concentrate large and extra-large scale projects are *Adaptive Grounds*, *Hybrid Spaces* and *Network Systems*.

*Figure 5.6* illustrates and classifies the primary spatial design tools used for resource management and community involvement by urban archetype. The main groups related to resource management (water, energy, and solid waste) and community involvement were identified. Each group was further classified according to the specific resource management processes or social-ecological practices carried out. For drinking water and wastewater management, the design tools were classified into collection (e.g., rainwater harvesting systems, fog catchers), infiltration (e.g., permeable surfaces), retention (e.g., vegetation, water ponds), and treatment (phytotreatment plants, channeling to main sewers). Energy management tools were classified into production (e.g., electrical energy from photovoltaic panels, biogas from anaerobic digestion) and sharing (e.g., shared electrical power points, drying common spaces). Solid waste management processes included reuse (e.g., compost, material transformation workshops) and storage (e.g., waste sheds for recycling and collection). Socio-ecological practices related to community involvement were categorized into meeting spaces (e.g., indoor spaces, playgrounds), knowledge sharing (e.g., pedagogical gardens, construction prototypes), networking (e.g., bulletin boards, mobile units), and working (e.g., greenhouses, workshops).

Based on the identified urban archetypes, their main characteristics, and the design tools used, set of design principles were derived to develop urban spaces with greater resource efficiency or greater community involvement (see *Figure 5.7*). For example, a more resource-efficient space could result from selecting the most appropriate urban archetype for the site under development (considering factors such as site type and geographic characteristics) and from incorporating a maximum number of design tools for resource harvesting and waste treatment in this archetype. For spaces aimed at fostering greater community involvement, it is essential to choose the most suitable urban archetype for the implementation of meeting areas, workspaces, knowledge-sharing venues, and other community-oriented functions, thereby achieving optimal design quality and enriching community spaces.

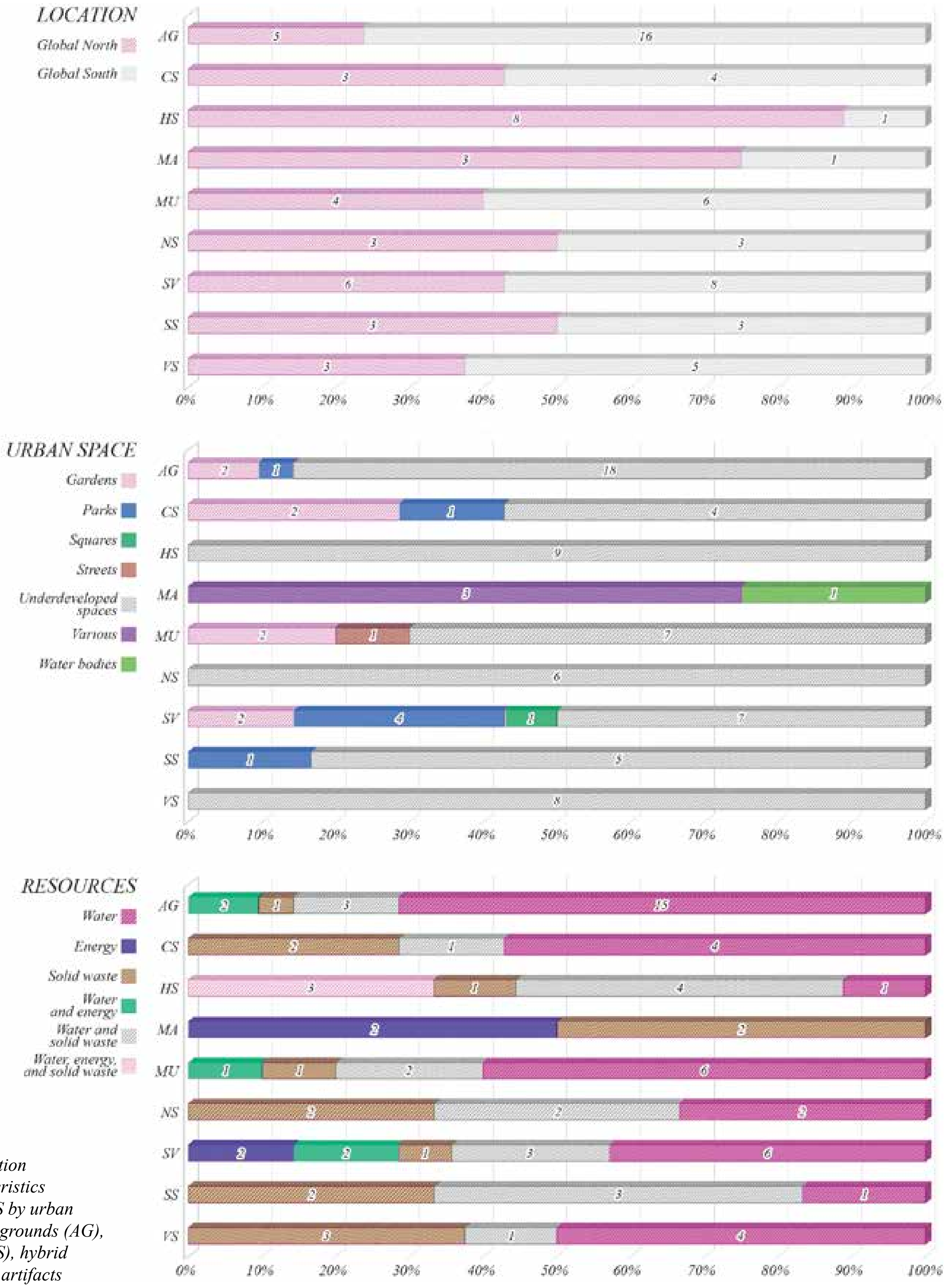
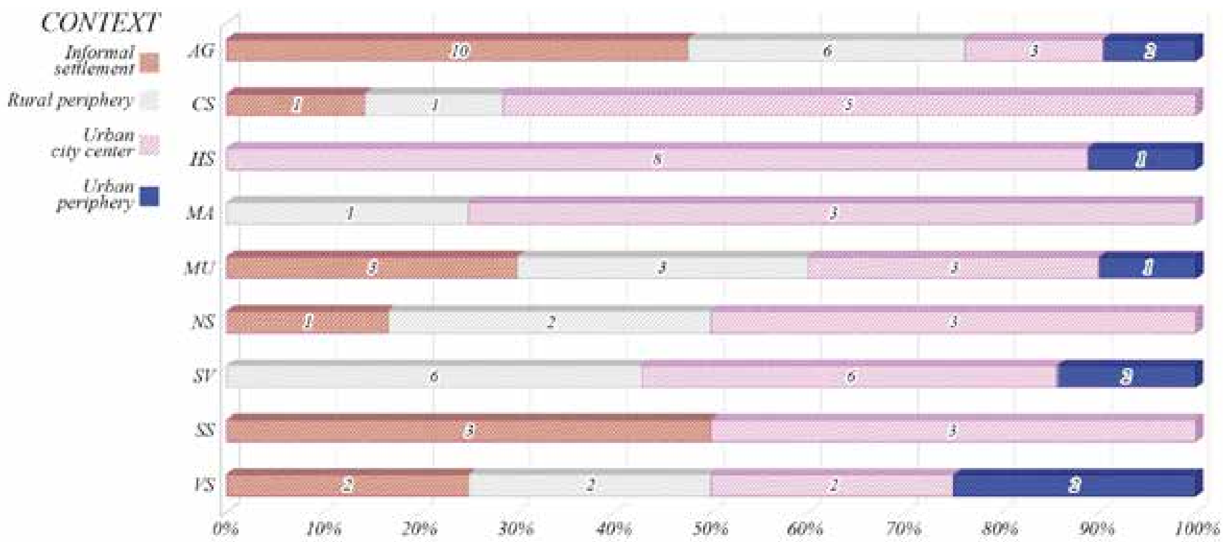
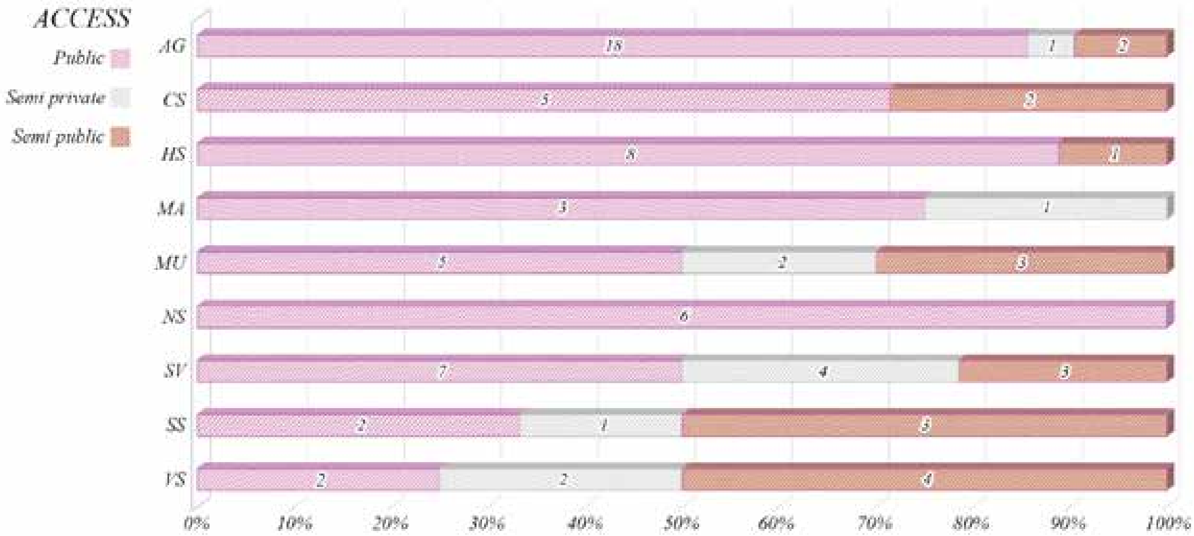



*Figure 5.5: Distribution of the main characteristics of the selected ARGS by urban archetype: adaptive grounds (AG), covered surfaces (CS), hybrid spaces (HS), mobile artifacts (MA), modular units (MU), networking systems (NS), shaped volumes (SV), symbiotic structures (SS), and vertical stackings (VS).*

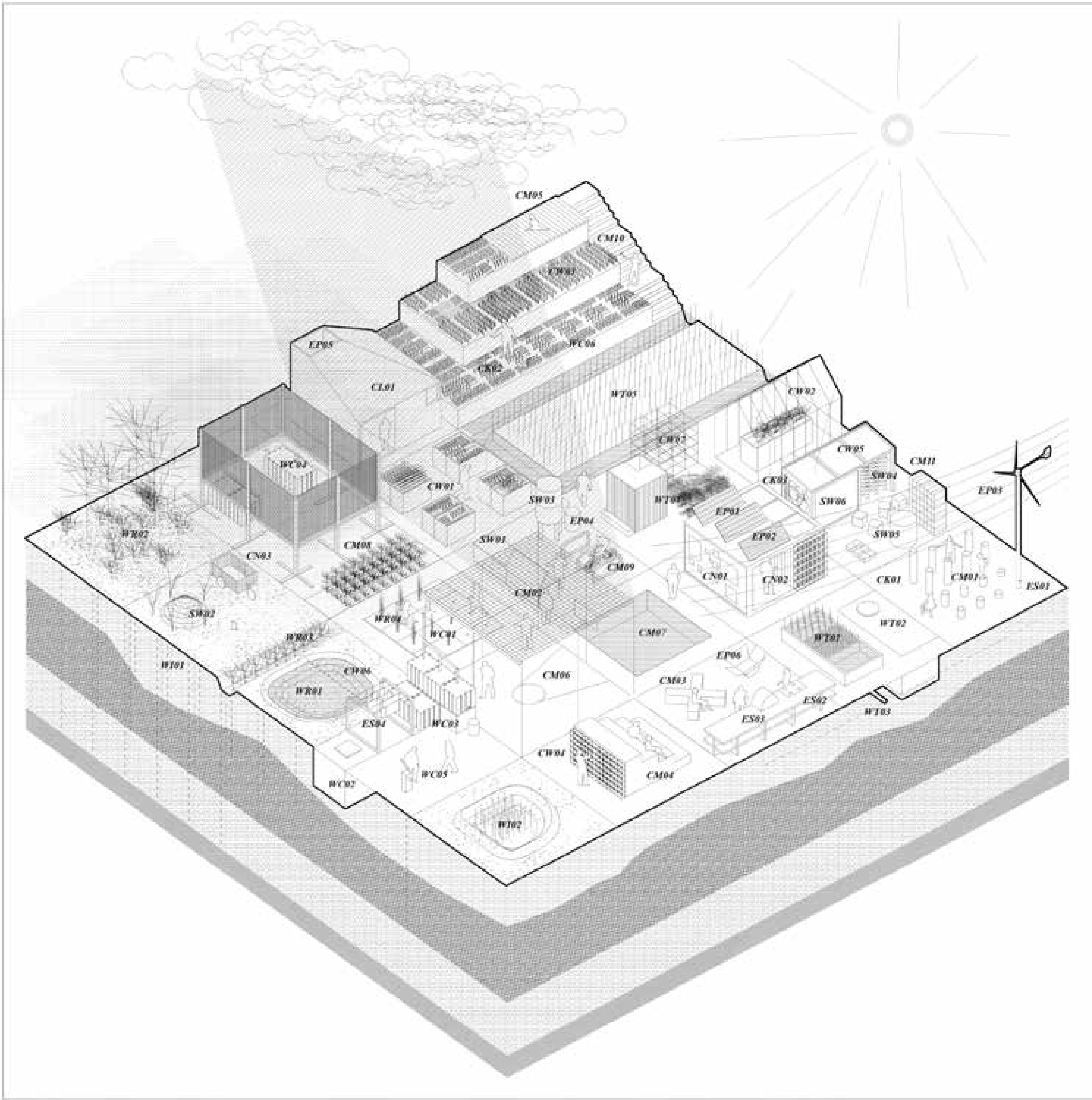

CONTEXT
Informal settlement
Rural periphery
Urban city center
Urban periphery
AG
CS
HS
MA
MU
NS
SV
SS
VS
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


ACCESS
Public
Semi private
Semi public
AG
CS
HS
MA
MU
NS
SV
SS
VS
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


SCALE
Extra-large
Large
Medium
Small
AG
CS
HS
MA
MU
NS
SV
SS
VS
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

| # | Clusters | Processes | Tools | AG | CS | SV | MU | VS | SS | MA | NS | HS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *WC01* | Water | Collection | Rainwater harvesting systems from roofs | - | x | x | x | x | x | x | x | x |
| *WC02* | Water | Collection | Underground rainwater harvesting systems | x | - | - | - | - | - | - | x | x |
| *WC03* | Water | Collection | Public taps | x | x | x | x | x | x | - | x | x |
| *WC04* | Water | Collection | Fog catchers | x | x | x | x | x | x | x | x | x |
| *WC05* | Water | Collection | Water wells | x | - | - | - | - | - | - | x | x |
| *WC06* | Water | Collection | Terraced irrigation systems from streams | x | - | - | - | - | - | - | x | x |
| *WI01* | Water | Infiltration | Permeable surfaces | x | x | - | - | - | - | - | x | x |
| *WI02* | Water | Infiltration | Floodable gardens (infiltration basins) | x | - | - | - | - | - | - | x | x |
| *WR01* | Water | Retention | Water ponds (retention basins) | x | x | - | - | - | - | - | x | x |
| *WR02* | Water | Retention | Trees and schrubs | x | x | - | - | x | - | - | x | x |
| *WR03* | Water | Retention | Vegetated ditches (green corridors) | x | - | - | - | - | - | - | x | x |
| *WR04* | Water | Retention | Dry fountains | x | x | - | - | x | x | - | x | x |
| *WT01* | Water | Treatment | Floating gardens (phytotreatment) | x | x | - | x | - | - | - | x | x |
| *WT02* | Water | Treatment | Septik tanks | x | - | - | - | x | x | - | x | x |
| *WT03* | Water | Treatment | Pipe network (sewage) | x | x | - | - | x | x | - | x | x |
| *WT04* | Water | Treatment | Dry toilets | x | x | x | x | x | x | x | x | x |
| *WT05* | Water | Treatment | Wetlands | x | - | - | - | - | - | - | x | x |
| *EP01* | Energy | Production | Photovoltaic pannels | x | x | x | x | x | x | x | x | x |
| *EP02* | Energy | Production | Thermal pannels | x | x | x | x | x | x | x | x | x |
| *EP03* | Energy | Production | Wind turbines (electricity) | x | x | x | x | x | x | x | x | x |
| *EP04* | Energy | Production | Biogas (from anaerobic digester) | x | x | x | x | x | x | x | x | x |
| *EP05* | Energy | Production | Solar chimneys | x | - | x | x | x | x | - | x | x |
| *EP06* | Energy | Production | Solar ovens | x | x | x | x | x | x | x | x | x |
| *ES01* | Energy | Sharing | Shared electrical power points | x | x | x | x | x | x | x | x | x |
| *ES02* | Energy | Sharing | Shared gas cookstoves | x | x | x | x | x | x | x | x | x |
| *ES03* | Energy | Sharing | Shared wood ovens | x | x | x | x | x | x | x | x | x |
| *ES04* | Energy | Sharing | Shared drying areas | x | x | x | x | x | x | x | x | x |
| *SW01* | Solid Waste | Reuse | Compost bins | x | x | x | x | x | x | x | x | x |
| *SW02* | Solid Waste | Reuse | Pit Gardens (banana circles) | x | x | x | - | - | x | - | x | x |
| *SW03* | Solid Waste | Reuse | Anaerobic digesters | x | x | x | x | x | x | x | x | x |
| *SW04* | Solid Waste | Reuse | Material transformation workshops | x | x | x | x | x | x | x | x | x |
| *SW05* | Solid Waste | Storage | Recycling centers (stock) | x | x | x | x | x | x | - | x | x |
| *SW06* | Solid Waste | Storage | Sheds for garbage containers | x | x | x | x | x | x | - | x | x |
| *CM01* | Community | Meeting | Playgrounds | x | x | x | x | x | x | - | x | x |
| *CM02* | Community | Meeting | Covered spaces | x | x | x | x | x | x | - | x | x |
| *CM03* | Community | Meeting | Fixed furniture | x | x | x | x | x | x | - | x | x |
| *CM04* | Community | Meeting | Bleachers (open-air amphitheater) | x | x | x | x | - | x | - | x | x |
| *CM05* | Community | Meeting | Viewpoints (belvedere) | x | - | x | x | x | x | - | x | x |
| *CM06* | Community | Meeting | Sports courts | x | x | x | x | x | x | - | x | x |
| *CM07* | Community | Meeting | Open-air swimming pools | x | x | - | - | - | x | - | x | x |
| *CM08* | Community | Meeting | Ornamental gardens | x | x | - | - | - | x | - | x | x |
| *CM09* | Community | Meeting | Bicycle racks (accessibility) | x | x | x | x | x | x | - | x | x |
| *CM10* | Community | Meeting | Pathways and stairs (accessibility) | x | - | - | - | - | x | - | x | x |
| *CM11* | Community | Meeting | Public transportation stops (accessibility) | x | x | - | x | - | x | - | x | x |
| *CK01* | Community | Knowledge Sharing | Construction prototypes | - | x | x | x | - | x | x | x | x |
| *CK02* | Community | Knowledge Sharing | Pedagogical gardens | x | x | - | x | - | x | x | x | x |
| *CK03* | Community | Knowledge Sharing | Murals | - | - | x | x | x | x | - | x | x |
| *CL01* | Community | Living | Temporary or permanent housing units | x | - | x | x | x | x | - | x | x |
| *CN01* | Community | Networking | Bulletin boards | x | x | x | x | x | x | x | x | x |
| *CN02* | Community | Networking | Community equipments (polyvalent spaces) | x | x | x | x | x | x | x | x | x |
| *CN03* | Community | Networking | Mobile units | - | - | x | x | - | x | x | - | x |
| *CW01* | Community | Working | Collective gardens | x | x | - | x | - | x | - | x | x |
| *CW02* | Community | Working | Greenhouses | x | x | x | x | x | x | x | x | x |
| *CW03* | Community | Working | Regenerative farming fields (non-intensive) | x | - | - | - | - | - | - | x | x |
| *CW04* | Community | Working | Moss walls (green walls) | - | x | x | x | x | x | - | x | x |
| *CW05* | Community | Working | Workshops (wood, steel) | x | x | x | x | x | x | x | x | x |
| *CW06* | Community | Working | Aquaculture ponds | x | x | - | x | - | x | - | x | x |
| *CW07* | Community | Working | Chiquen cops | x | x | x | x | x | x | x | x | x |

*Figure 5.6: Primary spatial design tools used for resource management and community involvement by urban archetype.*


CM05
CM10
CW03
EP05
WC06
CK02
CL01
WT05
CW02
WC04
CW07
CW05
CM11
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SW03
CK03
SW04
EP03
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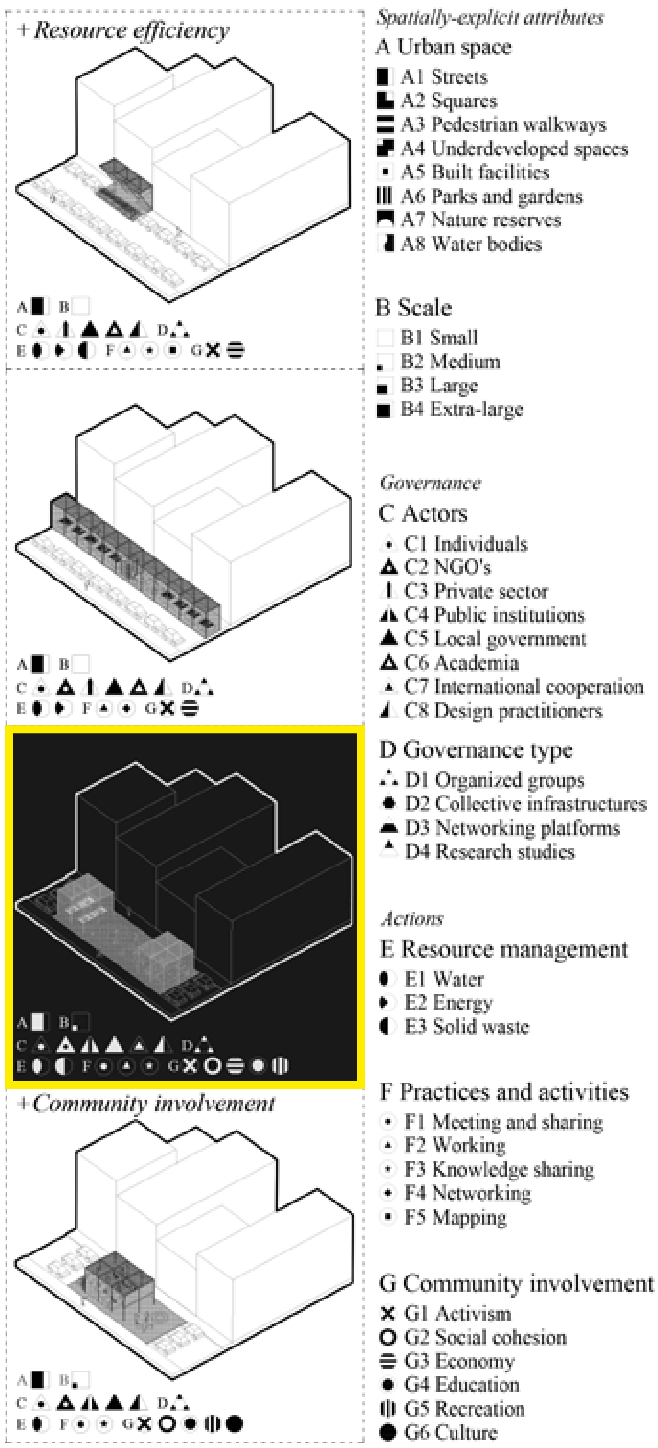
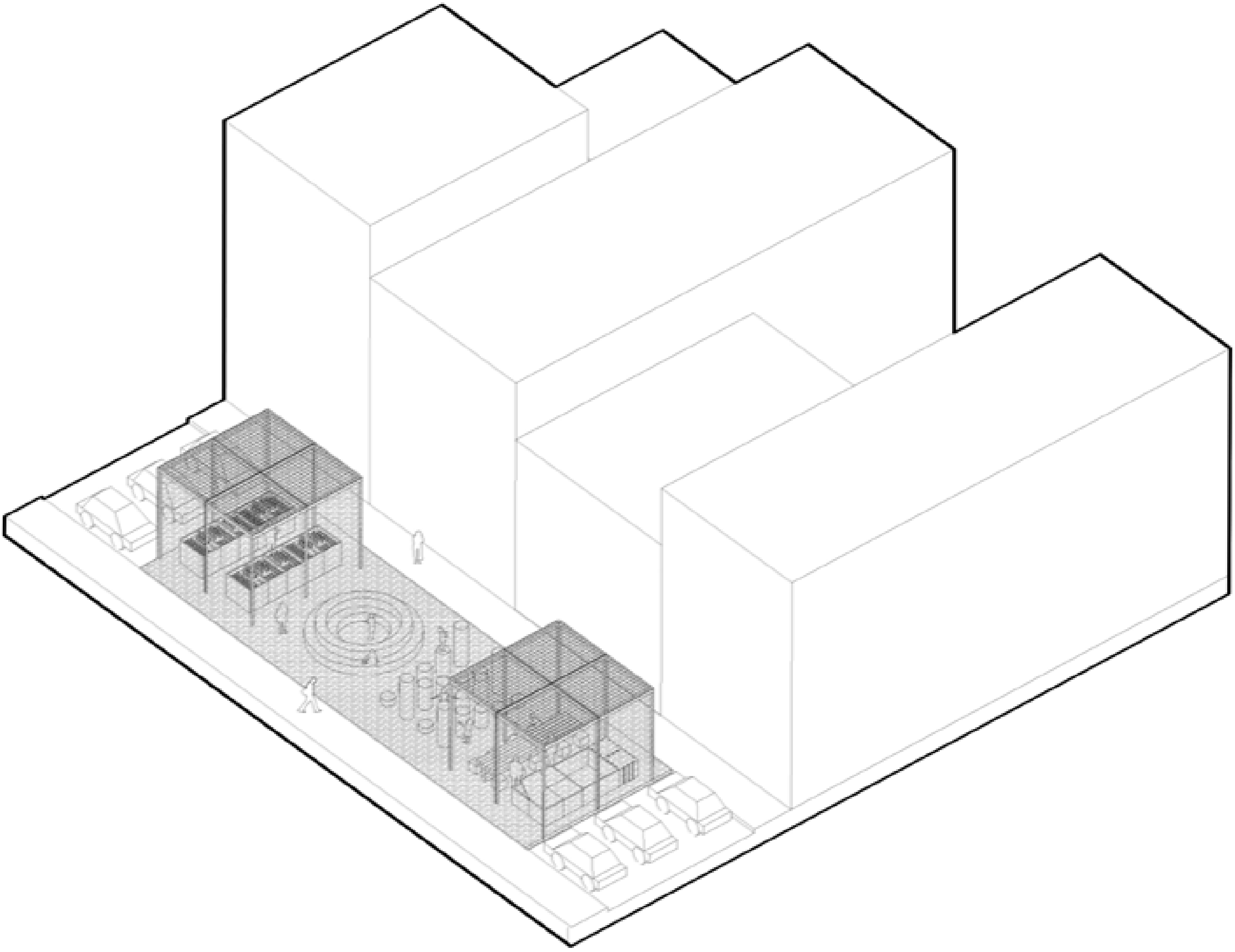



*Figure 5.7: Illustrated example of variations of the urban archetype "Covered surface" in urban spaces such as streets and sidewalks, describing the key characteristics that balance a design principle for developing urban design strategies with a focus on either resource efficiency or community involvement.*

Covered Surfaces



*Main characteristics*

A B

C D

E F G

*Percentage of urban space use*

*Resource management*
*15% Water*
*10% Energy*
*8% Solid waste*
*Community involvement*
*38% meeting*
*4% knowledge sharing*
*0% living*
*4% networking*

### *5.3.3 Case study analysis: 3 urban archetypes, 3 programmatic scenarios, and 3 site boundaries*

*Figure 5.8* illustrates the spatial configurations underpinning each of the twenty-seven programmatic scenarios developed. Each programmatic scenario features three variations of urban archetypes (*Adaptive Ground*s, *Covered Surfacse*, and *Vertical Stackings*) at three defined site boundaries. Meeting spaces were highlighted in green, working spaces in magenta, farming spaces in pink, rental spaces in orange, and rehearsal rooms in dark blue, and open-air rehearsal spaces in light blue. *Table 5.1* summarizes the information retrieved to describe resource efficiency and community involvement parameters in the case study. The data is organized by type of programmatic scenario and broken down by site boundary and urban archetype. Total square meters and maximum user capacity were calculated for each space. Rainwater harvesting, electricity production through solar panels, and organic waste treatment were also assessed for each spatial configuration.

In the first programmatic scenario (*urban farm*), the *Covered Surfaces* spatial configurations were the most efficient in terms of resource production and waste treatment in its three site-boundary variations (between 100 and 400 l/day of rainwater harvesting, 80 and 140 kWh/day of electrical energy, and 13 and 40 kg/day of organic waste treatment). However, they were the spatial configurations that could accommodate the least number of users (up to 3 farmers in the spatial configurations with the largest land area). In the second programmatic scenario (*community center*), the *Vertical Stackings* and *Adaptive Grounds* space configurations generated more square meters of meeting, working, and harvesting spaces (between 150 and 400 m2 of total construction). However, only the *Vertical Stackings* managed to generate larger spaces for rental areas. The urban archetypes that could deliver greater resource production and waste treatment were the *Adaptive Grounds* and *Covered Surfaces*. In the third programmatic scenario (*music school*), although in the *Adaptive Grounds* configurations more visitors could be accommodated, only the *Vertical Stackings* could provide almost the entire programmatic variety of spaces needed for the rehearsal rooms. In the *Adaptive Grounds* and *Covered Surfaces* spatial configurations community gardens could be integrated, increasing the variety of community involvement.

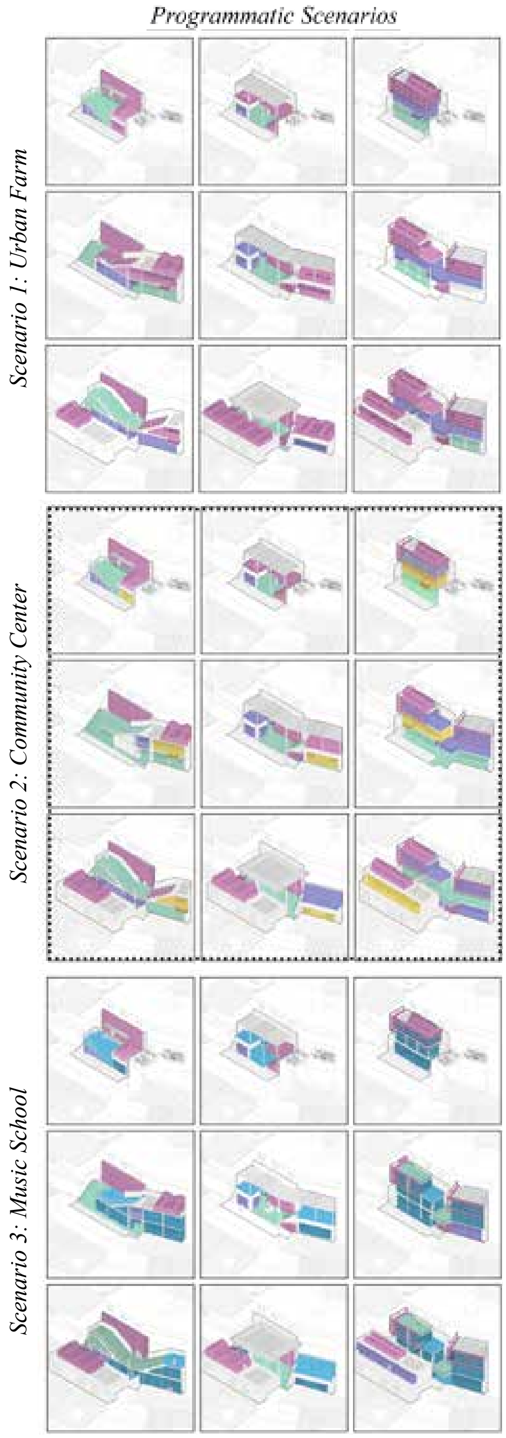



*Figure 5.8: Spatial configurations by type of urban archetype, programmatic scenario, and site boundaries. Refer to Figures S5.2, S5.3, and S5.4 in the Supporting Material for detailed data and visual illustrations of the spatial configurations developed under the community center programmatic scenario at Site A.*

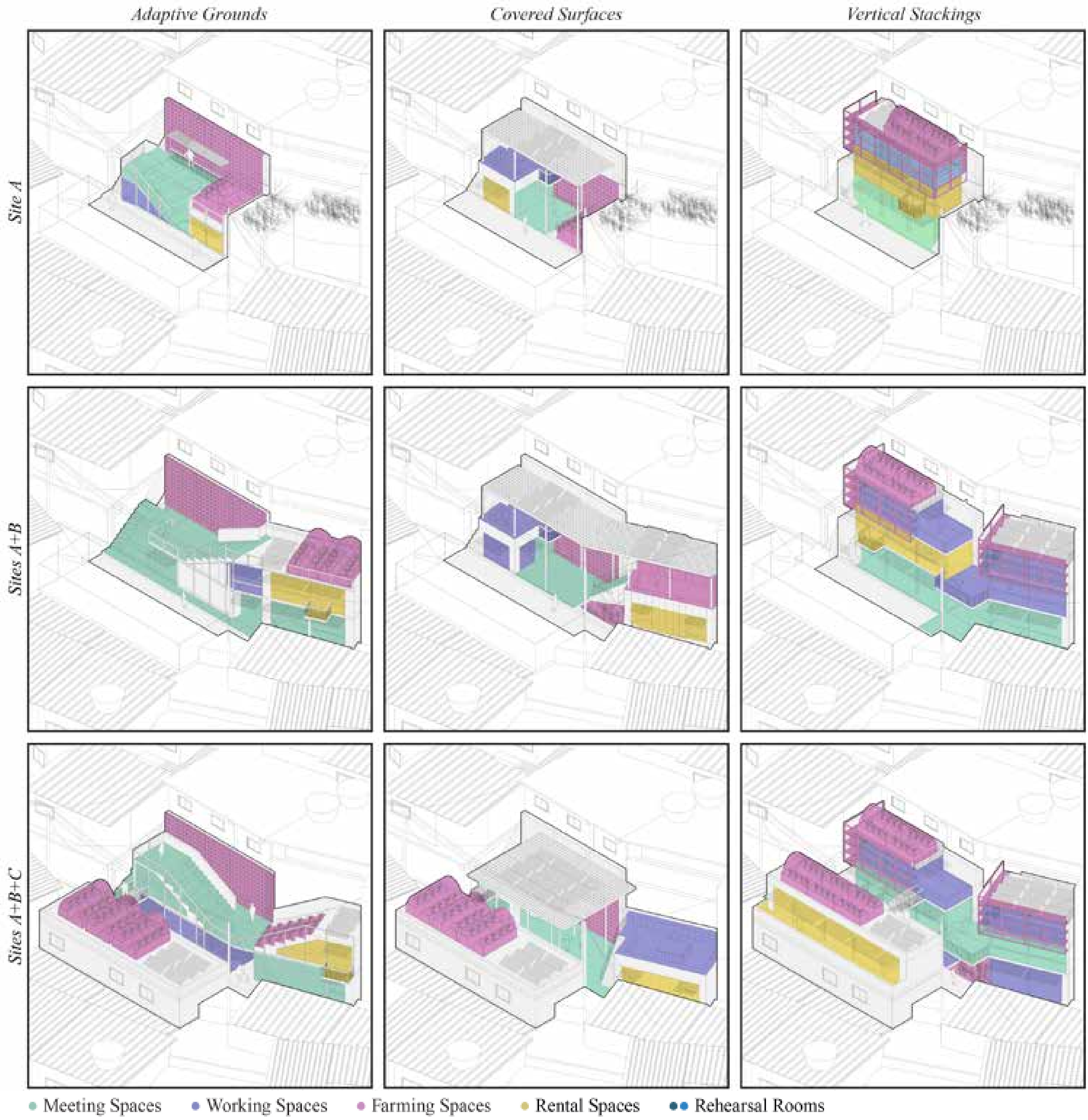

Adaptive Grounds
Covered Surfaces
Vertical Stackings
Site A
Sites A+B
Sites A+B+C
Meeting Spaces
Working Spaces
Farming Spaces
Rental Spaces
Rehearsal Rooms

*Table 5.1: Data framework summarizing the information retrieved to describe resource efficiency and community involvement parameters. The data is organized by type of programmatic scenario and broken down by site boundary and urban archetype. The three urban archetypes are evaluated across their different spatial configurations, with the highest values highlighted in light yellow, the middle values in dark yellow, and the lowest values in gray.*

**Scenario 1: Urban Farm** Emphasis on resource efficiency

| *Sites* | *A (La Parcela)* | | | *A+B (LP+underdeveloped areas)* | | | *A+B+C (LP+underdeveloped areas+neighboor)* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Archetype* | *AG* | *CS* | *VS* | *AG* | *CS* | *VS* | *AG* | *CS* | *VS* |
| *Total urban space area* | *135 m2* | *95 m2* | *190 m2* | *306 m2* | *188 m2* | *411 m2* | *381 m2* | *298 m2* | *566 m2* |
| *Meeting and sharing (total area)* | *36 m2* | *14 m2* | *32 m2* | *57 m2* | *32 m2* | *90 m2* | *67 m2* | *32 m2* | *90 m2* |
| Polyvalent spaces (market area) | - | - | 32 m2 | 35 m2 | - | 79 m2 | - | - | 79 m2 |
| Outdoor meeting spaces | 36 m2 | 14 m2 | - | 22 m2 | 32 m2 | 11 m2 | 67 m2 | 32 m2 | 11 m2 |
| Visitors | 24 people | 9 people | 21 people | 38 people | 22 people | 60 people | 45 people | 22 people | 60 people |
| *Working (total area)* | *12 m2* | *14 m2* | *32 m2* | *32 m2* | *27 m2* | *80 m2* | *67 m2* | *29 m2* | *80 m2* |
| Workshops | 12 m2 | 14 m2 | 32 m2 | 32 m2 | 10 m2 | 55 m2 | 67 m2 | 29 m2 | 55 m2 |
| Outdoor working spaces | - | - | - | - | 17 m2 | 25 m2 | - | - | 25 m2 |
| Users | 1 people | 2 people | 4 people | 4 people | 3 people | 9 people | 7 people | 3 people | 9 people |
| *Farming (total area)* | *71 m2* | *59 m2* | *85 m2* | *162 m2* | *108 m2* | *154 m2* | *161 m2* | *149 m2* | *268 m2* |
| Indoor farming | 11 m2 | - | 25 m2 | 46 m2 | 29 m2 | 46 m2 | 46 m2 | - | 101 m2 |
| Vertical farming | 53 m2 | 35 m2 | 41 m2 | 53 m2 | 35 m2 | 70 m2 | 53 m2 | 35 m2 | 70 m2 |
| Collectible gardens | - | 6 m2 | - | 40 m2 | 15 m2 | 22 m2 | 26 m2 | 57 m2 | 22 m2 |
| Farmers | 2 people | 1 people | 2 people | 3 people | 2 people | 3 people | 3 people | 2 people | 6 people |
| Gardeners (community) | - | 2 people | - | 10 people | 4 people | 6 people | 7 people | 14 people | 6 people |
| *Support and services (total area)* | *16 m2* | *9 m2* | *42 m2* | *55 m2* | *20 m2* | *88 m2* | *86 m2* | *87 m2* | *128 m2* |
| Water (rainwater harvest) | 124 l/day | 102 l/day | 86 l/day | 181 l/day | 208 l/day | 140 l/day | 323 l/day | 377 l/day | 282 l/day |
| Energy (solar pannels) | 9 kWh/day | 80 kWh/day | 8 kWh/day | 19 kWh/day | 113 kWh/day | 35 kWh/day | 82 kWh/day | 141 kWh/day | 71 kWh/day |
| Solid Waste (organic compost) | 26 kg/day | 13 kg/day | 26 kg/day | 53 kg/day | 30 kg/day | 75 kg/day | 60 kg/day | 40 kg/day | 78 kg/day |

**Scenario 2: Community Center** Balance between resource efficiency and community involvement

| *Sites* | *A (La Parcela)* | | | *A+B (LP+underdeveloped areas)* | | | *A+B+C (LP+underdeveloped areas+neighboor)* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Archetype* | *AG* | *CS* | *VS* | *AG* | *CS* | *VS* | *AG* | *CS* | *VS* |
| *Total urban space area* | *127 m2* | *81 m2* | *151 m2* | *212 m2* | *154 m2* | *355 m2* | *275 m2* | *232 m2* | *432 m2* |
| *Meeting and sharing* | *36 m2* | *14 m2* | *27 m2* | *89 m2* | *32 m2* | *129 m2* | *47 m2* | *59 m2* | *106 m2* |
| Polyvalent spaces | - | - | 27 m2 | 67 m2 | - | 121 m2 | 25 m2 | 10 m2 | 98 m2 |
| Outdoor meeting spaces | 36 m2 | 14 m2 | - | 22 m2 | 32 m2 | 8 m2 | 22 m2 | 49 m2 | 8 m2 |
| Visitors | 24 people | 9 people | 18 people | 59 people | 22 people | 86 people | 31 people | 39 people | 71 people |
| *Working* | *13 m2* | *17 m2* | *25 m2* | *14 m2* | *27 m2* | *50 m2* | *42 m2* | *29 m2* | *73 m2* |
| Workshops | 13 m2 | - | 25 m2 | 14 m2 | 10 m2 | 25 m2 | 42 m2 | - | 73 m2 |
| Outdoor working spaces | - | 17 m2 | - | - | 17 m2 | 25 m2 | - | 29 m2 | - |
| Users | 1 people | 2 people | 3 people | 2 people | 3 people | 6 people | 5 people | 3 people | 8 people |
| *Farming* | *60 m2* | *41 m2* | *59 m2* | *79 m2* | *75 m2* | *97 m2* | *125 m2* | *96 m2* | *150 m2* |
| Rooftop farming | - | - | 18 m2 | - | 25 m2 | 22 m2 | 46 m2 | 46 m2 | 75 m2 |
| Vertical farming | 53 m2 | 35 m2 | 41 m2 | 53 m2 | 35 m2 | 53 m2 | 53 m2 | 35 m2 | 53 m2 |
| Collectible gardens | 7 m2 | 6 m2 | - | 27 m2 | 15 m2 | 22 m2 | 27 m2 | 15 m2 | 22 m2 |
| Farmers | 1 people | 1 people | 1 people | 1 people | 1 people | 2 people | 2 people | 2 people | 3 people |
| Gardeners (community) | 2 people | 2 people | - | 7 people | 4 people | 6 people | 7 people | 4 people | 6 people |
| *Rental space* | *11 m2* | *14 m2* | *30 m2* | *36 m2* | *29 m2* | *26 m2* | *47 m2* | *29 m2* | *55 m2* |
| *Residents / Users* | 2 people | 2 people | 2 people | 2 people | 2 people | 2 people | 2 people | 2 people | 2 people |
| *Support and services* | *17 m2* | *9 m2* | *40 m2* | *30 m2* | *20 m2* | *80 m2* | *61 m2* | *49 m2* | *102 m2* |
| Water (rainwater harvest) | 124 l/day | 103 l/day | 86 l/day | 182 l/day | 208 l/day | 158 l/day | 182 l/day | 404 l/day | 301 l/day |
| Energy (solar pannels) | 9 kWh/day | 25 kWh/day | 8 kWh/day | 19 kWh/day | 48 kWh/day | 35 kWh/day | 69 kWh/day | 98 kWh/day | 71 kWh/day |
| Solid Waste (organic compost) | 20 kg/day | 10 kg/day | 16 kg/day | 45 kg/day | 20 kg/day | 65 kg/day | 30 kg/day | 32 kg/day | 57 kg/day |

**Scenario 3: Music School** Emphasis on community involvement

| *Sites* | *A (La Parcela)* | | | *A+B (LP+underdeveloped areas)* | | | *A+B+C (LP+underdeveloped areas+neighboor)* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Archetype* | *AG* | *CS* | *VS* | *AG* | *CS* | *VS* | *AG* | *CS* | *VS* |
| *Total urban space area* | *82 m2* | *63 m2* | *135 m2* | *254 m2* | *148 m2* | *270 m2* | *309 m2* | *237 m2* | *404 m2* |
| *Meeting and sharing* | *51 m2* | *32 m2* | *103 m2* | *152 m2* | *111 m2* | *149 m2* | *182 m2* | *104 m2* | *179 m2* |
| Main rehearsal room (strings) | - | - | 43 m2 | 42 m2 | 29 m2 | 47 m2 | 42 m2 | 29 m2 | 47 m2 |
| Percussion rehearsal room | - | - | 16 m2 | - | - | 21 m2 | 16 m2 | - | 21 m2 |
| Rehearsal room (woods/brass) | 15 m2 | - | 16 m2 | - | - | 21 m2 | - | 10 m2 | - |
| Woods rehearsal room | - | - | - | 16 m2 | - | - | - | - | 21 m2 |
| Brass rehearsal space | - | - | - | 16 m2 | - | - | - | - | 25 m2 |
| Outdoor rehearsal space | 36 m2 | 32 m2 | - | - | 50 m2 | - | 42 m2 | 33 m2 | - |
| Outdoor meeting spaces | - | - | 29 m2 | 78 m2 | 32 m2 | 59 m2 | 82 m2 | 32 m2 | 64 m2 |
| Visitors | 17 people | 11 people | 42 people | 77 people | 48 people | 66 people | 86 people | 72 people | 78 people |
| *Working (workshops)* | *12 m2* | *10 m2* | - | *17 m2* | *10 m2* | *25 m2* | *16 m2* | *17 m2* | *55 m2* |
| Users | 1 people | 1 people | - | 2 people | 1 people | 3 people | 2 people | 2 people | 6 people |
| *Farming (collectible gardens)* | *7 m2* | *14 m2* | - | *27 m2* | *15 m2* | *13 m2* | *46 m2* | *61 m2* | *51 m2* |
| Gardeners (community) | 2 people | 3 people | - | 7 people | 4 people | 3 people | 11 people | 15 people | 13 people |
| *Support and services* | *13 m2* | *8 m2* | *32 m2* | *58 m2* | *12 m2* | *83 m2* | *65 m2* | *56 m2* | *119 m2* |
| Water (rainwater harvest) | 41 l/day | 102 l/day | 86 l/day | 47 l/day | 208 l/day | 131 l/day | 129 l/day | 337 l/day | 215 l/day |
| Energy (solar pannels) | 9 kWh/day | 25 kWh/day | 8 kWh/day | 19 kWh/day | 48 kWh/day | 35 kWh/day | 69 kWh/day | 98 kWh/day | 35 kWh/day |
| Solid Waste (organic compost) | 6 kg/day | 5 kg/day | 13 kg/day | 27 kg/day | 17 kg/day | 23 kg/day | 32 kg/day | 28 kg/day | 31 kg/day |

### *5.4 Discussion*

#### *5.4.1 Urban archetypes of ARGS in the Global South and Global North*

The definition of resource-sensitive and community-inclusive urban archetypes, based on a compilation and analysis of ARGS projects, has been illustrated in the form of a design catalogue to address the following guiding research question: how can design strategies for publicly accessible urban spaces be developed based on most common spatial characteristics of ARGS in both the Global South and Global North? This design catalogue is intended to serve as a practical tool for design practitioners, offering a series of design principles, tools, and examples that can be applied in the initial phases of urban design projects. Despite the fact that all ARGS projects analyzed are involved in resource collection or waste treatment, only 25% explicitly focus on improving resource accessibility and reducing living costs of the community involved. Most of these initiatives focus on urban agriculture practices, such as farms, collective gardens, and greenhouses, as well as recycling facilities, including artisan workshops, waste collection centers, and material libraries.

Previous research has demonstrated the benefits of incorporating these practices to enhance community involvement and improve the efficiency of resource management (Elwakil et al., 2023; Gondhalekar & Ramsauer, 2017). For instance, two of the selected *Mobile Artifacts (N33*, *S04)* are two floating greenhouses that share similar objectives but differ in their spatial characteristics. *N33* is an academic project that developed a prototype of a mobile floating hydroponic garden, designed to optimize resource efficiency in food production by implementing solar energy harvesting through photovoltaic panels and desalinization of seawater into potable water, in addition to growing vegetables. In contrast, *S04* was developed under a call for projects aimed at expanding food production in areas vulnerable to climate change, designed to hover during flood seasons, serving both as a greenhouse for a family unit and as a resilient agricultural space to be replicated.

Various *Symbiotic Structures* (*N19*, *N42*, *S32)* demonstrated how design practices and artisan workshops can be employed to reactivate abandoned buildings by engaging local communities. *N42* was a summer participatory design initiative that used recycled construction materials to rebuild and reanimate the common spaces of an abandoned community center in a lower-income urban suburb. Local youth were actively involved in this process, which fostered stronger relationships between residents through the creation of urban furniture such as benches and amphitheaters. However, due to budget constraints, the project was limited to temporary improvements to outdoor spaces through garden pruning and creation of outdoor furniture, and the spaces of the community center could not be fully developed for long-term use. *N19* is a construction materials library that operates within a temporary occupation framework in an abandoned warehouse. This space is used not only to store construction materials but also to provide design consulting services and furniture construction assistance to nearby residents. Additionally, it can be used to organize events and builds street furniture during the summer, contributing to the local community's involvement and resource use. *S32* is a self-organized cultural center located in a former office building that once operated as an illegal casino. After the local government reclaimed the building, a group of design practitioners collaborated with residents to transform it into a cultural production hub. The process involved knowledge exchange and hands-on participation in designing and building both interior and exterior spaces. Located in a tropical climate city center, part of the building's curtainwall façade was dismantled to enhance internal ventilation, and a balcony was constructed facing the city, symbolizing openness and connection to the broader urban environment. These examples illustrate the flexibility of transforming abandoned buildings into centers of production and exchange across various contexts. Moreover, they highlight the potential of these initiatives to foster citizen participation in decision-making, promoting more inclusive urban planning policies that engage all stakeholders (Patti & Polyak, 2015).

More than three-quarters of ARGS projects are located in underdeveloped areas, with the majority primarily focused on fostering community engagement through recreational, educational, cultural, and decentralized resource management programs. This underscores the crucial role of design practitioners in identifying potential intervention sites and supporting grassroots initiatives for the creation of urban spaces through citizen-led organization and participation. For instance, several employ permanent wood or steel structures to shelter open-air spaces, protecting them from adverse weather conditions while facilitating community events like markets and neighborhood festivals. In some cases, these *Covered Surfaces* are supported by enclosed volumes that increase the utility of parks (*S38*, *N35*), courtyards of abandoned buildings *(N15)*, and underdeveloped areas (*S09*, *S50*, *S52*). As demonstrated by previous research (Stewart et al., 2019), the enhancement of urban spaces through citizen-driven initiatives promotes social interaction, which in turn deepens attachment to places and fosters a stronger sense of community. In other instances, projects take a more ambitious approach by developing complex spatial programs tailored to the specific needs of local residents. This is the case of *Shaped Volumes*, which integrate multifunctional facilities that go beyond simple meeting spaces. Some of these projects focus on developing agricultural production hubs (*S34*), using passive thermal control techniques to protect from heat such as the use of openwork blocks, brise-soleil facades, and the integration of internal courtyards. Others address critical needs in areas lacking municipal water systems by providing infrastructure for washing and drying clothes (*S40*), incorporating spaces for water and waste treatment in environmentally sensitive regions (*S56*), classrooms and collective gardens (*S20*), and even indoor playgrounds to ensure a safe and comfortable environment for children during colder months (*N29*).

Furthermore, our analysis revealed that 85% of the selected ARGS are of public access, while the remaining 15% are restricted by access controls and are intended for specific user groups, such as children within a community or workers in a collective garden. Notably, over 80% of the ARGS in the Global South are located in areas with vulnerable communities, highlighting the growing interest and commitment among design practitioners to enhance public spaces, expand access to essential resources, and foster active community participation in these contexts. 24 of the 57 identified ARGS are located in informal settlements, 19 in underdeveloped areas within lower-income neighborhoods on the rural periphery, and 4 have been established in repurposed, formerly abandoned infrastructure in urban centers. Many of the projects within informal settlements are located in underdeveloped areas characterized by steep topographic slopes. To address these challenging conditions, *Adaptive Grounds* strategies were employed to stabilize slopes and create usable spaces through the construction of terraces and belvederes (*S02*, *S03*, *S10*, *S28*, *S55*). In other instances, more extensive infrastructure developments were necessary, leading to the creation of enclosed spaces, such as communal kitchens and workshops, beneath new terraces and open-air amphitheaters (*S22*, *S45*).

Nearly half of the projects located in rural areas are associated with academic initiatives of varying scope and scale. The implementation of *Vertical Stackings* to densify these areas has been applied in diverse ways, such as constructing a four-level facility to house and support refugees in transition (*S31*) and developing a two-level cultural center dedicated to the arts and music of indigenous peoples (*S35*). In urban centers, several projects have revitalized abandoned parks through programmatic land delimitations (*S23*), which include playgrounds and collective gardens, and the construction of canopies to facilitate community meetings and provide essential services (*S52*). Even though almost all of the ARGS in the Global North are located in urban centers or their periphery, more than 75% are located in underdeveloped areas, and specifically, almost half of these are located in former abandoned infrastructure and brownfields. Consistent with recommendations from previous studies on the potential to repurpose urban infrastructure into accessible open spaces to enhance resource efficiency and ecological connectivity in cities (Nalumu et al., 2023; Otero Peña et al., 2022), several of these projects have been implemented within rail infrastructure spaces, as well as green and blue infrastructure networks. For instance, the transformation of a retention pond in a former airport zone into a linear *Network System* scheme (*N18*), featuring pavilions and open areas for knowledge sharing (e.g., workshops and classrooms), has provided a platform for the development of cultural, transdisciplinary, and socio-political programs aimed at preserving and experimenting with endangered green spaces.

The urban archetypes are versatile and can be adapted to various sites, geographical settings, and socio-economic contexts, as demonstrated by the selected analyzed ARGS projects. Furthermore, the identification of the design tools employed (see *Figure 5.6*) provides design practitioners with a concrete set of options that can be tailored to meet the spatial and programmatic needs of future developments. For these reasons, and considering recent research that has examined the benefits of ARGS for improving resource management and social cohesion (Otero Peña et al., 2025), the use of resource-sensitive and community-inclusive urban archetypes by design practitioners to develop publicly accessible space presents substantial potential to enhance UM assessments in both urban and rural settings. This approach also offers the opportunity to connect with local vulnerable communities in diverse contexts, further contributing to sustainable and inclusive development.

### *5.4.2 Spatial analysis of three urban archetypes*

Three urban archetypes (*Adaptive Grounds*, *Covered Squares*, and *Vertical Stackings)* were selected for their suitability to gather more detailed insights on the case study. Their resource harvesting capacity and spatial versatility were evaluated to facilitate community involvement. Based on the specific needs of the *El Calvario* community, three programmatic scenarios were developed: (1) an urban farm maximizing resource harvesting capacity, (2) a community center with rental spaces balancing resource harvesting and community involvement, and (3) a music school with specific spaces to accommodate a larger number of community members.

The *Vertical Stacking* spatial configurations generated the largest square meters of newly created urban space in all programmatic scenarios by maximizing site density (three levels in Sites A and B, and two levels in Site C). Consequently, in the first programmatic scenario, these spatial configurations yielded the greatest variety and surface areas for urban farming, with up to 268 $m^2$ and 9 direct users in the combined Site A+B+C spatial configuration. It also facilitated the creation of a diverse array of overlapping spaces with varying climatic conditions for food production, such as enclosed areas for hydroponic systems, facades with light structures to support vertical pot-based cultivation, and the potential for greenhouses and rooftop gardens. However, the *Covered Square* and

*Adaptive Ground* spatial configurations achieved the highest resource harvesting capacity at Site A (102 l/day and 124 l/day of rainwater, 80 kWh/day and 9 kWh/day of electricity, and 13 kg/day and 26 kg/day of organic waste treatment, respectively) and Site A+B (208 l/day and 181 l/day of rainwater, 113 kWh/day and 19 kWh/day of electricity, and 30 kg/day and 53 kg/day of organic waste treatment, respectively). As a reference, Caracas has a consumption pattern of 577 l/day of drinkable water, 2.4 kWh/day/capita of electricity, and generates 1.5 kg/day/capita of solid waste. All spatial configurations, except for the *Vertical Stackings*, have the possibility to locate working spaces at the ground floor level, facilitating material loading and unloading, and enabling direct contact with residents. Consistent with prior findings on the economic, ecological, and social benefits of integrating urban agriculture projects within informal settlements (Acevedo-De-los-Ríos & Perrotti, 2024; Wolff et al., 2023), the application of urban archetypes during the preliminary design phases, in collaboration with the community, could aid in formalizing the spatial needs and relationships between agricultural production and resource efficiency.

In the second programmatic scenario at Site A, the *Adaptive Ground* spatial configuration proved most capacity in resource harvesting (124 l/day of rainwater, 9 kWh/day of electricity, and 20 kg/day of organic waste treatment) while also integrating a two-level open-air meeting space with the existing community stairways, accommodating up to 24 people. In contrast, the other two urban archetypes allowed to locate the meeting spaces on the ground level within built spaces, with capacities of 9 people for the *Covered Square* and 18 people for the *Vertical Stacking* spatial configurations. The *Covered Square* spatial configuration, however, does not allow to provide controlled or enclosed workspaces, which limits its ability to house fixed machinery as envisioned by the community. As the spatial configurations are tested on the other sites (sites A+B and A+B+C), the *Covered Surface* spatial configuration emerges as the option that offers the most resource collection capacity (404 l/day of rainwater, 98 kWh/day of electricity and 32 kg/day of organic waste treatment), as its large triple-height canopy allows for a larger surface area for water collection and solar panel installation, as well as successfully integrating the main pathway with the meeting spaces. Nevertheless, only the *Vertical Stacking* spatial configurations offer independent rental spaces which have the possibility of being located in upper levels from the main pathway, allowing for the potential construction of a single housing unit. In contrast, the other two urban archetypes allow the possibility of providing rental spaces less than half the size, located at ground level, which are more suited for commercial use.

In the third programmatic scenario, the *Vertical Stacking* spatial configurations demonstrated superior versatility in accommodating a program with rehearsal rooms of varying heights, along with providing open spaces for rehearsal and public events. Similarly, the *Adaptive Ground* spatial configurations at Sites A+B and A+B+C were able to generate diverse spaces by incorporating large open-air amphitheaters. However, among the nine spatial configurations, only one (*Vertical Stacking* at Site A+B+C), was able to fully integrate the required program.

#### *5.4.3 Limitations of the study*

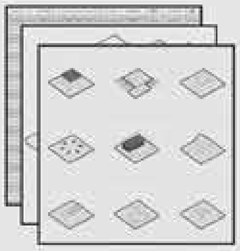
This study focused on defining and illustrating urban archetypes within ARGS by analyzing projects in Latin America and Europe. This approach was selected to encompass a range of geographic contexts, offering examples from both the Global South and Global North. However, this decision excluded many geographic regions beyond the scope of the study, which possess diverse socio-economic (e.g., informality in Africa and Asia), socio-cultural (e.g., religion and traditions), and socio-political (e.g., citizens' rights to organize or gather in public) contexts that could significantly influence the type of ARGS developed and the relationship between communities, resources, and urban space. Another important consideration is the methodology employed to identify the selected projects. To include a larger number of projects across different countries designed by practitioners, the study primarily relied on desktop research, referring to leading online databases and well-known architecture, urban planning, and landscape biennials of the regions covered by the study. However, this approach may have overlooked many projects not published on these platforms, yet equally relevant. For instance, some ARGS included in the inventory were sourced from the research of Otero Peña et al. (2025) in Brussels that were not available online, highlighting potential gaps in the data collection.

Among the nine urban archetypes identified, only three were tested by conducting a spatial feasibility study in the case study located in *El Calvario*, Caracas, Venezuela. These urban archetypes demonstrated promising versatility and spatial quality, alongside measurable benefits in terms of resource harvesting, community involvement, and the creation of public spaces. However, further research is required to evaluate the localized impact of each proposal on a per-capita basis.  This assesment should be conducted across multiple spatial scales, including the informal settlement, neighborhood, municipality, and city scales, in order to estimate the potential improvements in the urban resource efficiency that could result from implementing urban archetypes. This assessment should occur at the scale of the informal settlement, neighborhood, municipality, and city to estimate the potential improvements in an UM efficiency resulting from the implementation of resource-sensitive and community-inclusive urban archetypes. Additionally, to fully examine the spatial adaptability of the tested archetypes and given both the preliminary stage of design and the economic volatility of material prices in the case study area, material costs were not included as a variable in the current study. Nonetheless, future research should explore the economic feasibility of these spatial configurations in greater detail to support fundraising efforts and facilitate the eventual construction of the proposed projects by the community.

### *5.5 Conclusions*

The study has defined and illustrated nine resource-sensitive and community-inclusive urban archetypes, based on the spatial characteristics of ARGS projects in both the Global South and Global North. These urban archetypes constitute, together with the inventory of more than one hundred identified ARGS, a design catalogue that can be accessed by design practitioners during preliminary planning phases of publicly accessible spaces dealing with resource efficiency and community involvement. Additionally, by identifying the design tools employed in ARGS, each urban archetype can be tailored to meet diverse objectives, such as optimizing resource efficiency or enhancing community involvement. The in-depth assessment of three urban archetypes in the case study has pointed to their resource harvesting capacity and the versatility in creating functional meeting and working spaces within a real-world context. This also demonstrates the potential spatial qualities that can be achieved by applying different spatial configurations in relation to specific programmatic scenarios or implantation sites.

This study focused on the spatial dimension of urban archetypes, detailing and categorizing various types of spaces that can be designed for purposes such as meetings, working, resource harvesting, collection and storage, waste treatment, service provision, and circulation, across different spatial configurations. However, future research should involve directly testing these urban archetypes with design practitioners to gather feedback on their practical application, classification, and the design of space types. This testing process should be conducted in real-world contexts, engaging with a community of users to incorporate all relevant contextual and geographic variables. Furthermore, to evaluate the real inclusiveness and the needs they are responding to and the specific vulnerabilities of a community. Such an approach is essential to refining the design catalogue and its associated tools, ensuring they are robust and adaptable to diverse urban environments. Furthermore, collaborating with design practitioners and community members would allow for a more detailed study of the quantification of various resource flows within UM frameworks, such as food, materials, and gas emissions. This, in turn, could provide deeper insights into the potential impacts of future projects within a broader-scale metabolic analysis. Implementing this spatial, quantitative, and qualitative approach could enhance the practical application of UM studies in the planning and design of both urban and rural systems across Global South and Global North contexts.



***Supporting Material***

# *Chapter 5 Urban Archetypes*
# *Methods and tools to enhance UM applicability by design practitioners*

*Summary*

This supporting material provides supplementary information that complements the methods and findings included in *Chapter 5*, including the online source datasets used in the study, thedetailed programmatic scenarios, and the ARGS inventory.

*This section is organized as an original research article to be published in a scientific journal as supporting material of Chapter 5 Urban Archetypes. Methods and tools to enhance UM applicability by design practitioners.*

*Table S5.1: Online source datasets.*

| Source | Name | Website | Language | Year | Description |
|---|---|---|---|---|---|
| Project dissemination platforms | Archdaily (.com) | archdaily.com | English | 2000-2024 | The online sources were analyzed using a keyword search in the primary languages of the sites. The keywords employed included: community design, participatory design, citizen participation, collective project, grassroots, participatory action, participation, sustainable architecture, social architecture, rainwater harvesting, recycling, solar energy, water, energy, and solid waste, along with the names of all Latin American and European countries. |
| | Archdaily (.cl) | archdaily.cl | Spanish | | |
| | Archdaily (.br) | archdaily.br | Portuguese | | |
| Design awards | Ibero-American Biennial of Architecture and Urbanism (BIAU) | bienaliberoamericana.org | Spanish | | The online sources were analyzed through the virtual catalogs of the following editions: II BIAU Mexico City (2000), III BIAU Santiago de Chile (2002), IV BIAU. LIMA (2004), V BIAU Montevideo (2006), VI BIAU Lisbon (2008), VII BIAU. Medellin (2010), VIII BIAU Cadiz (2012), IX BIAU Rosario (2014), X BIAU Sao Paolo (2016), XI BIAU Asuncion (2019), and XII BIAU Mexico City (2022). |
| | Pan-American Biennial of Architecture of Quito (BAQ) | bac-cae.ec | Spanish | | The online sources were analyzed through the virtual catalogs of the following editions: BAQ 2004, BAQ 2006, BAQ 2008, BAQ 2010, BAQ 2012, BAQ 2014, BAQ 2016, BAQ 2018, BAQ 2020, and BAQ 2022. |
| | Venice Biennial of Architecture (La Biennale) | labiennale.org | English | | The online sources were analyzed through the virtual catalogs of the following editions: La Biennale 2014, La Biennale 2016, La Biennale 2018, La Biennale 2021, and La Biennale 2023. |
| | European Union Prize for Contemporary Architecture (EUmies Awards) | miesarch.com | English | | The online sources were analyzed through the virtual catalogs of the following editions: 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2022, and 2024. |
| | Mies Crown Hall Americas Prize (MCHAP) | mchap.co | English | | The online sources were analyzed through the virtual catalogs of the following editions: MCHAP 2014, MCHAP 2016, MCHAP 2018, MCHAP 2022, and MCHAP 2024. |
| | Eurpean Prize for Public Space | publicspace.org | English | | The online sources were analyzed through the virtual catalogs of the following editions: 2000, 2002, 2006, 2008, 2010, 2012, 2014, 2016, 2018, 2022, and 2024. |
| | Landezine International Landscape Award (LILA) | landezine-award.com | English | | The online sources were analyzed through the virtual catalogs of the following editions: LILA 2023, LILA2022, LILA 2021, LILA 2020, LILA 2019, LILA 2018, LILA 2017, and LILA 2016. |

**(a) Scenario 1: Urban Farm**
*(emphasis on resource efficiency)*
Water: maximum rainwater harvesting from roofs and canopies
(including water tanks, pumps, and gutters), and rainwater infiltration (permeable areas).
Energy: maximum photovoltaic electricity production from roofs and façades
(including storage space for batteries and controllers).
Solid waste: Maximum storage space for renovable materials and composting areas.

**(b) Scenario 2: Community Center**
*(balance between resource efficiency and community involvement)*
Water: rainwater harvesting from canopies
(including water tanks, pumps, and gutters).
Energy: photovoltaic electricity production from roofs
(including storage space for batteries and controllers).
Solid waste: storage space for recyclable materials and composting areas.

**(c) Scenario 3: Music School**
*(emphasis on community involvement)*
Water: rainwater harvesting from roofs and canopies
(including water tanks, pumps, and gutters).
Energy: photovoltaic electricity production from roofs
(including storage space for batteries and controllers).
Solid waste: composting areas.

*Table S5.2: Three programmatic scenarios based on the specific needs of El Calvario community: (a) an urban farm maximizing resource harvesting capacity, (b) a community center with rentable spaces balancing resource harvesting and community involvement, and (c) a music school with specific spaces to accommodate a larger number of community members.*

| Type | Description | Location | Volume | Surface | Cover | Interiors | Accessibility | % |
|---|---|---|---|---|---|---|---|---|
| *Farming* | Rooftop farming | Upper levels to maximize sunlight exposure and rainwater collection | - | Maximize crop-growing areas in relation to circulation. 40 m2 per farmer. | Flexible structure (retractable canopies or greenhouses) | Containers or raised beds | Controlled access | 40% |
| *Farming* | Indoor farming | Spaces within enclosed structures to control environmental factors and to create optimal growing conditions | Single height | | - | Containers or raised beds | Controlled access | |
| *Farming* | Vertical farming | Outdoor areas using vertical stacked structures | - | | - | Containers or systems without using soil (hydroponic, aeroponic). | Public access | |
| *Farming* | Collectible gardens | Outdoor areas that are easily accessible to the community | - | Maximize crop-growing areas in relation to circulation. 4 m2 per farmer. | Flexible structure (retractable canopies or greenhouses) | Farming beds, containers or raised beds | Public access | |
| *Working* | Workshop space | Flexible indoor space to allow woodworking and metalworking activities | Single height | Efficient workflow to allow transitions between activities. 9 m2 per user. | - | Work tables, table saws, welding machines, and mobile working tools | Controlled access | 20% |
| *Meeting and Sharing* | Market (polyvalent space) | Outdoor or indoor space to allow commercialization of local products, organization of municipal markets and other activities | In indoor spaces, provide a clear height of 3m | Capacity to allow at least 4 sales areas. 1.5 m2 per user. | In outside spaces, provide a flexible structure or retractable canopy | Flexible furniture for product display and storage | Public access | 20% |
| *Support and Services* | Circulation, restrooms, storage, and technical rooms | Indoor spaces | - | Efficient space layout to reduce unnecessary floor areas. | - | - | Controlled access | 10% |

| Type | Description | Location | Volume | Surface | Cover | Interiors | Accessibility | % |
|---|---|---|---|---|---|---|---|---|
| *Farming* | Rooftop farming | Upper levels to maximize sunlight exposure and rainwater collection | - | Maximize crop-growing areas in relation to circulation. 40 m2 per farmer. | Flexible structure (retractable canopies or greenhouses) | Containers or raised beds | Controlled access | 20% |
| *Farming* | Vertical farming | Outdoor areas using vertical stacked structures | - | | - | Containers or systems without using soil (hydroponic, aeroponic). | Public access | |
| *Farming* | Collectible gardens | Outdoor areas that are easily accessible to the community | - | Maximize crop-growing areas in relation to circulation. 4m2 per farmer. | Flexible structure (retractable canopies or greenhouses) | Farming beds, containers or raised beds | Public access | |
| *Working* | Workshop space | Flexible indoor space to allow woodworking and metalworking activities | Single height | Efficient workflow to allow transitions between activities. 4 m2 per farmer. | - | Work tables, table saws, welding machines, and mobile working tools | Controlled access | 20% |
| *Meeting and Sharing* | Polyvalent space | Outdoor or indoor space to allow communitiy meetings, organization of municipal markets, and other activities | In indoor spaces, provide a clear height of 3m | Capacity to allow at least 4 sales areas. 1.5 m2 per user. | In outside spaces, provide a flexible structure or retractable canopy | Flexible furniture for product display and storage | Public access | 30% |
| *Rental space* | Living or commercial space for rent | Indoor spaces | Single height | Living space for up to 2 persons or commercial space. | - | Bbedroom, living room, and bathroom; or sales and eating areas, restrooms, storage | Controlled access | 20% |
| *Support and Services* | Circulation, restrooms, storage, and technical rooms | Indoor spaces | - | Efficient space layout to reduce unnecessary floor areas. | - | - | Controlled access | 10% |

| Type | Description | Location | Volume | Surface | Cover | Interiors | Accessibility | % |
|---|---|---|---|---|---|---|---|---|
| *Farming* | Collectible gardens | Outdoor areas that are easily accessible to the community | - | Maximize crop-growing areas in relation to circulation. 4m2 per farmer. | Flexible structure (retractable canopies or greenhouses) | Farming beds, containers or raised beds | Public access | 10% |
| *Meeting and Sharing* | Main rehearsal space (orchestra, strings, polyvalent space) | Indoor or covered outdoor space to accomodate max. 120 musicians | Triple height | 1.5m2 per musician | - | - | Controlled access | 60% |
| *Meeting and Sharing* | Percussion rehearsal space | Indoor space to accomodate max. 8 musicians | Double height | 1.5m2 per musician | - | Storage space for percussion instruments | Controlled access | |
| *Meeting and Sharing* | Metal/wood rehearsal space | Indoor space to accomodate max. 30 musicians | Single height | 1.5m2 per musician | - | - | Controlled access | |
| *Working* | Workshop space | Flexible indoor space to allow woodworking and metalworking activities | Single height | Efficient workflow to allow transitions between activities. 4 m2 per farmer. | - | Work tables, table saws, welding machines, and mobile working tools | Controlled access | 20% |
| *Support and Services* | Circulation, restrooms, storage, and technical rooms | Indoor spaces | - | Efficient space layout to reduce unnecessary floor areas. | - | - | Controlled access | 10% |

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Adaptive Grounds | AG03 | S03 | Mirante do Cabral | Square and belvedere | 2023 | Vitoria (BR) | Informal settlement |
| Adaptive Grounds | AG03 | S02 | Her City Pocket Parks | Pocket park and square | 2023 | Lima (PE) | Informal settlement |
| Adaptive Grounds | AG03 | S10 | Las Lomas Stairs | Slope stability infrastructure | 2022 | Lima (PE) | Informal settlement |
| Adaptive Grounds | AG04 | S18 | Sistema Colectivo Humedal Sanitario | Community center | 2021 | Concepción (CL) | Informal settlement |
| Adaptive Grounds | AG01 | S11 | El Mirador II | Playground and square | 2021 | Lima (PE) | Informal settlement |
| Adaptive Grounds | AG01 | S23 | Praça da Árvore | Square and playground | 2020 | Recife (BR) | Urban city center |
| Adaptive Grounds | AG02 | S22 | Community Practices for Food Security | Community center and kitchen | 2020 | Lima (PE) | Informal settlement |
| Adaptive Grounds | AG03 | S21 | Claverito Waterfront Park | Slope stability infrastructure | 2020 | Iquitos (PE) | Rural periphery |
| Adaptive Grounds | AG02 | S33 | La Quebradora Water Park | Water retention park | 2019 | Mexico City (MX) | Urban city center |
| Adaptive Grounds | AG03 | S28 | La Chacarita | Neighborhood park | 2019 | Asunción (PY) | Informal settlement |
| Adaptive Grounds | AG01 | S25 | Alto Fucha Garden | Collective garden | 2019 | Bogota (CO) | Rural periphery |
| Adaptive Grounds | AG03 | S24 | Acciones al Margen | Slope stability infrastructure | 2019 | Caracas (VE) | Informal settlement |
| Adaptive Grounds | AG04 | S43 | Plaza del Agua | Square and fisher's market | 2017 | Rosario (AR) | Rural periphery |

*Table S5.3a: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 1).*

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Underdeveloped spaces | Open air dumpsite | Public | Small | Organized Groups | Spatial practitioners, NGOs, and individuals | Recreational | Water (infiltration) | Cidade Quintal |
| Underdeveloped spaces | High slope space | Public | Small | Organized Groups | Spatial practitioners, NGOs, municipal government, international institutions, and individuals | Recreational, social, and resource management | Water (rainwater harvest) and food (collective garden) | Ocupa Tu Calle |
| Underdeveloped spaces | Abandoned site | Public | Large | Organized Groups | Municipal government, NGOs, spatial practitioners, and individuals | Social and resource management | Solid waste (compost), and food (collective garden) | Ama Amancaes |
| Underdeveloped spaces | River banks | Public | Small | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Resource management and recreational | Water (waste water treatment) | Corporación Emergente Arquitectura Práctica |
| Parks | Abandoned park | Public | Small | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Recreational, social, and resource management | Water (rainwater harvest), solid waste (compost and recycling workshops), and food (collective garden) | Ocupa Tu Calle |
| Underdeveloped spaces | Abandoned park | Public | Large | Organized Groups | Public institutions, individuals, and spatial practitioners | Recreational | Water (rainwater harvest), energy (solar pannels), and food (collective garden) | Lazo Arquitetura e Urbanismo |
| Underdeveloped spaces | Stairways | Public | Large | Research Studies | Individuals, NGOs, academia, and spatial practitioners | Resource management, recreational, social | Water (rainwater harvesting and treatment system), solid waste (compost), and food (collective garden) | KNOW-Lima |
| Underdeveloped spaces | High slope space | Public | Large | Research Studies | Spatial practitioners, academia, international institutions, municipal government, and individuals | Resource management and recreational | Water (infiltration) and food (collective garden) | Traction |
| Underdeveloped spaces | Vacant lot | Public | Extra-large | Research Studies | Academia, spatial practitioners, municipal government, and individuals | Resource management, recreational and social | Water (biological water treatment) | A. Perló + Taller Capital + UNAM |
| Underdeveloped spaces | Stairways | Public | Small | Research Studies | Public institutions, NGOs, spatial practitioners, and individuals | Recreational and social | Water (infiltration) | Rozana Montiel |
| Underdeveloped spaces | Open air dumpsite | Public | Medium | Organized Groups | Spatial practitioners, NGOs, individuals, public institutions, and academia | Social and recreational | Food (collective garden) and solid waste (compost) | Arquitectura Expandida + Colectiva Huertopía |
| Underdeveloped spaces | River banks | Public | Medium | Organized Groups | NGOs, spatial practitioners, academia, and individuals | Resource management, social, and recreation | Water (infiltration) and food (collective garden) | Fundación Espacio |
| Underdeveloped spaces | Flat ground | Public | Medium | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Social and recreational | Water (rainwater harvesting) | Matéricos Periféricos |

Table S5.3b: *Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 2).*

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Adaptive Grounds | AG03 | S42 | Eliseo Collazos Fog Water Farm | Water harvesting park | 2017 | Lima (PE) | Rural periphery |
| Adaptive Grounds | AG04 | S49 | Tapis Rouge Square | Square and water reservoir | 2016 | Port au Prince (HT) | Informal settlement |
| Adaptive Grounds | AG02 | S45 | 1100 La Ceiba | Community center and square | 2016 | Caracas (VE) | Informal settlement |
| Adaptive Grounds | AG03 | S55 | Rocinha Mais Verde | Collective garden | 2012 | Rio de Janeiro (BR) | Informal settlement |
| Adaptive Grounds | AG04 | S54 | La Cañada | Chapel and waste water infrastructure | 2012 | Querétaro (MX) | Rural periphery |
| Adaptive Grounds | AG01 | N06 | El Tanque Cultural Space Garden | Cultural center and park | 2022 | Santa Cruz de Tenerife (ES) | Urban city center |
| Adaptive Grounds | AG01 | N05 | Bridgefoot Street Park | Neighborhood park | 2022 | Dublin (IE) | Urban city center |
| Adaptive Grounds | AG03 | N03 | Pocket Park La Halte | Belvedere park | 2022 | Brussels (BE) | Urban city center |
| Adaptive Grounds | AG04 | N02 | Montonés Norte Park | Water infiltration park | 2022 | Barcelona (ES) | Urban periphery |
| Adaptive Grounds | AG01 | N16 | GROW Totteridge Farm | Urban farm | 2019 | London (GB) | Urban periphery |
| Adaptive Grounds | AG03 | N21 | Prodac Norte / Sul | Square and amphiather | 2017 | Lisboa (PT) | Urban city center |
| Adaptive Grounds | AG04 | N31 | Las Huertas Termales | Irrigation System and collective gardens | 2015 | Caldes de Montbui (ES) | Rural periphery |
| Covered Surfaces | CS03 | S09 | Quebradeiras de Babaçu | Workshop and community center | 2022 | Vitória do Mearim (BR) | Rural periphery |

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Underdeveloped spaces | High slope space | Public | Large | Research Studies | Individuals, spatial practitioners, NGOs, and academia | Resource management and recreational | Water (fog harvesting) and food (collective garden) | Traction |
| Underdeveloped spaces | Open air dumpsite | Public | Large | Organized Groups | Spatial practitioners, NGOs, international institutions, and individuals | Recreational, social, and resource management | Water (groundwater harvest and water infiltration) and energy (solar illumination) | EVA Studio |
| Underdeveloped spaces | Stairways | Public | Large | Organized Groups | Individuals, municipal government, public institutions, and spatial practitioners | Recreational and social | Water (pavement desealing for water infiltration) | Pico Colectivo + AGA |
| Underdeveloped spaces | Abandoned garden | Semi private | Small | Organized Groups | NGOs, academia, individuals, and spatial practitioners | Resource management, educational, and social | Water (infiltration) and food (collective garden) | Green My Favela |
| Underdeveloped spaces | Flat ground | Public | Medium | Research Studies | Academia, spatial practitioners, municipal government, and individuals | Social, recreational, and resource management | Water (waste water treatment) | Taller Activo |
| Underdeveloped spaces | Abandoned refinery | Public | Large | Collective Infrastructure | NGOs, spatial practitioners, individuals, public institutions, and municipal government | Recreational and social | Water (rainwater harvest) and food (collective garden) | Fernando Menis |
| Underdeveloped spaces | Vacant lot | Public | Extra-large | Organized Groups | Municipal government, NGOs, spatial practitioners, and individuals | Recreational, social, and resource management | Water (infiltration) | DFLA |
| Underdeveloped spaces | Abandoned train station | Public | Large | Organized Groups | Municipal government, public institutions, spatial practitioners, NGOs, and individuals | Recreational | Water (infiltration) | VVV |
| Underdeveloped spaces | Abandoned sport facility | Public | Extra-large | Organized Groups | Municipal government, spatial practitioners, public institutions, and individuals | Resource management and recreational | Water (infiltration) | Hiha Studio |
| Gardens | Grassfield | Semi public | Extra-large | Organized Groups | Spatial practitioners, NGOs, and individuals | Resource management, educational, and social | Water (rainwater harvest), solid waste (compost), and food (collective garden) | Assemble |
| Underdeveloped spaces | Stairways | Public | Medium | Organized Groups | NGOs, individuals, municipal government, and spatial practitioners | Social and recreational | Water (infiltration) | Atelier MOB |
| Gardens | Polluted gardens | Semi public | Extra-large | Organized Groups | Municipal government, spatial practitioners, public institutions, and individuals | Resource management and recreational | Water (groundwater harvest and water infiltration) and food (collective garden) | Cavaa Arquitectes |
| Underdeveloped spaces | Vacant lot | Semi public | Small | Collective Infrastructure | Spatial practitioners and individuals | Social and educational | Water (rainwater harvest and sewage treatment) | Estudio Flume |

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Covered Surfaces | CS04 | S20 | Mejillones Community Center | Community center | 2021 | Mejillones (CL) | Rural periphery |
| Covered Surfaces | CS03 | S17 | Plaza Santa Cruz | Square and bus terminal | 2021 | Caracas (VE) | Informal settlement |
| Covered Surfaces | CS01 | S38 | Urban Agro Station | Collective garden | 2018 | Barquisimeto (VE) | Urban city center |
| Covered Surfaces | CS01 | S50 | Ancestral Knowledge Educational Park | Community center | 2014 | Vigía del Fuerte (CO) | Rural periphery |
| Covered Surfaces | CS02 | S52 | La Esperanza Community Center | Square and recycling center | 2013 | Querétaro (MX) | Urban city center |
| Covered Surfaces | CS01 | N07 | Eau de Couture | Water harvesting garden | 2021 | Brussels (BE) | Urban city center |
| Covered Surfaces | CS02 | N15 | Granby Winter Garden | Collective garden | 2019 | Liverpool (GB) | Urban city center |
| Covered Surfaces | CS01 | N35 | Jardin des Quatre-Vents | Collective garden | 2014 | Brussels (BE) | Urban city center |
| Hybrid Spaces | HS02 | S57 | Tiuna El Fuerte Cultural Park | Cultural and community center | 2005 | Caracas (VE) | Urban periphery |
| Hybrid Spaces | HS02 | N08 | Flow | Open-air swimming pool | 2021 | Brussels (BE) | Urban city center |
| Hybrid Spaces | HS01 | N12 | Molenwest Square | Temporary multifunctional square | 2020 | Brussels (BE) | Urban city center |
| Hybrid Spaces | HS01 | N17 | Story Garden | Collective garden | 2019 | London (GB) | Urban city center |
| Hybrid Spaces | HS01 | N28 | Loughborough Junction | Urban farm | 2016 | London (GB) | Urban city center |

*Table S5.3c: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 3).*

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Underdeveloped spaces | Vacant lot | Semi public | Medium | Collective Infrastructure | Municipal government, NGOs, spatial practitioners, and individuals | Social and recreational | Water (rainwater harvest) and food (collective garden) | CAW Arquitectos |
| Underdeveloped spaces | Open air dumpsite | Public | Medium | Organized Groups | Individuals, municipal government, public institutions, and spatial practitioners | Resource management and recreational | Solid waste (domestic waste disposal) | Enlace Arquitectura |
| Gardens | Vacant lot | Public | Medium | Organized Groups | Spatial practitioners, public institutions, NGOs, and individuals | Resource management and social | Water (rainwater harvest) and food (collective garden) | LAB.PRO.FAB |
| Underdeveloped spaces | Vacant lot | Public | Large | Collective Infrastructure | Municipal government, NGOs, spatial practitioners, and individuals | Social and recreational | Water (rainwater harvest) | Taller Síntesis + D. Herrera + M. Valencia |
| Parks | Abandoned park | Public | Large | Research Studies | Academia, spatial practitioners, municipal government, and individuals | Social, recreational, and resource management | Solid waste (recycling center) | Taller Activo |
| Gardens | Private garden | Semi public | Small | Organized Groups | NGOs and spatial practitioners | Cultural and resource management | Water (rainwater harvesting) | Latitude Platform + Collectif Dallas |
| Underdeveloped spaces | Abandoned building | Semi public | Medium | Collective Infrastructure | Spatial practitioners, public institutions, NGOs, and individuals | Social and recreational | Water (rainwater harvest) and solid waste (compost) | Assemble |
| Underdeveloped spaces | Abandoned park | Public | Medium | Organized Groups | NGOs, individuals, municipal government, and spatial practitioners | Recreational and social | Water (infiltration) and food (collective garden) | Baukunst |
| Underdeveloped spaces | Parking lot | Public | Extra-large | Collective Infrastructure | Individuals, NGOs, municipal government, and spatial practitioners | Cultural, educational, lucrative, and social | Water (rainwater harvesting), food (colleegive garden), and materials (reused construction materials) | LAB.PRO.FAB |
| Underdeveloped spaces | River banks | Semi public | Large | Collective Infrastructure | NGOs, spatial practitioners, individuals, public institutions, and municipal government | Recreational, social, and resource management | Water (biological water treatment) | Pool is Cool |
| Underdeveloped spaces | Vacant lot | Public | Large | Collective Infrastructure | Regional government, municipal government, spatial practitioners, NGOs, and individuals | Cultural, recreational, social, and resource management | Water (rainwater harvest), solid waste (compost), energy (windmill and solar pannels), and food (collective garden) | 1010 Architecture and Urbanism |
| Underdeveloped spaces | Vacant lot | Public | Large | Research Studies | NGOs, academia, individuals, and private sector | Social, educational, recreational, and resource management | Water (rainwater harvest), solid waste (compost and recyleing), and food (collective garden) | Jan Kattein Architects |
| Underdeveloped spaces | Vacant lot | Public | Large | Collective Infrastructure | Municipal government, public institutions, spatial practitioners, NGOs, and individuals | Social, educational, recreational, and resource management | Water (rainwater harvest), solid waste (compost, biodigester, and recycling), energy (biogas), and food (collective garden) | Public Works |

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Hybrid Spaces | HS01 | N30 | Kings Cross Skip Garden | Collective garden | 2015 | London (GB) | Urban city center |
| Hybrid Spaces | HS01 | N41 | R-Urban Poplar | Urban farm | 2012 | London (GB) | Urban city center |
| Hybrid Spaces | HS01 | N40 | R-Urban Colombes | Urban farm | 2012 | Colombes (FR) | Urban city center |
| Hybrid Spaces | HS01 | N39 | Espai Germanetes | Collective garden | 2012 | Barcelona (ES) | Urban city center |
| Mobile Artifacts | MA04 | S04 | The Floating Greenhouse | Collective garden | 2023 | Samborondón (EC) | Rural periphery |
| Mobile Artifacts | MA01 | N01 | Remorque Réno | Solar energy laboratory | 2023 | Brussels (BE) | Urban city center |
| Mobile Artifacts | MA03 | N24 | Jardins Mobiles | Collective garden | 2017 | Courbevoie (FR) | Urban city center |
| Mobile Artifacts | MA02 | N23 | The W.O.W. | Workshop on wheels | 2017 | Berlin (DE) | Urban city center |
| Mobile Artifacts | MA04 | N33 | Jellyfish Barge | Collective garden | 2015 | Milano (IT) | Urban city center |
| Mobile Artifacts | MA01 | N38 | R-Urban Wick | Workshop on wheels | 2013 | London (GB) | Urban city center |
| Modular Units | MA01 | S01 | Fazendinha Nursery | Seedling Nursery | 2024 | Belo Horizonte (BR) | Informal settlement |
| Modular Units | MU02 | S06 | San Luis Fog Catcher | Community fog catcher | 2022 | Bogota (CO) | Informal settlement |
| Modular Units | MU01 | S30 | Maloca Community Kitchen | Community kitchen | 2019 | Iquitos (PE) | Rural periphery |

*Table S5.3d: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 4).*

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Underdeveloped spaces | Vacant lot | Public | Large | Organized Groups | NGOs, academia, individials, and private sector | Social, educational, recreational, and resource management | Water (rainwater harvest), solid waste (compost and recyleing), and food (collective garden) | Jan Kattein Architects |
| Underdeveloped spaces | Vacant lot | Public | Large | Networking Platforms | Spatial practitioners, international institutions, municipal government, public institutions, NGOs, academia, and individuals | Resource management, social, educational, and recreational | Water (rainwater harvest), solid waste (compost, biodigester, dry toilets), energy (biogas), and food (collective garden) | Public Works + AAA |
| Underdeveloped spaces | Vacant lot | Public | Large | Networking Platforms | Spatial practitioners, international institutions, municipal government, public institutions, NGOs, academia, and individuals | Resource management, social, educational, and recreational | Water (rainwater harvest), solid waste (compost), and food (collective garden) | AAA + Collectif ETC |
| Underdeveloped spaces | Vacant lot | Public | Medium | Organized Groups | NGOs, individuals, and spatial practitioners | Resource management, social, and educational | Solid waste (compost), and food (collective garden) | Straddle3 |
| Water bodies | Common spaces | Semi private | Small | Organized Groups | Spatial practitioners and individuals | Resource management | Energy (solar pannels) and food (collective garden) | Natura Futura + J.C. Bamba |
| Various | - | Public | Small | Organized Groups | NGOs, spatial practitioners, municipal government, and individuals | Resource management | Energy (solar pannels) | City Mine(d) |
| Squares | Vacant lot | Public | Small | Organized Groups | Municipal government, spatial practitioners, NGOs, and individuals | Resource management, educational, and social | Solid waste (compost), and food (collective garden) | Coloco |
| Various | - | Public | Small | Organized Groups | Spatial practitioners and individuals | Social and educational | Solid waste (reuse of construction materials) | Constructlab |
| Water bodies | Common spaces | Semi private | Small | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Resource management | Water (rainwater harvest), energy (solar pannels), and food (collective garden) | PNAT |
| Various | - | Public | Small | Networking Platforms | Spatial practitioners, international institutions, municipal government, public institutions, NGOs, academia, and individuals | Resource management, social, educational, and recreational | Solid waste (recycling center and workshop) | Public Works + AAA |
| Underdeveloped spaces | Vacant lot | Semi public | Small | Research Studies | Academia, spatial practitioners, and individuals | Social and educational | Solid waste (compost) and food (collective garden) | PFLEX |
| Gardens | Vacant lot | Semi private | Small | Organized Groups | Spatial practitioners, individuals, and public institutions | Resource management | Water (rainwater harvest) and food (collective garden) | Alsar Atelier + O. Zamora + C. Salomon |
| Underdeveloped spaces | Common spaces | Public | Small | Research Studies | Individuals, municipal government, academia, and spatial practitioners | Resource management and social | Water (rainwater harvesting and treatment system) and energy (solar barbecue) | CASA PUCP |

| urban archetype | variant | # | name | description | year | city | context |
|---|---|---|---|---|---|---|---|
| Modular Units | MU01 | S29 | Macarao Community Kitchen | Community kitchen | 2019 | Caracas (VE) | Informal settlement |
| Modular Units | MU01 | S26 | Collective Care Spaces | Community showers | 2019 | Iquitos (PE) | Rural periphery |
| Modular Units | MU01 | S41 | Ciudad Dormitorio communal space | Community center | 2017 | Lima (PE) | Informal settlement |
| Modular Units | MU02 | S48 | Brigadas en Frontera | Community toilets | 2016 | Loreto (PE) | Rural periphery |
| Modular Units | MU01 | N04 | Space for Solidarity | Homeless service center | 2022 | Bucharest (RO) | Urban city center |
| Modular Units | MU01 | N27 | Giardino Ammirato | Collective garden | 2016 | Lecce (IT) | Urban city center |
| Modular Units | MU03 | N25 | Agronautas Villaverde | Collective garden | 2016 | Madrid (ES) | Urban periphery |
| Modular Units | MU03 | N34 | Alhambra Garden | Collective garden | 2014 | Brussels (BE) | Urban city center |
| Modular Units | MU01 | N44 | Jardins Da-Ko-T | Collective garden | 2010 | Paris (FR) | Urban city center |
| Networking Systems | NS03 | S46 | Água Carioca Wetlands | Constructed wetlands | 2016 | Rio de Janeiro (BR) | Informal settlement |
| Networking Systems | NS01 | S53 | Palomino Cultural Infrastructure | Community center | 2013 | Guajira (CO) | Rural periphery |
| Networking Systems | NS02 | S51 | Centro Social Las Margaritas | Community center | 2013 | San Luis de Potosí (MX) | Rural periphery |
| Networking Systems | NS01 | N11 | Krater | Production space | 2020 | Ljubljana (SI) | Urban city center |

*Table S5.3e: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 5).*

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Gardens | Private patio | Semi private | Small | Organized Groups | Individuals, NGOs, and spatial practitioners | Social and educational | Water (rainwater harvest) | Incursiones |
| Underdeveloped spaces | Common spaces | Public | Small | Research Studies | Individuals, municipal government, academia, and spatial practitioners | Resource management and social | Water (rainwater harvesting and treatment system) | CASA PUCP |
| Underdeveloped spaces | High slope space | Semi public | Small | Research Studies | Academia, spatial practitioners, NGOs, and individuals | Educational, social, and resource management | Water (fog harvesting) and food (collective garden) | Natura Futura + J.F. Gómez + F. Quiroz |
| Underdeveloped spaces | Vacant lot | Public | Small | Research Studies | Public institutions, academia, spatial practitioners, NGOs, and individuals | Resource management and social | Water (rainwater harvest and dry toilets) | Plan Selva |
| Underdeveloped spaces | Abandoned site | Public | Small | Organized Groups | NGOs, spatial practitioners, municipal government, and individuals | Social | Energy (photovoltaic pannels) | Atelier Ad Hoc Comunitate |
| Underdeveloped spaces | Abandoned garden | Semi public | Small | Organized Groups | Public institutions, NGOs, spatial practitioners, and individuals | Social, educational, and recreational | Food (collective garden) | Constructlab |
| Underdeveloped spaces | Vacant lot | Public | Small | Organized Groups | Municipal government, spatial practitioners, NGOs, and individuals | Resource management, social, and educational | Solid waste (compost), and food (collective garden) | Pez Estudio |
| Streets | Road surface | Semi public | Small | Organized Groups | Individuals, NGOs, spatial practitioners, regional government, and private sector | Resource management and social | Food (collective garden), solid waste (compost), and water (rainwater harvesting and infiltration) | KIS studio |
| Underdeveloped spaces | Abandoned park | Public | Medium | Organized Groups | Municipal government, public institutions, spatial practitioners, NGOs, and individuals | Social, educational, and resource management | Water (rainwater harvest), solid waste (compost), and food (collective garden) | Bruit du Frigo |
| Underdeveloped spaces | High slope space | Public | Small | Research Studies | Spatial practitioners, NGOs, academia, municipal government, and individuals | Resource management | Water (waste water treatment) | Ooze Architects |
| Underdeveloped spaces | Vacant lot | Public | Medium | Research Studies | Academia, spatial practitioners, and individuals | Resource management, social, and educational | Water (rainwater harvest and dry toilets) | Yemail Arquitectura |
| Underdeveloped spaces | Vacant lot | Public | Medium | Organized Groups | Individuals, spatial practitioners, NGOs, municipal government, and private sector | Social, educational, and recreational | Solid waste (reuse of construction materials) | Dellekamp Arquitectos + TOA |
| Underdeveloped spaces | Abandoned site | Public | Large | Organized Groups | Municipal government, public institutions, spatial practitioners, NGOs, and individuals | Resource management, educational, and social | Water (rainwater harvest) and solid waste (recylcing) | Krater Collectif |

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Networking Systems | NS01 | N18 | Floating University | Water retention park and laboratory | 2018 | Berlin (DE) | Urban city center |
| Networking Systems | NS01 | N43 | El Campo de Cebada | Community center | 2010 | Madrid (ES) | Urban city center |
| Networking Systems | NS01 | N47 | Institute for X | Cultural center and park | 2009 | Aarhus (DE) | Urban city center |
| Shaped Volumes | SV01 | S08 | Lomas de Paraiso Greenhouse | Collective garden | 2022 | Lima (PE) | Informal settlement |
| Shaped Volumes | SV01 | S07 | The Center for Added Value | Community center | 2022 | Caimancito (AR) | Rural periphery |
| Shaped Volumes | SV01 | S05 | Mencoriari Environment Laboratory | Community center | 2022 | Tanquín (PE) | Rural periphery |
| Shaped Volumes | SV01 | S15 | Minga Concón Greenhouse | Collective garden | 2021 | Valparaiso (CL) | Urban city center |
| Shaped Volumes | SV01 | S13 | Entre Ríos | Environmental education classroom | 2021 | Concordia (AR) | Rural periphery |
| Shaped Volumes | SV01 | S12 | El Rincón | Environmental classroom | 2021 | San Jerónimo (CO) | Rural periphery |
| Shaped Volumes | SV01 | S34 | Castanhas de Caju Extension | Community center | 2018 | Bom Jesus das Selvas (BR) | Rural periphery |
| Shaped Volumes | SV02 | S40 | Centro Hídrico Comunitario | Community laundry space | 2017 | Piñícuaro (MX) | Rural periphery |
| Shaped Volumes | SV01 | S56 | Estación Ecológica Las Malvinas | Community center | 2011 | Sto. Domingo (DO) | Urban periphery |
| Shaped Volumes | SV03 | N13 | Bookgarden | Library and gardens | 2019 | Madrid (ES) | Urban city center |

*Table S5.3f: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 6).*

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Underdeveloped spaces | Abandoned airport | Public | Extra-large | Networking Platforms | Spatial practitioners, academia, public institutions, NGOs, individuals, and private sector | Educational, cultural, social, and resource management | Water (rainwater harvest and sewage treatment), solid waste (compost and biodigester), and food (collective garden) | Raumlabor |
| Underdeveloped spaces | Vacant lot | Public | Large | Organized Groups | Individuals, spatial practitioners, NGOs, public institutions, and municipal government | Social, educational, cultural, and recreational | Solid waste (compost and recycling) and food (collective garden) | El Campo de Cebada + Todo X La Praxis |
| Underdeveloped spaces | Abandoned site | Public | Extra-large | Networking Platforms | Individuals, spatial practitioners, NGOs, public institutions, and municipal government | Resource management, educational, and social | Water (rainwater harvest and sewage treatment), solid waste (compost and biodigester), and food (collective garden) | Trans Europe Halles |
| Underdeveloped spaces | Vacant lot | Semi private | Medium | Organized Groups | Municipal government, NGOs, spatial practitioners, and individuals | Social and resource management | Food (collective garden) and solid waste (compost) | Colectivo Más Ciudad |
| Underdeveloped spaces | Vacant lot | Semi public | Small | Organized Groups | NGOs, spatial practitioners, and individuals | Resource management and social | Water (rainwater harvesting and treatment system), solid waste (compost), and food (collective garden) | CIMBRA |
| Gardens | Vacant lot | Semi private | Medium | Organized Groups | NGOs, spatial practitioners, and individuals | Educational and resource management | Water (rainwater harvest) and food (collective garden) | Marta Maccaglia + Semillas |
| Parks | Vacant lot | Semi public | Small | Organized Groups | NGOs, Individuals, national government, and spatial practitioners | Educational and social | Food (collective garden) and solid waste (compost) | Minga Valpo |
| Parks | Vacant lot | Semi private | Medium | Collective Infrastructures | NGOs, spatial practitioners, public institutions, and individuals | Cultural, educational, and resource management | Water (rainwater harvesting), energy (solar pannels), and food (collective garden) | TAGMA + a77 |
| Gardens | Vacant lot | Semi private | Small | Collective Infrastructures | NGOs, spatial practitioners, public institutions, and individuals | Cultural, educational, and resource management | Water (rainwater harvesting), energy (solar pannels), and food (collective garden) | Plan B Arquitectos |
| Underdeveloped spaces | Abandoned house | Semi private | Medium | Organized Groups | NGOs, spatial practitioners, and individuals | Social and resource management | Water (rainwater harvest and sewage treatment), solid waste (compost and biodigester), and food (collective garden) | Estudio Flume |
| Underdeveloped spaces | Vacant lot | Public | Small | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Resource management and social | Water (groundwater harvest) | Taller Experimental UNAM |
| Parks | Vacant lot | Public | Small | Organized Groups | Public institutions, municipal government, academia, spatial practitioners, NGOs, and individuals | Resource management, social, educational, and recreational | Water (rainwater harvest and dry toilets) | Pez Estudio |
| Underdeveloped spaces | Vacant lot | Public | Small | Organized Groups | Municipal government, spatial practitioners, public institutions, and individuals | Social and recreational | Food (collective garden) | Kune Office |

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Shaped Volumes | SV01 | N20 | Les Cabanes du Jardin Spinelly | Neighborhood park | 2018 | Marseille (FR) | Urban city center |
| Shaped Volumes | SV01 | N22 | Tandem | Urban furniture | 2017 | Madrid (ES) | Urban city center |
| Shaped Volumes | SV01 | N29 | Ressò | Community center | 2016 | Rubí (ES) | Urban periphery |
| Shaped Volumes | SV01 | N37 | The Proper Water Pavilion | Rain water harvester space | 2014 | Brussels (BE) | Urban city center |
| Shaped Volumes | SV01 | N36 | Parckfarm Farmhouse | Collective garden | 2014 | Brussels (BE) | Urban city center |
| Symbiotic Structures | SS01 | S32 | Casino | Cultural center | 2019 | Caracas (VE) | Urban city center |
| Symbiotic Structures | SS01 | S27 | La Casa de Todos | Cultural and community center | 2019 | Caracas (VE) | Informal settlement |
| Symbiotic Structures | SS01 | S39 | Divina Community Station | Community center | 2018 | Tijuana (MX) | Urban periphery |
| Symbiotic Structures | SS02 | S37 | Taller Tropical Moravia | Community center and collective garden | 2018 | Medellin (CO) | Informal settlement |
| Symbiotic Structures | SS02 | S44 | San Martín Center | Community center and kitchen | 2017 | Lima (PE) | Informal settlement |
| Symbiotic Structures | SS03 | N09 | Jardin Collectif Gray Moineaux | Collective garden | 2021 | Brussels (BE) | Urban city center |
| Symbiotic Structures | SS01 | N19 | Guilbard | Recycling center and material workshop | 2018 | Brussels (BE) | Urban city center |
| Symbiotic Structures | SS02 | N32 | Mon(s) invisible | Community center | 2015 | Mons (BE) | Urban city center |

*Table S5.3g: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 7).*

| *urban space* | *site type* | *access* | *scale* | *governance* | *stakeholders involved* | *activities and practices* | *resource management* | *design practitioners* |
|---|---|---|---|---|---|---|---|---|
| Parks | Abandoned park | Public | Small | Organized Groups | Individuals, NGOs, municipal government, and spatial practitioners | Social and recreational | Water (infiltration) | Collectif ETC |
| Squares | Vacant lot | Public | Small | Organized Groups | Municipal government, spatial practitioners, NGOs, and individuals | Resource management and recreational | Energy (photovoltaic pannels) | Todo X La Praxis |
| Underdeveloped spaces | Vacant lot | Semi public | Medium | Research Studies | Academia, spatial practitioners, municipal government, public institutions and individuals | Resource management and social | Energy (photovoltaic and thermal pannels) | Ressò |
| Underdeveloped spaces | Brownfield | Public | Small | Organized Groups | NGOs, individuals, and regional government | Resource management, social, educational, and recreational | Water (rainwater harvest) | City Mine(d) |
| Underdeveloped spaces | Abandoned railway | Public | Medium | Collective Infrastructures | NGOs, individuals, spatial practitioners, municipal government, and public institutions | Resource management, educational, and social | Water (dry toilets) and solid waste (recycling) | 1010 Architecture and Urbanism |
| Underdeveloped spaces | Abandoned building | Semi public | Medium | Collective Infrastructures | Spatial practitioners, NGOs, academia, municipal government, and individuals | Cultural, educational, and resource management | Solid waste (recycling center) | Pico Colectivo |
| Underdeveloped spaces | Abandoned building | Semi public | Large | Collective Infrastructures | Individuals, NGOs, municipal government, international institutions, private sector, and spatial practitioners | Cultural, educational and social | Water (rainwater harvest) and food (collective garden) | Enlace Arquitectura |
| Underdeveloped spaces | Vacant lot | Semi public | Small | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Educational, social, and resource management | Solid waste (compost and recycling) and food (collective garden) | Estudio Teddy Cruz + Fonna Forman |
| Underdeveloped spaces | Abandoned building | Semi public | Small | Collective Infrastructures | NGOs, academia, individuals, and spatial practitioners | Social, educational, cultural, and recreational | Water (infiltration), solid waste (compost and recycling), and food (collective garden) | Urban Lab Medellin / Berlin |
| Parks | Existing building | Public | Medium | Collective Infrastructures | Individuals, municipal government, NGOs, academia, and spatial practitioners | Cultural, recreational, and social | Solid waste (wood workshop and materials reusage) and food (collective garden) | Proyecto Fitekantropus |
| Underdeveloped spaces | Vacant lot | Public | Large | Organized Groups | Individuals, NGOs, spatial practitioners, and municipal government | Resource management, recreational and social | Water (rainwater harvest, water infiltration, and dry toilets), solid waste (compost), and food (collective garden) | Collectif Gray Moineaux |
| Underdeveloped spaces | Abandoned building | Semi private | Large | Organized Groups | Spatial practitioners, NGOs, regional government, and individuals | Resource management | Solid waste (reuse of construction materials) | Guilbard |
| Underdeveloped spaces | Abandoned park | Semi public | Medium | Organized Groups | Public institutions, municipal government, spatial practitioners, NGOs, and individuals | Social, educational, and recreational | Water (rainwater harvest and dry toilets), solid waste (compost), and food (collective garden) | Constructlab + Colectivo Warehouse |

| *urban archetype* | *variant* | *#* | *name* | *description* | *year* | *city* | *context* |
|---|---|---|---|---|---|---|---|
| Symbiotic Structures | SS01 | N42 | Cantiere Barca | Recycling center and wood workshop | 2011 | Turin (IT) | Urban city center |
| Vertical Stackings | VS01 | S19 | Lá da Favelinha Cultural Center | Cultural and community center | 2021 | Belo Horizonte (BR) | Informal settlement |
| Vertical Stackings | VS02 | S16 | Pilares | Community center | 2021 | Mexico City (MX) | Informal settlement |
| Vertical Stackings | VS01 | S14 | Instituto Vila Praia | Community center | 2021 | Sao Paolo (BR) | Urban city center |
| Vertical Stackings | VS01 | S31 | Alacrán Community Station | Refugee camp and community center | 2019 | Tijuana (MX) | Rural periphery |
| Vertical Stackings | VS01 | S36 | La Comuna | Workshop and recycling center | 2018 | Huaquillas (EC) | Rural periphery |
| Vertical Stackings | VS01 | S35 | Chamanga cultural center | Community center | 2018 | San José de Chamanga (EC) | Rural periphery |
| Vertical Stackings | VS01 | S47 | Atacucho Cultural Factory | Workshop and recycling center | 2016 | Quito (EC) | Informal settlement |
| Vertical Stackings | VS02 | N10 | Ebury Edge Community Center | Community center and collective garden | 2020 | Westminster (GB) | Urban city center |
| Vertical Stackings | VS01 | N14 | Centro Comunitario Cañada Real | Community center and workshops | 2019 | Madrid (ES) | Urban periphery |
| Vertical Stackings | VS02 | N26 | Conquer La Marina | Community center | 2016 | Madrid (ES) | Urban periphery |
| Vertical Stackings | VS02 | N45 | Esto no es un Solar | Community center and collective garden | 2010 | Zaragoza (ES) | Urban city center |
| Vertical Stackings | VS01 | N46 | Passage 56 | Cultural and ecological space | 2009 | Paris (FR) | Urban city center |

*Table S5.3h: Inventory of selected 104 ARGS classified by urban archetype and variants, project, description, year of construction, location, urban space used, site and access type, scale, stakeholders, type of community involvement, resources managed, and design practitioners involved. (Inventory sheet 8).*

| ***urban space*** | ***site type*** | ***access*** | ***scale*** | ***governance*** | ***stakeholders involved*** | ***activities and practices*** | ***resource management*** | ***design practitioners*** |
|---|---|---|---|---|---|---|---|---|
| Underdeveloped spaces | Abandoned building | Semi private | Large | Organized Groups | Public institutions, municipal government, spatial practitioners, NGOs, and individuals | Social and educational | Solid waste (recycling center) | Raumlabor |
| Underdeveloped spaces | Abandoned building | Semi public | Medium | Organized Groups | NGOs and spatial practitioners | Social, cultural, and recreational | Solid waste (textile recycling center) | Colectivo Levante |
| Underdeveloped spaces | Vacant lot | Semi public | Medium | Collective Infrastructures | Municipal government, public institutions, spatial practitioners, NGOs, and individuals | Social, educational, cultural, and resource management | Water (rainwater harvest) | AGENdA + TO arq + UdeB + Studio ZV |
| Underdeveloped spaces | Abandoned building | Semi public | Small | Collective Infrastructures | NGOs, spatial practitioners, and individuals | Social, recreational, and resource management | Solid waste (recycling center and workshopl) | Comunità |
| Underdeveloped spaces | Vacant lot | Semi private | Large | Research Studies | Academia, spatial practitioners, individuals, and NGOs | Social | Solid waste (compost) and food (collective garden) | Estudio Teddy Cruz + Fonna Forman |
| Underdeveloped spaces | Abandoned house | Semi private | Medium | Collective Infrastructures | Individuals, NGOs, private sector, and spatial practitioners | Resource management and social | Solid waste (recycling center and workshopl) | Natura Futura + Frontera Sur |
| Underdeveloped spaces | Vacant lot | Semi private | Medium | Collective Infrastructures | Academia, spatial practitioners, and individuals | Cultural, educational, social, and resource management | Water (rainwater harvest and dry toilets) | Atarraya Taller de Arquitectura |
| Underdeveloped spaces | Vacant lot | Semi public | Medium | Organized Groups | Spatial practitioners, academia, NGOs, and individuals | Cultural, educational, social, and resource management | Solid waste (recycling center and workshop) and materials (reuse) | Al Borde |
| Underdeveloped spaces | Vacant lot | Public | Large | Collective Infrastructures | Municipal government, spatial practitioners, public institutions, and individuals | Social and recreationl | Water (rainwater harvest), solid waste (compost), and food (collective garden) | Jan Kattein Architects |
| Underdeveloped spaces | Vacant lot | Semi public | Medium | Collective Infrastructures | Municipal government, spatial practitioners, NGOs, and individuals | Social and educational | Water (dry toilets) | Recetas Urbanas |
| Underdeveloped spaces | Abandoned building | Public | Small | Organized Groups | Individuals, spatial practitioners, and municipal government | Social and recreational | Food (collective garden) | Todo X La Praxis |
| Underdeveloped spaces | Vacant lot | Semi public | Medium | Organized Groups | Spatial practitioners, NGOs, municipal government, public institutions, and individuals | Social, educational, and recreational | Solid waste (compost), and food (collective garden) | P. Di Monte + I. Grávalos |
| Underdeveloped spaces | Vacant lot | Public | Medium | Organized Groups | Municipal government, public institutions, spatial practitioners, NGOs, and individuals | Cultural, educational, social, and resource management | Water (rainwater harvest and dry toilets), solid waste (compost and recycling), and food (collective garden) | AAA |

*Table S5.4: Sources of photos used as references in Figures 5.4a, 5.4b, and 5.4c.*

*(1) La Chacarita in Asunción (PY), Rozana Montiel, 2019. Retrieved April 14, 2024, from https://rozanamontiel.com/en/chacarita/ . Copyright by design practitioners.*

*(2) Las Huertas Termales in Caldes de Montbui (ES), Cavaa Arquitectes, 2015. Retrieved April 14, 2024, from https://www.cavaa.net/portfolio/hortes-de-caldes-de-montbui/ . Photo by Adrià Calbetó. Copyright by design practitioners.*

*(3) 1100 Multifuncional La Ceiba in Caracas (VE), Pico Colectivo + AGA, 2016. Retrieved April 14, 2024, from https://www.aga-estudio.com/1100-la-ceiba . Photo by José Bastidas. Copyright by design practitioners.*

*(4) Eau de Couture in Brussels (BE), Latitude Platform + Collectif Dallas, 2021. Retrieved April 14, 2024, from https://collectifdallas.eu/eau-de-couture . Photo by Bruno Dias Ventura. Copyright by design practitioners.*

*(5) La Esperanza Community Center in Querétaro (MX), Taller Activo, 2013. Retrieved April 14, 2024, from https://g3arquitectos.com/portfolio/centro-comunitario-la-esperanza/ . Photo by Yoshihiro Koitani. Copyright by design practitioners.*

*(6) Plaza Santa Cruz, Enlace Arquitectura, 2021. Retrieved April 14, 2024 from http://www.enlacearquitectura.net/work/2021/12/plaza-santa-cruz/ . Photo by Régulo Gómez/Enlace Foundation. Copyright by design practitioners.*

*(7) El Rincón in San Jerónimo (CO), Plan B Arquitectos, 2021. Retrieved April 14, 2024 from https://www.planbarq.com/#/una-escuela-sustentable/ . Photo by Alejandro Arango. Copyright by design practitioners.*

*(8) Parckfarm Farmhouse in Brussels (BE), 1010 Architecture and Urbanism, 2014. Retrieved April 14, 2024 from https://1010au.net/projects/farmhouse-parckdesign-2014 . Photo by Stijn Beeckman. Copyright by design practitioners.*

*(9) Estación Ecológica Las Malvinas in Santo Domingo (DO), Pezestudio, 2011. Retrieved April 14, 2024 from https://pezestudio.org/2011_09_icsdee/#!org/2011_09_icsdee/#!. Copyright by design practitioners.*

*(10) San Luis Fog Catcher in Bogota (CO), Alsar Atelier + O. Zamora + C. Salomon, 2022. Retrieved April 14, 2024 from https://alsar-atelier.com/Atrapanieblas . Copyright by design practitioners.*

*(11) Macarao Community Kitchen in Caracas (VE), Incursiones , 2019. Retrieved April 14, 2024 from https://incursiones-ve.com/MACARAO . Copyright by design practitioners.*

*(12) Jardins Da-Ko-Tin Paris (FR), Bruit du Frigo, 2010. Retrieved April 14, 2024 from https://bruitdufrigo.com/projets/fiche/jardins-da-ko-t/ . Copyright by design practitioners.*

*(13) Ebury Edge Community Center in Westminster (GB), Jan Kattein Architects, 2020. Retrieved April 14, 2024 from https://jankattein.com/projects/ebury-edge/ . Copyright by design practitioners.*

*(14) Pilares in Mexico City (MX), AGENdA + TO arq + UdeB + Studio ZV, 2021. . Retrieved April 14, 2024 from https://agendarquitectura.com/pilares-cdmxcuicuilco/ . Photo by Jaime Navarro. Copyright by design practitioners.*

*(15) Instituto Vila Praia in Sao Paolo (BR), Comunità, 2021. Retrieved April 14, 2024 from https://www.archdaily.com.br/br/1000416/instituto-vila-praia-comunita?ad_source=search&ad_medium=projects_tab&ad_source=search&ad_medium=search_result_projects . Photo by Carolina Lacaz. Copyright by design practitioners.*

*(16) Jardin Collectif Gray Moineaux in Brussels (BE), Collectif Fray Moineaux, 2021. Photo by authors.*

*(17) La Casa de Todos in Caracas (VE), Enlace Arquitectura, 2019. Retrieved April 14, 2024 from http://enlacearquitectura.net/work/2022/10/annex-casa-de-todos/ . Photo by Enlace Foundation. Copyright by design practitioners.*

*(18) Taller Tropical Moravia in Medellin (CO), Natural Building Lab + TU Berlin + Urban Oasis + Arquitectura del Oximoron, 2018. Retrieved August 28, 2024 from https://www.nbl.berlin/projects/taller-tropical/ . Copyright by design practitioners.*

*(19) The W.O.W. in Berlin (DE), Constructlab, 2017. Retrieved April 14, 2024 from https://constructlab.net/projects/w-o-w/#media857 . Copyright by design practitioners.*

*(20) Rémorque Réno in Brussels (BE), City Mine(d), 2023. Retrieved April 14, 2024 from http://www.lapile.org/en/remorque-reno-1 . Copyright by design practitioners.*

*(21) The Floating Greenhouse in Samborondón (EC), 2023. Retrieved April 14, 2024 from https://www.archdaily.com/1001434/the-floating-greenhouse-natura-futura-arquitectura-plus-juan-carlos-bamba?ad_source=search&ad_medium=projects_tab&ad_source=search&ad_medium=search_result_projects . Copyright by design practitioners.*

*(22) Floating University in Berlin (DE), Raumlabor, 2018. Retrieved April 14, 2024 from https://floating-berlin.org/ . Photo by Victoria Tomashko. Copyright by design practitioners.*

*(23) Palomino Cultural Infrastructure in Guajira (CO), Yemail Arquitectura, 2013. Retrieved April 14, 2024 from https://yemailarquitectura.co/portfolio/palomino-cultural/ . Copyright by design practitioners.*

*(24) El Campo de Cebada in Madrid (ES), El Campo de Cebada + Todo X La Praxis, 2010. Retrieved August 28, 2024 from https://openverse.org/image/65cca0c6-b812-4ebd-bb91-0311eb76d00d?q=campo+de+cebada+madrid . Photo by Manuel Domínguez Fernández, CC BY-SA 4.0.*

*(25) Espai Germanetes in Barcelona (ES), Straddle3, 2012. Retrieved April 14, 2024 from https://straddle3.net/en/proyectos/germanetes . Copyright by design practitioners.*

*(26) R-Urban in Colombes (FR), AAA + Collectif ETC, 2012. Retrieved August 28, 2024 from https://openverse.org/image/ef32f580-79e7-4218-a514-bdb252103796?q=r-urban . Photo by xkidx, CC BY-SA 2.0.*

*(27) Tiuna El Fuerte Cultural Park in Caracas (VE), LAB.PRO.FAB, 2005. Retrieved April 14, 2024 from https://labprofab.org/intersticial-park/ . Copyright by design practitioners.*

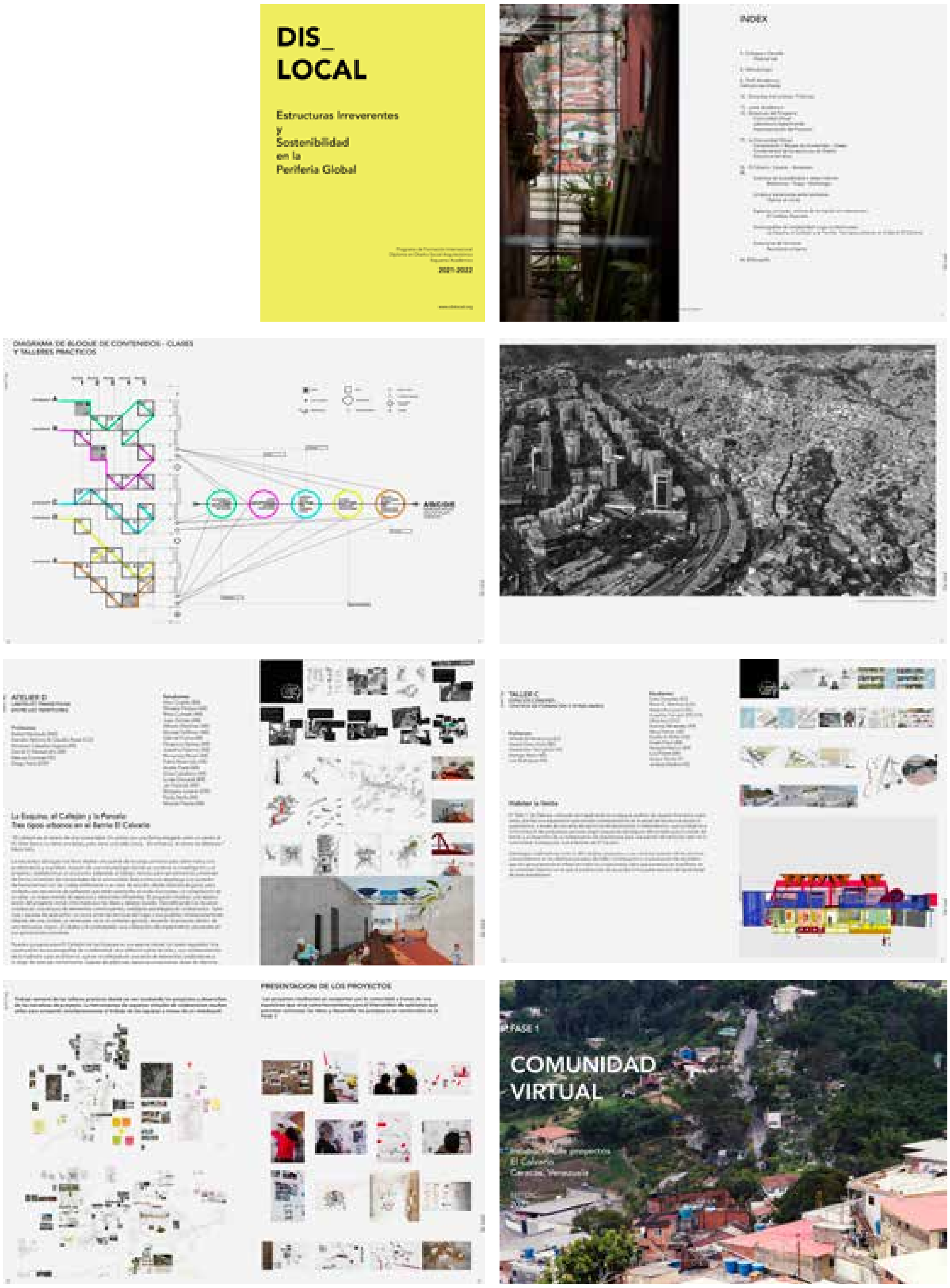
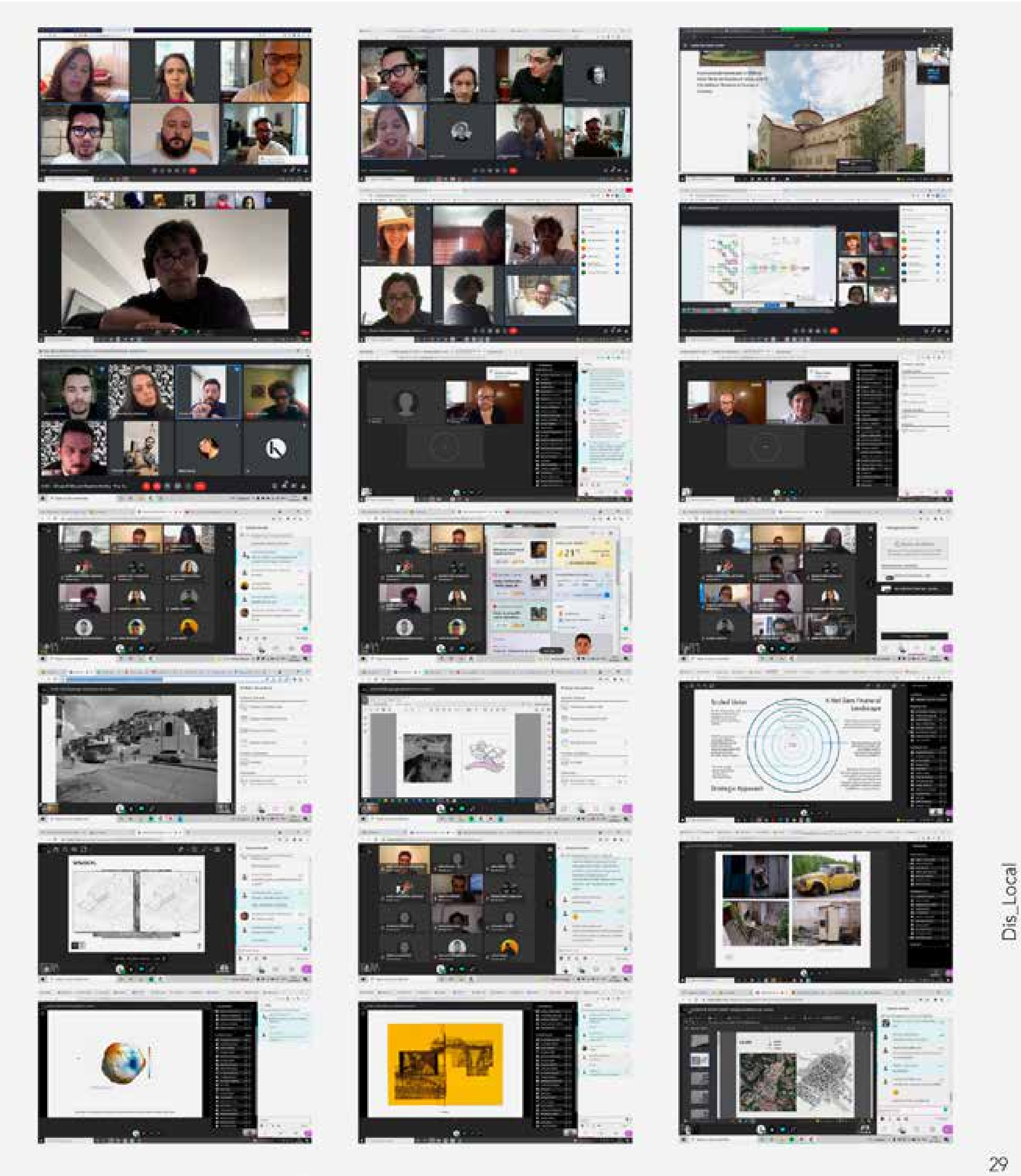
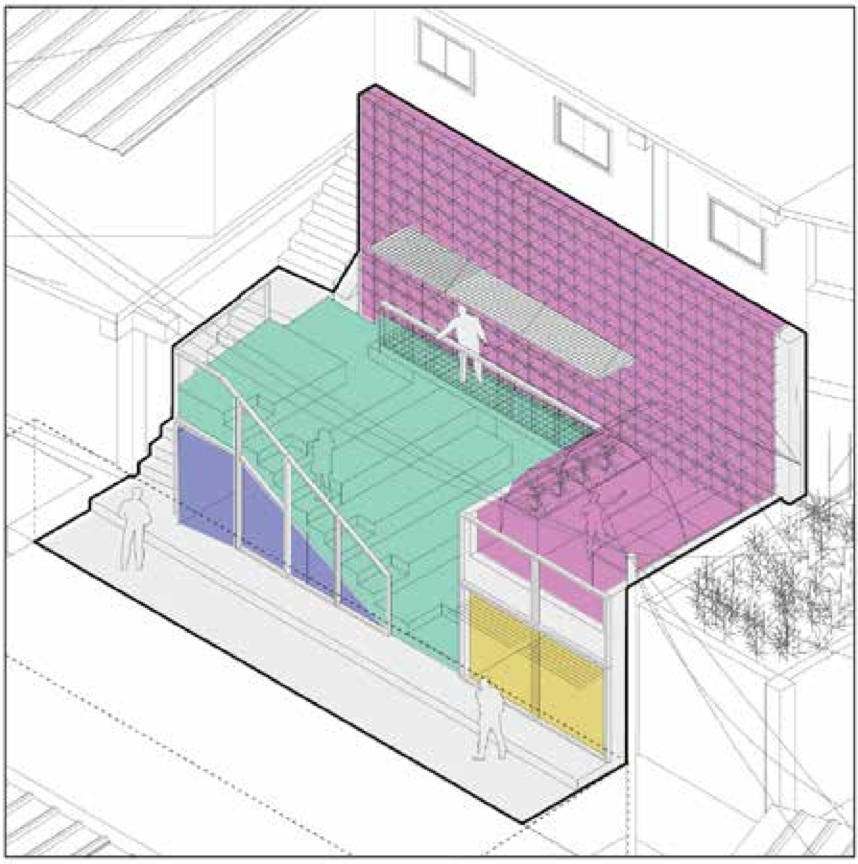



*Figure S5.1: An excerpt from the results and processes of the 2021 workshop Irreverent Structures and Sustainability in the Global Periphery, organized by the architecture platform DISLOCAL. This workshop was conducted through a hybrid format, combining online sessions with on-site activities in the community of El Calvario, Caracas, Venezuela..*


Dis_Local
29

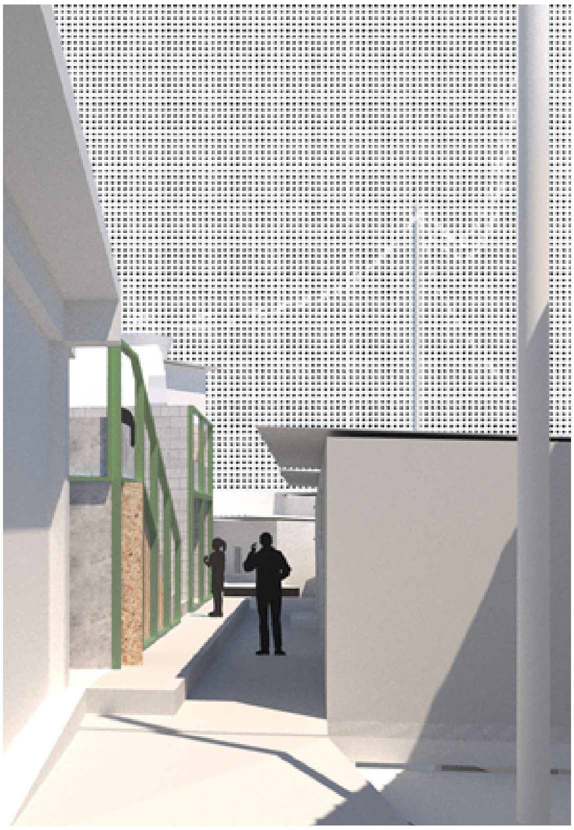
**Scenario 2** *La Parcela Community Center*
*Site A: 52 m2*



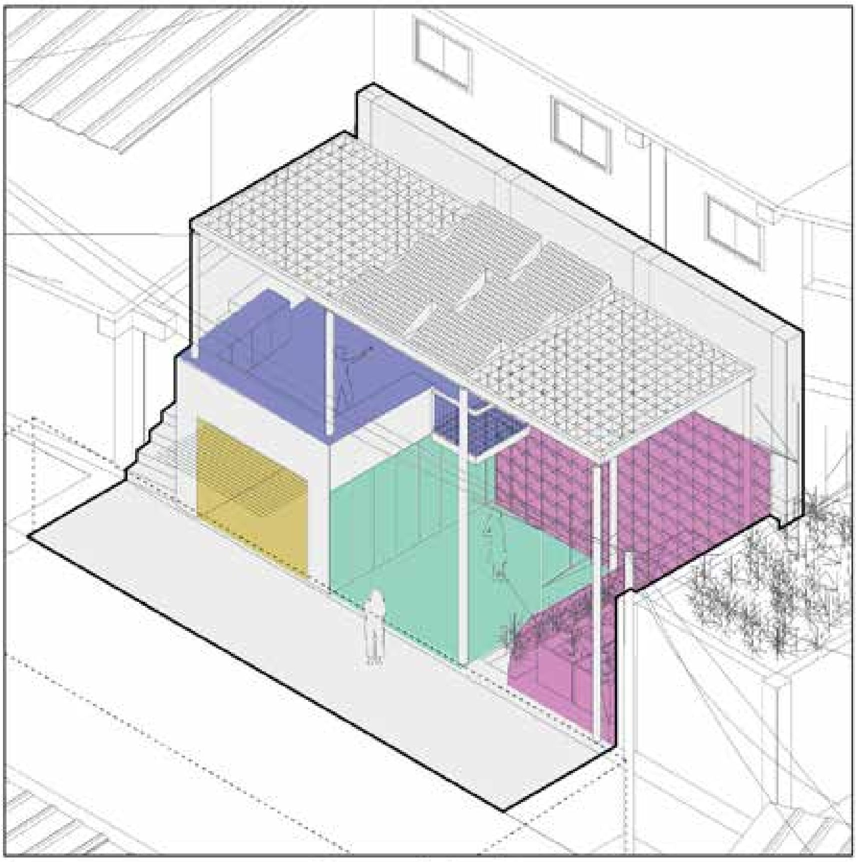
*Adaptive Ground*

| | |
|---|---|
| **Urban Space** | **137 m2** |
| **User capacity** | **30 people** + *visitors* |
| Meeting Spaces ● | 36 m2 |
| Working Spaces ● | 13 m2 |
| Farming Spaces ● | 7 m2 |
| Rental Spaces ● | 11 m2 |
| Harvesting greenwalls | 53 m2 |
| Gardens *(pemeable area)* | 2 m2 |
| Other *(technical spaces, storage)* | 17 m2 |
| **Water** *(rainwater harvest)* | **42 l/day** |
| **Energy** *(solar pannels)* | **9.48 kWh/day** |
| **Solid Waste** *(organic compost)* | **72 kg/day** |

*Figure S5.2: Excerpt of 3D model of the Adaptive Ground urban archetype, applying the Programmatinc Scenario 2 (Community Center) to Plot A (La Parcela). The figure includes detailed quantitative data on the number of urban spaces created, potential users, and resource harvest and waste treatment capacities. Additionally, the representation features illustrative views from within the community, showcasing perspectives from the primary access points.*



**Scenario 2** *La Parcela Community Center*
*Site A: 52 m2*



*Covered Surface*

| | |
|---|---|
| **Urban Space** | **92 m2** |
| **User capacity** | **20 people** *+ visitors* |
| Meeting Spaces ● | 14 m2 |
| Working Spaces ● | 17 m2 |
| Farming Spaces ● | 8 m2 |
| Rental Spaces ● | 11 m2 |
| Harvesting greenwalls | 35 m2 |
| Gardens *(pemeable area)* | 3 m2 |
| Other *(technical spaces, storage)* | 7 m2 |
| **Water** *(rainwater harvest)* | **102 l/day** |
| **Energy** *(solar pannels)* | **21.49 kWh/day** |
| **Solid Waste** *(organic compost)* | **37 kg/day** |

*Figure S5.3: Excerpt of 3D model of the Covered Surface urban archetype, applying the Programmatinc Scenario 2 (Community Center) to Plot A (La Parcela). The figure includes detailed quantitative data on the number of urban spaces created, potential users, and resource harvest and waste treatment capacities. Additionally, the representation features illustrative views from within the community, showcasing perspectives from the primary access points.*

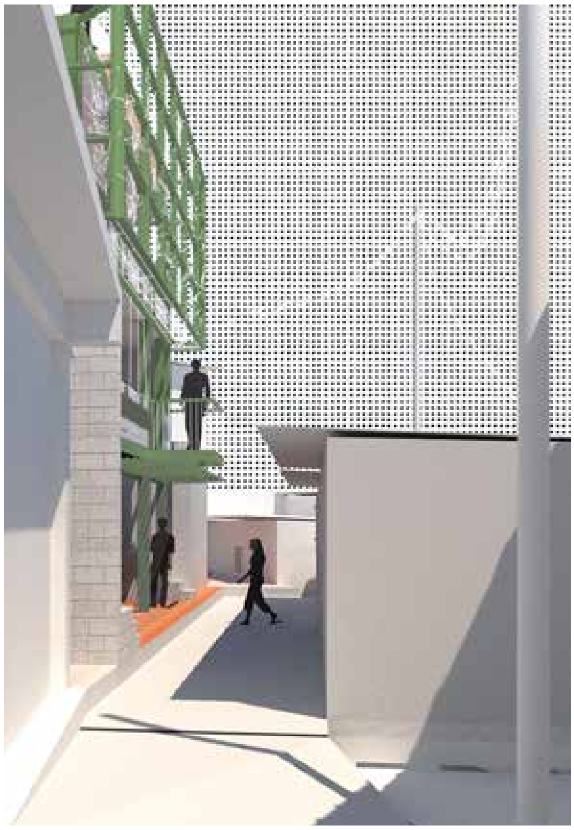
**Scenario 2** *La Parcela Community Center*
*Site A: 52 m2*

*Vertical Stacking*

| | |
|---|---|
| **Urban Space** | **175 m2** |
| **User capacity** | **30 people** *+ visitors* |
| Meeting Spaces ● | 27 m2 |
| Working Spaces ● | 25 m2 |
| Farming Spaces ● | 19 m2 |
| Rental Spaces ● | 30 m2 |
| Harvesting greenwalls | 41 m2 |
| Gardens *(pemeable area)* | - |
| Other *(technical spaces, storage)* | 33 m2 |
| **Water** *(rainwater harvest)* | **87 l/day** |
| **Energy** *(solar pannels)* | **7.60 kWh/day** |
| **Solid Waste** *(organic compost)* | **55 kg/day** |

*Figure S5.4: Excerpt of 3D model of the Vertical Stacking urban archetype, applying the Programmatinc Scenario 2 (Community Center) to Plot A (La Parcela). The figure includes detailed quantitative data on the number of urban spaces created, potential users, and resource harvest and waste treatment capacities. Additionally, the representation features illustrative views from within the community, showcasing perspectives from the primary access points.*


LA PARCELA



*Canopy with solar panels in a public space in Mexico City, Mexico. Photo by author, 2023*

# *6 Conclusions*

*General conclusions, research limitations, and further research.*

## *6 Conclusions*

This research aimed to study the spatial dimension of urban metabolism (UM) as applied to urban planning and design across diverse social and geographical contexts and at varying scales of resource infrastructure. In particular, by implementing spatially explicit UM assessments as a diagnostic tool including geographic and socio-ecological data inputs to explore *how can public space design enhance resource efficiency and community involvement in urban environments*. This main research question centered on the intersection of UM frameworks and public space design, acknowledging the multidimensional role of public space as both physical infrastructures and social systems that link resource flows with community organization. To address this question, three interconnected studies implementing UM frameworks were conducted and focused on *i*) the physical dimension of public space and resource efficiency through the concentration of open space networks (*Chapter 3*), *ii*) the social dimension of public space emphasizing in community involvement through resource management (*Chapter 4*), *iii*) and the design of public space by developing resource-sensitive and community-inclusive urban archetypes (*Chapter 5*), see *Figure 6.1*. Each study addressed specific sub-questions to achieve the stated objectives, employing diverse methodologies that integrated top-down and bottom-up approaches, geographic information system (GIS) mapping, quantitative and qualitative analyses of spatially explicit data, 3D spatial modeling, and research by design approaches.

Moreover, this research contributes to the field of Industrial Ecology by adopting a spatially explicit approach to resource flows and stocks quantification across diverse contexts, particularly in urban environments of the Global South, which UM studies remain underexplored. The spatial implications of UM frameworks addressed in this study encompass both the representation of resource flow consumption and its infrastructure at the city scale (*Chapter 3*) and the collection and spatial representation of fine-grained data at the local scale (*Chapter 4*). This approach also emphasized the role of urban space as a tool to enhance resource efficiency and foster community involvement. In the disciplines of Urban Planning and Design, the research advances methodological approaches for applying UM frameworks to urban planning strategies at the regional scale (*Chapters 3* and *4*) and to design strategies for public space and facilities at a more localized scale (*Chapters 4* and *5*). This dual-scale approach addressed gaps in existing methodologies, enabling a deeper integration of resource management and community involvement into urban planning and design practices.

In *Chapter 3*, the research aimed to understand to *what extent GIS-explicit data can improve the applicability of UM studies in the planning and management of open space networks*. By spatializing resource flows and infrastructure, open space networks, and vulnerable communities in Mexico City, the results highlighted hotspots based on resource efficiency through the *Borough Pattern Scan* and GIS mapping. These hotspots provided a foundation for discussing possible design strategies that urban planners and designers could implement to address resource-related vulnerabilities and promote more equitable and sustainable open space networks.

In *Chapter 4*, the research aimed to understand *which socio-ecological activities and practices within alternative resource governance systems (ARGS) can be identified as drivers to enhance the applicability of resource-sensitive and community led urban planning and design strategies*; while exploring *what kind of finer-grain spatially explicit data could be collected to enhance a context- and community-specific UM*. Through a UM spatially explicit analysis of Brussels Capital Region, integrating GIS mapping, fieldwork and interviews of

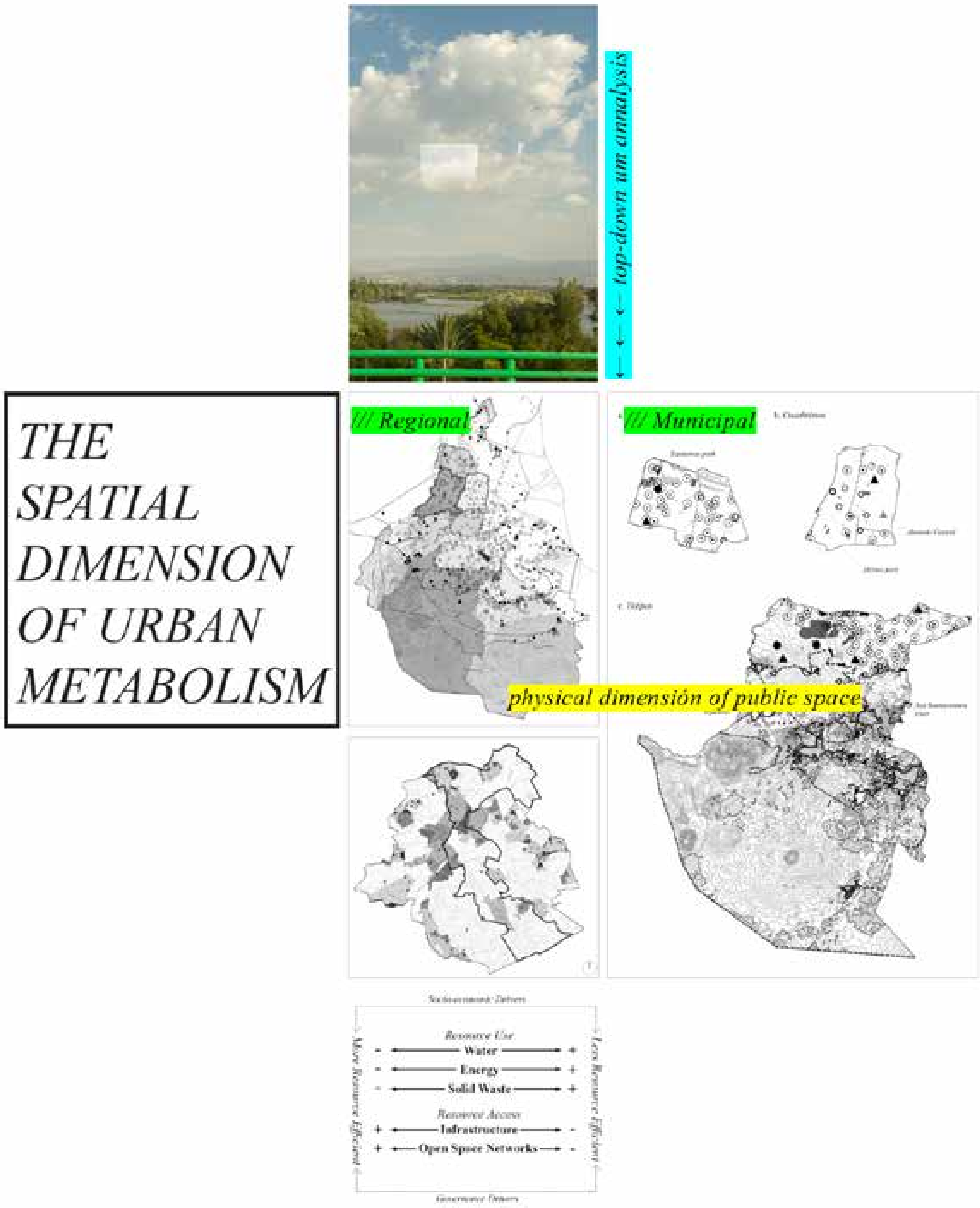
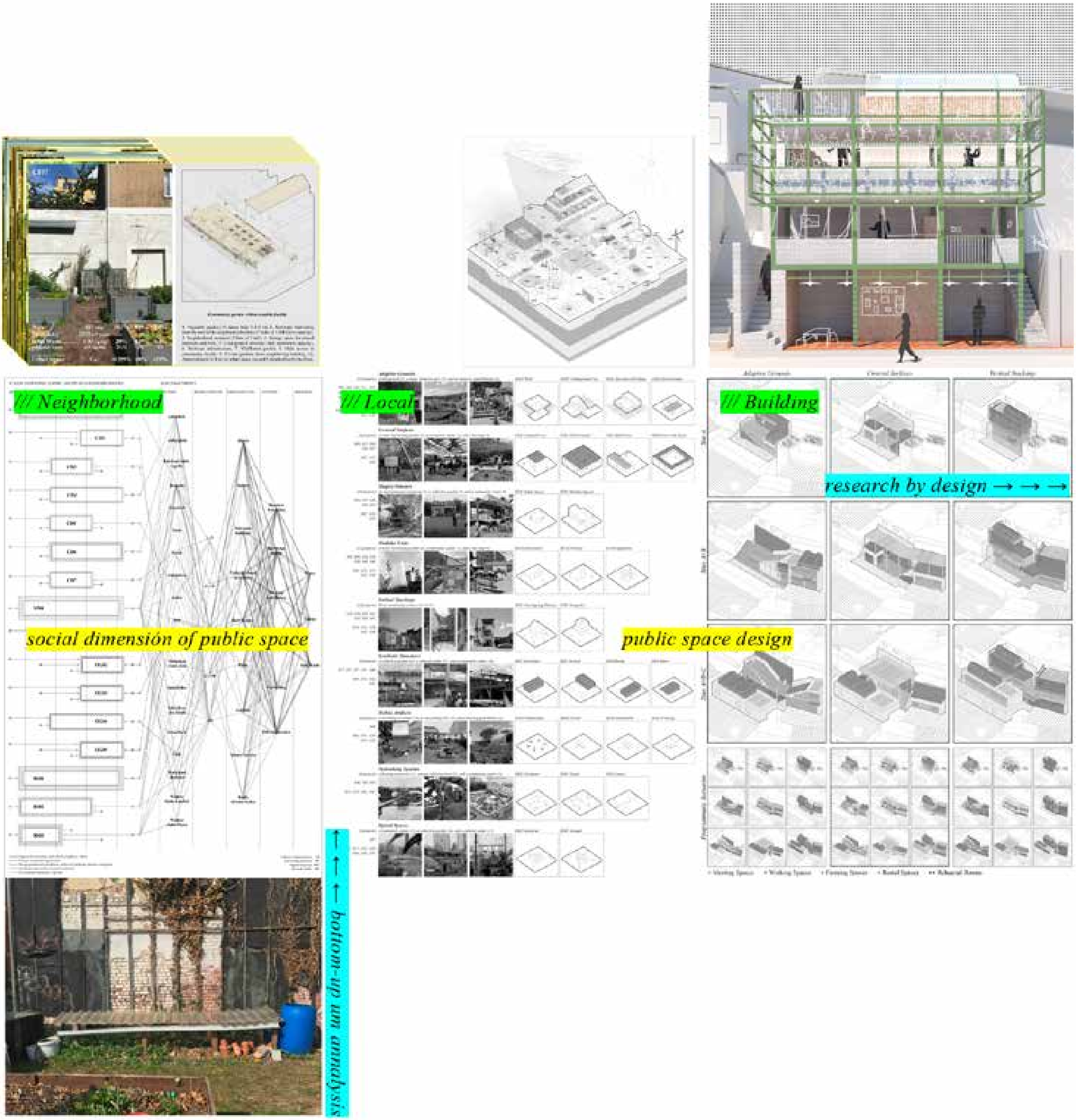



*Figure 6.1: The role of space in urban metabolism, spatially explicit UM assesments, and the urban design potential..*


/// Neighborhood
/// Local
/// Building
research by design → → →
social dimension of public space
public space design
← ← ← bottom-up um annalysis

localized ARGS, and 3D models, the results identified socio-ecological activities and practices that foster the appropriation of public space through resource management, enhancing community sense of belonging and identity. Furthermore, the results identified the types of spaces used by the community and collected detailed data on the collection, transformation, and use of resources at the local scale.

In *Chapter 5*, the research aimed to explore *how can design strategies for publicly accessible urban spaces be developed taking into consideration the most common spatial characteristics of ARGS in both the Global South and North*. By defining and illustrating nine resource-sensitive and community-inclusive urban archetypes, based on the analysis of the spatial characteristics of an inventory of ARGS projects in both the Global South and Global North, a design catalogue was developed to provide a practical tool for design practitioners during preliminary planning phases of publicly accessible spaces dealing with resource efficiency and community involvement. Additionally, three of these urban archetypes were evaluated in a vulnerable community in Caracas, Venezuela, assessing their versatility in designing urban spaces that accommodate a variety of architectural programs, forms, and urban design qualities.

The findings of these studies share common elements that connect them to the main research question, including *i*) the role of urban space at different scales as a catalyst for enhancing resource efficiency and fostering community involvement, *ii*) the use of graphic representations such as GIS mapping, 3D models, and illustrations to enhance the communication of scientific insights to design practitioners, *iii*) and the potential of urban design to optimize resource infrastructure while creating multifunctional and inclusive public space.

### *6.1 The role of space in Urban Metabolism*

The research findings underscore the transformative potential of resource-sensitive public space design in significantly enhancing resource efficiency and community involvement within urban environments, particularly by integrating spatially explicit UM frameworks. Building on the growing interest in the spatialization of UM, referred to by Bahers et al. (2022) as the *spatial turn* in UM in their recent bibliometric analysis, this research makes a strategic contribution by emphasizing the role of urban space as a means for reducing resource consumption and fostering community involvement. A particular focus is placed on adopting a multi-scale approach, ranging from city-regions to built spaces, while analyzing the spatial dynamics performed by various stakeholders in local resource management practices, with an emphasis on applications for design practitioners. This objective was achieved through three distinct methodological approaches aimed at informing urban planning and design practices.

In the first study (*Chapter 3*), the *Borough Pattern Scan* revealed urban hotspots of resource consumption flows and its infrastructure overlapping the open space networks and vulnerable communities at the municipal scale. Using Mexico City, Mexico as a case study, the research highlighted disparities among boroughs in terms of resource consumption patterns, open space availability, and the distribution of vulnerable communities. These findings provided a spatial understanding of specific areas where targeted urban planning and design strategies could be implemented, besides contributing to the growing body of literature on UM application in Latin America (Acevedo-De-los-Ríos & Perrotti, 2024; Delgado-Ramos, 2015; Espinosa-Aquino et al., 2023; Guibrunet et al., 2017; Kennedy et al., 2015). Depending on the local context and goals, these strategies could involve reinforcing existing open space networks, leveraging infrastructure synergies to minimize resource flow distances, or creating new public space in informal settlements and underserved neighborhoods where resource stocks could be stored. The *Borough Pattern Scan* thematic tables and maps provided a quantitative and spatially explicit analysis of the three resource flows studied: water, energy, and solid waste. This methodology, when applied by design practitioners, can facilitate the identification of specific areas, spaces, or infrastructure where new projects could be developed. By quantifying resource consumption and waste generation at the municipal scale, future urban service infrastructure projects can be calculated and designed taking into account precise objectives of reducing resource consumption or increasing public space. Furthermore, the results can enhance the identification of vulnerable communities where public space initiatives could be promoted, incorporating decentralized resource management practices aiming to enhance accessibility to essential resources and increase the availability of qualitative open spaces in areas with a lack of adequate urban infrastructure.

The second study (*Chapter 4*) explored the potential of community-led urban space interventions to address local resource management and public space creation. Using the Brussels Capital Region, Belgium, as a case study, the research captured fine-grained and informal data, such as rainwater harvesting and composting total volumes from alternative resource governance systems (ARGS) projects, which are typically absent from governmental records. The findings revealed the tangible impacts of ARGS at the local scale, as explored in previous research (Berigüete et al., 2023; Estrada et al., 2023; Guibrunet et al., 2017; Verga & Khan, 2022), but from an urban planning and design perspective. Specifically, the results highlighted ARGS's potential to significantly reduce resource consumption and improve waste management practices through community composting practices in collective gardens and in material recycling centers with construction workshops. In addition, the study emphasized the scalability of these systems by calculating the per capita percentage of resources generated within ARGS in relation to their users and the broader community involved (core group, network, and street scales). Particularly, these initiatives demonstrated the potential to address water consumption patterns, organic waste treatment, and the generation of new public spaces at the local scale. In some instances, they were able to meet more than half of the resource requirements at the street scale, underscoring their significant impact and feasibility within localized urban contexts.Although the resource harvesting or transformation figures achieved by ARGS at the street scale remain relatively low (ranging from 1% to 3% of total per capita consumption depending on the type of resource), this analysis underscores their potential for replication across the city with more resource-efficient objectives. It also provides a foundation for assessing their cumulative impact within the broader framework of the city's UM evaluation.

Building on this exploration, the third study (*Chapter 5*) presented nine urban archetypes from an analysis of ARGS projects in both the Global South and Global North. To this end, an inventory of ARGS across various geographic contexts was developed, identifying the urban archetypes used, location, type of context and urban space used, scale, type of access, stakeholders involved, governance structures, resource management practices, activities and practices held by the community, and type of community involvement. Additionally, the design tools employed by the different projects to enhance resource collection and foster community involvement were analyzed. The resulting catalog of urban archetypes aims to illustrate diverse spatial configurations and their variations, providing design practitioners with adaptable tools to consider during the preliminary phases of urban design projects. Depending on the desired spatial and programmatic objectives, as well as the characteristics of the urban environment where the project will be implemented, these archetypes offer a range of responses that can be tested and tailored. To evaluate their practical viability, the research conducted an architectural feasibility study of three urban archetypes within an informal settlement in Caracas, Venezuela. The study demonstrated the adaptability of these urban archetypes in accommodating diverse programs and spatial configurations that support diverse levels of effective resource management and community involvement. Each configuration incorporated calculations for rainwater harvesting, electricity generation through solar panels, and organic waste transformation via community composting areas. These setups enabled the development of a range of programmatic scenarios, emphasizing either greater resource efficiency or enhanced community involvement, which resulted in various types of shared spaces, including enclosed gathering areas, open meeting points, workshops, food production zones, and spaces for resource harvesting. This feasibility study confirmed the adaptability of urban archetypes in dense and complex environments, particularly in communities with an urgent need for expanded public space and improved access to essential resources.

Aligned with recent studies integrating UM frameworks and material flow accounting tools with spatially explicit sociotechnical and socioecological inputs (Camacho-Caballero et al., 2024; Currie et al., 2017; Soto et al., 2024), this research contributes to the UM literature by spatializing *black box* processes and underscoring the critical role of space in UM applications tailored for design practitioners. Collectively, combining top-down and bottom-up approaches, these conducted studies illustrate the transformative potential of public space design across regional, urban, and local scales. They emphasize the impact of resource harvesting and waste management through decentralized and community-led strategies while offering a framework to optimize resource infrastructure and foster inclusive and multifunctional public space. Considering the added value of spatial use in improving resource efficiency, this research underscores the relevance of identifying resource infrastructure deficiencies and resource consumption patterns at the regional scale in order to provide insights for strategic interventions to optimize resource allocation and infrastructure planning. At the local scale, integrating communities into decentralized resource management processes through urban design and architectural projects further amplifies these efforts. This dual-scale approach highlights the potential of urban planning and design as a key tool for fostering more sustainable and equitable urban environments.

### *6.2 Spatially explicit UM assesment: GIS mapping, 3D models, and illustrations*

From the outset, this research established a methodology for conducting spatially explicit UM assessments, emphasizing the use of GIS tools to visualize and analyze resource flows and infrastructure within urban environments. This approach aimed to enhance the knowledge transfer of UM studies to design practitioners, providing a spatial framework to address resource and infrastructure challenges. The integration of open space networks and vulnerable communities datasets further supported the idea of using space as a medium to enhance resource efficiency and foster community involvement in urban contexts. For example, this methodological approach offers a valuable tool for identifying deficiencies in resource infrastructure by analyzing its spatial distribution and proximity to complementary facilities involved in the production, storage, and treatment of resources. The underlying premise is that greater distances between processing centers result in increased time and energy consumption for transportation and logistics. Moreover, this approach can highlight areas of urban populations that lack access to basic services, correlating these deficiencies with the resource efficiency of the municipalities in which they are situated. This correlation can inform the development of urban strategies that align with municipal objectives while simultaneously addressing the specific needs of vulnerable communities through targeted local actions. Additionally, the identification and potential classification of open space network typologies based on their location within the city or the type of landform they occupy can provide a nuanced understanding for the design of urban projects. By linking spatial typologies to their contextual roles, this framework can guide the development of targeted urban strategies that leverage specific types of public spaces to enhance both resource efficiency and community involvement.

The creation of thematic maps, such as those illustrating water consumption and infrastructure, waste generation and infrastructure, and open space networks, among others, have the potential to significantly improve the accessibility of UM assessments for urban planners and designers. These maps enable the identification of areas or administrative boundaries associated with resource management, as well as urban spaces that could be prioritized for intervention at various scales. While the methodology developed aims to facilitate a deeper understanding of UM assessments, it is also designed to be replicable for use by design practitioners. However, evaluating its application by urban planners and designers was outside the scope of this research. Furthermore, locating ARGS or similar practices within private areas could provide insights into their direct impact on the surrounding communities, considering factors such as their size, type of resource harvesting, and location. Design practitioners could leverage such spatial analyses to propose future networks of ARGS interconnected by the types of resources they transform. These networks would aim to foster synergies between resource management practices while maintaining strategically equidistant locations to extend their reach across urban areas, including underserved and vulnerable communities lacking access to basic services. An additional advantage of using GIS-based mapping lies in its ability to link spatial and temporal dimensions of the studied elements, such as resource flows. Since the data incorporated into the maps are tied to specific temporalities (e.g., yearly resource consumption), this approach provides opportunities for dynamic analyses of patterns and trends in resource flows and infrastructure over time. This temporal-spatial linkage allows for more precise urban planning and design strategies informed by projections and simulations. By integrating these dimensions, future applications of this methodology could yield insights into evolving resource dynamics and enable the development of more adaptive and forward-looking design strategies.

The use of 3D models to analyze ARGS and illustrate the catalog of urban archetypes proved to be an effective methodology for understanding spatial configurations across diverse site typologies and the spatial relationships established by key actors. Firstly, the spatialization of ARGS provided valuable insights into the scale and potential impact of each project, ranging from collective gardens at the municipal level to small modular structures supporting activities in public spaces. Secondly, emplying 3D modeling, a common practice in the field of urban and architectural design, to conduct UM related studies constitutes a significant step forward in fostering knowledge transfer between scientific research and the professional practice. The use of 3D models enabled a detailed presentation of urban archetypes and their spatial variants, ensuring alignment with professional design practices. The implementation of this technique also required the collection of detailed and precise data on the projects analyzed gathered from field visits and interviews from main stakeholders. While such fine-grained data is uncommon in traditional top-down UM research, it aligns with standard practices in the early phases of urban planning and design. This allowed for the identification, representation, and detailing of various design tools used in different projects for resource harvest (e.g., low-tech systems for rainwater collection using local materials) and waste management (e.g., compost storage systems in collective gardens). Additionally, the application of 3D models in *El Calvario* community case study facilitated the development of 27 spatial configurations designed to optimize resource capture through architectural components such as terraces, roofs, green spaces, and facades. It also supported analyses of optimal spatial arrangements for solar energy capture, accounting for the impact of shadows cast by surrounding buildings. Integrating 3D modeling into UM frameworks offers significant value for advancing urban planning and design projects. This methodology promotes collaboration among stakeholders, including users and governmental entities, fostering support for unsolicited initiatives (i.e., self-generated initiatives by groups of individuals, NGOs, or design practitioners to achieve institutional support and funding in places where there is a lack of public space and access to basic services) aimed at improving resource efficiency and enhancing community involvement, particularly in informal settlements.

Spatially explicit graphic representations, through diagrams, inventories, and catalogs, were developed throughout this research to effectively illustrate the application of UM frameworks in urban planning and design. The ARGS catalog (*Chapter 4*) presents existing cases using per capita data on new public space created and resources captured, offering a valuable reference for design practitioners interested in replicating similar initiatives. Each case includes a photograph, per capita impact figures at multiple user scales, and a detailed model outlining the spatial tools and artifacts used to enhance resource efficiency and community participation. The ARGS inventory (*Chapter 5*), compiled from cases in both the Global South and North, supports the classification and comparison of ARGS across diverse geographic and socio-economic contexts. It combines theoretical spatial configurations of nine identified urban archetypes (and their variants) with photographic examples, enhancing accessibility for practitioners. Additionally, a diagram of design tools employed by ARGS was created to highlight the spatial impacts of various design and planning strategies, with tools categorized by resource type and public space function. *Chapter 6* further applies these methodologies in a case study in Caracas, Venezuela, summarizing 27 spatial configurations of urban archetypes through urban design representation tools. These illustrations include access strategies and integration into the existing settlement fabric, supporting the practical application of findings in complex urban environments.

### *6.3 Urban design potential in UM studies*

This research underscores the significant potential of urban design to optimize resource infrastructure while simultaneously creating multifunctional and inclusive public space. Through an interdisciplinary approach, the studies conducted explored this potential through city-scale strategies for resource infrastructure design (*Chapter 3*), spatial analysis using 3D models of ARGS (*Chapter 4*), and a research by design approach for developing resource-sensitive and community-inclusive urban archetypes (*Chapter 5*). In the Mexico City case study, city-scale strategies were developed to integrate resource infrastructure design with nature-based solutions within existing open space networks. These strategies addressed critical challenges such as resource consumption, capture, and treatment, while also linking resource management initiatives with leadership from vulnerable communities. Key insights also emerged from the Brussels Capital Region case study, where interviews with ARGS stakeholders provided a deeper understanding of the challenges and opportunities faced by design practitioners. One significant finding was the potential for resource harvesting through community-managed public spaces independent of existing complex resource infrastructure networks (e.g., high-production urban agriculture farms and community gardens that are fully autonomous in water collection and organic waste treatment at the municipal level, as well as a network of material banks distributed across various neighborhoods to achieve a localized scale).These spaces, if successfully replicated across different urban contexts, could substantially enhance localized resource management while reducing resource consumption and creating qualitative public space.

The research also identified two urban typologies, street networks and common spaces, as particularly favorable for developing ARGS due to their high user density and potential to foster social interaction. In addition, private green spaces such as gardens and parks emerged as valuable complements to these typologies. However, challenges remain in clearly defining the role of urban design in shaping the future of public areas that are currently under temporary permit frameworks negotiated with governmental entities. This is particularly relevant in the development of urban commons that contribute to decentralized resource management, especially in social housing contexts where both local governments and grassroots actors are involved.

In both the Mexico City and Brussels contexts, co-creation processes were emphasized as essential for fostering dialogue and negotiation between governmental bodies and communities. These collaborative approaches are crucial for ensuring the feasibility, sustainability, and long-term success of proposed interventions, aligning urban design with social and ecological priorities. These co-creation and participatory workshops involving diverse stakeholders can be effectively facilitated by design practitioners to address urban challenges, serving as platforms for identifying underdeveloped or neglected urban spaces, fostering active community engagement and leadership, and co-developing strategic design interventions in collaboration with local governments, as explored in recent research (Bonello et al., 2022; De Muynck & Nalpas, 2021; Obersteg et al., 2020). By leveraging frameworks centered on temporary occupations, such initiatives can explore flexible and adaptive uses of space, promote inclusive urban regeneration, and encourage decentralized approaches to resource management. Additionally, these participatory processes can stimulate innovation, build social cohesion, and empower communities to take an active role in shaping their built environment.

Furthermore, the findings underscored the pivotal role of design practitioners in integrating grassroots resource management practices with institutional frameworks. Practitioners were seen as mediators capable of bridging community-led initiatives and government objectives, ensuring the optimal spatial design of resource infrastructure. Beyond resource management, this mediation extends to creating new, multifunctional spaces that serve community needs, such as gathering areas, workspaces, and recreational zones. By aligning grassroots practices with formal urban strategies, design practitioners can advance holistic urban solutions that enhance resource efficiency and community involvement.

### *6.4 Research limitations*

The multidisciplinary nature of the methodologies applied in this research, alongside the diversity of data sources and case studies, presents certain limitations, particularly regarding data consistency across case studies and challenges in translating findings into practical applications for design practitioners. The limitations encountered at each stage of the research stages are elaborated below.

The diversity of case studies introduces challenges in comparing socio-ecological datasets due to differing contextual realities of each location, as explored in *Chapters 3* and *4*. For instance, in Mexico City, the study analyzed vulnerable communities such as informal settlements and areas with a high urban marginality index, identified by local indeces measuring the lack of basic services. This approach may not align with indices used in other contexts, limiting cross-contextual comparisons. Additionally, the study incorporated administrative areas with independent governance structures, such as indigenous areas and communal lands, which offer unique legal and spatial frameworks for decentralized and community-led resource management. In contrast, for the Brussels Capital Region, the study focused on low-income neighborhoods defined by socio-economic data at the neighborhood scale and neighborhoods with a higher share of social housing units than the average in the region. The reliance on regional administrative boundaries for data collection further excluded resource flows, its infrastructure, open spaces networks, and vulnerable communities located beyond these boundaries in both case studies. Such exclusions overlooked broader territorial dynamics that interact with and potentially influence internal resource management processes within the study areas.

In *Chapter 4*, limitations arose during the inclusion of ARGS datasets in Brussels Capital Region. Data collection relied on desk research, field visits, and snowball sampling of interview participants. The selection of projects was constrained by search filters applied to project descriptions available on governmental and non-governmental organization websites. Due to time constraints, not all identified and shortlisted projects were visited, potentially overlooking relevant initiatives. Furthermore, the study could have been enhanced by conducting additional interviews with a wider range of ARGS stakeholders, including community leaders, activists, and representatives of non-governmental organizations. This would have provided a more comprehensive understanding of ARGS initiatives across the region's municipalities and the type of ARGS. Additionally, the framing of interviews as part of a doctoral study may have introduced recruitment bias, potentially influencing both participants' willingness to engage and the content of their responses.

For the development of the ARGS inventory (*Chapter 5*), the study focused on two specific regions within the Global South and Global North, excluding other regions that fell outside the scope due to time constraints. While three urban archetypes were evaluated through a case study in Caracas, Venezuela, the archetypes were not assessed by other design practitioners. This lack of external evaluation limited the opportunity to obtain feedback on the usability and relevance of the archetypes, which could have enhanced their applicability to a broader audience of urban planners and designers. These limitations highlight areas where future research could address gaps, particularly through expanded datasets and case studies, broader regional coverage, and greater practitioner involvement to strengthen the applicability and impact of the findings.

### *6.5 Future research*

The results and contributions outlined in the preceding chapters can be summarized into three key areas: the advancement of spatializing resource flows at various scales, the development of UM analyses using case studies from the Global South, and efforts to enhance the practical application of metabolic frameworks by design practitioners for public space design. Building on these contributions, three avenues for future research are proposed to expand, refine, and deepen the insights presented in this study.

First, spatially explicit comparative studies could be pursued to identify patterns of resource consumption linked to the geographic and socio-ecological characteristics of diverse urban areas. Such studies might also investigate the influence of administrative boundaries, including indigenous areas, communal lands, or commons, as potential theoretical frameworks for implementing ARGS within specific public spaces. By doing so, these studies could offer more nuanced strategies for aligning resource-sensitive public space design with unique territorial and cultural contexts.

Second, it is essential to extend metabolic analyses in the Global South, with a particular focus on informal settlements and vulnerable communities. These areas are home to large populations, not only in low-income nations but also in certain urban regions of the Global North. Given their high population densities and challenging physical conditions, such as steep terrains or proximity to water bodies, the role of design practitioners becomes critical. Here, public space design could serve as a transformative tool to restructure resource management systems, addressing both local vulnerabilities and broader municipal objectives.

Finally, future research should aim to evaluate and demonstrate the impact of small-scale projects, such as ARGS, on resource efficiency and community involvement at the city and regional scales. Expanding the ARGS inventory developed in *Chapter 5* with additional case studies could strengthen the proposed resource-sensitive classification of urban archetypes. Furthermore, studies that involve the practical application of these urban archetypes by design practitioners are needed to validate and refine their relevance and utility in urban design and planning contexts. These efforts could bridge the gap between theoretical frameworks and practical implementation, making metabolic frameworks more actionable for professionals engaged in shaping urban environments.

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*The Spatial Dimension of Urban Metabolism*
*Resource flows, public space, and vulnerable communities.*

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*All drawings, photos, and graphic design by the author, unless otherwise stated.*

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# THE SPATIAL DIMENSION OF URBAN METABOLISM