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# Designing inclusive urban spaces 2

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abstract

# Collaborative GIS for sustainable waste management: the case of Ulaanbaatar in 3R4UB

***Francesco Stefano Sammarco, Gaia Daldanise, Fabio Maria Esposito, Gantuya Ganbat, Gabriella Esposito De Vita, Marina Rigillo***

*Abstract*

The paper is included in the international project "The 3Rs for a sustainable use of natural resources in Ulaanbaatar - 3R4UB", which develops an innovative method to enhance collaboration between citizens and public authorities in sustainable waste management. Ulaanbaatar (UB), the capital of Mongolia, faces serious challenges due to rapid urbanisation and fragmented planning that lacks tools to integrate social, environmental, and infrastructural dynamics. The city is divided into three areas: the planned city (Soviet legacy), the spontaneous city (the informal settlements of the "gher"), and the city in transition (between planned and spontaneous city).

The research proposes the "Ulaanbaatar Spatial Sustainable Waste Management" (UBSWM) approach, which includes spatialising data and information based on GIS tools. The combination of quantitative data (e.g., the number of infrastructures and waste streams) and qualitative data (photographic reportage and awareness-raising strategies in schools) facilitated a multi-scalar narrative of urban dynamics, enhancing the cultural diversity of UB. The results obtained, including an open-access platform on ArcGIS StoryMaps, offer a replicable model to address the challenges of sustainable waste management in similar urban contexts, promoting collaborative planning of more sustainable and equitable public spaces. The study is guided by the research question: How can a spatial and collaborative GIS-based approach support circular and sustainable waste management in transitional urban contexts such as Ulaanbaatar?

**Keywords:**

*Collaborative planning; circular economy; sustainable waste management; GIS; awareness*

# GIS collaborativo per la gestione sostenibile dei rifiuti: il caso di Ulaanbaatar in 3R4UB

*Abstract*

Il contributo rientra nel progetto internazionale "The 3Rs for a sustainable use of natural resources in Ulaanbaatar – 3R4UB", che sviluppa un metodo innovativo che valorizzi la collaborazione tra cittadini e autorità pubbliche nella gestione sostenibile dei rifiuti. Ulaanbaatar (UB), capitale della Mongolia, affronta gravi sfide dovute alla rapida urbanizzazione e ad una pianificazione frammentata priva di strumenti capaci di integrare le dinamiche sociali, ambientali e infrastrutturali. La città è divisa in tre aree: la città pianificata (retaggio sovietico), la città spontanea (gli insediamenti informali delle "gher") e la città in movimento (città in trasformazione tra città pianificata e città spontanea).

La ricerca propone l'approccio "Ulaanbaatar Spatial Sustainable Waste Management" (UBSWM), che prevede un approccio basato sulla spazializzazione di dati e informazioni basato su strumenti GIS. La combinazione di dati quantitativi (es. numero infrastrutture e flussi di rifiuti) e qualitativi (reportage fotografico e strategie di sensibilizzazione nelle scuole) ha facilitato una narrazione multi-scalare delle dinamiche urbane, valorizzando le diversità culturali di UB. I risultati ottenuti, tra cui una piattaforma open access su ArcGIS StoryMaps, offrono un modello replicabile per affrontare le sfide della gestione sostenibile dei rifiuti in contesti urbani simili, promuovendo una pianificazione collaborativa di spazi pubblici più sostenibili ed equi. Lo studio si sviluppa a partire dalla seguente domanda di ricerca: in che modo un approccio collaborativo e spaziale basato su GIS può supportare la gestione sostenibile e circolare dei rifiuti in contesti urbani in transizione come Ulaanbaatar?

**Parole Chiave:**

*Pianificazione collaborativa; economia circolare; gestione sostenibile dei rifiuti; GIS; sensibilizzazione*

# Collaborative GIS for sustainable waste management: the case of Ulaanbaatar in 3R4UB

***Francesco Stefano Sammarco, Gaia Daldanise, Fabio Maria Esposito, Gantuya Ganbat, Gabriella Esposito De Vita, Marina Rigillo***

## 1. Introduction

The current global environmental challenges call for a deep and urgent revision of policies, governance models, and natural resource management tools towards a circular economy (CE) model, in line with the Sustainable Development Goals (SDGs) defined by the United Nations. In this scenario, circular waste management (Memon, 2010) emerges as one of the fundamental pillars for responsible, far-sighted, and sustainability-oriented spatial planning (Esposito et al., 2023).

According to Geissdoerfer et al. (2016), CE is a regenerative system that minimises the use of resources and the generation of waste, emissions, and energy loss by tightening material and energy cycles. The integration of CE principles into waste management systems can foster economic growth by synergistically combining the pillars of sustainable development - economic, environmental, and social - through the recovery of energy and materials from waste, the design of durable products and the extension of the useful life of systems, for the benefit of present and future generations (Sharma et al., 2021).

However, political, technological, and public involvement issues may hinder the transition to the CE model (Adami & Schiavon, 2021). In particular, the lack of a centralised platform to promote CE and fragmented regulatory systems can be detrimental. Furthermore, weak global demand for environmentally superior technologies, inadequate technical capacities and limited financial resources represent technological barriers (Sharma et al., 2021).

Waste continues to be perceived as such by the public (Hawkins, 2006), whereas in the circular bioeconomy it represents a valuable resource (Geirdal et al., 2021). Changing the perception to 'waste-as-a-resource' in the mind of the average consumer may be a lengthy process, but it could lead to the mindset and market shift needed to fully value biomass where possible (Neofotistos et al., 2023).

In this perspective, applying integrated waste management to municipal services is a key component of the CE, including all phases, from collection in households, streets and markets to disposal in landfills. The main objective of an Integrated Solid Waste Management (ISWM) system is to ensure environmental benefits, economic efficiency and social acceptability by integrating the different phases of waste management - from collection and separation to treatment, recovery and disposal - to optimise the use of resources (Gurjar & Gaur, 2022).

The planning and monitoring of these phases rely on the use of geospatial technologies, such as Remote Sensing (RS), Geographical Information System (GIS) and Global

Positioning System (GPS), to optimise routes, locate storage and disposal sites, and manage waste flow (Gurjar & Gaur, 2022). In particular, the use of GIS can be an advanced tool to improve the effectiveness of ISWM, especially in developing realities such as Ulaanbaatar (UB) in Mongolia, by providing crucial information on waste generation, collection routes, site selection for landfills, and identification of the most suitable areas for waste-to-energy conversion projects (Sakshi et al., 2023). In addition, the integration of RS and GIS provides valuable data for waste composition analysis, landfill stability assessment, and environmental impact analysis, helping to improve the overall efficiency and sustainability of waste management (Singh, 2019).

In this context, in order to implement both the integrated waste management process and the perception of 'waste-as-a-resource', citizen involvement through citizen science approaches is crucial. Citizen science can help overcome public participation barriers and provide useful data for research and policy (Vohland, et al. 2021; Tauginienė et al., 2020; Mitchell et al., 2017) in a collaborative planning perspective (Healey, 2003).

This is the framework for the '3Rs for a sustainable use of natural resources in Ulaanbaatar (3R4UB)' project, funded under the European SWITCH-Asia programme, which has the primary objective of transferring a sustainable approach for municipal solid waste management specifically adapted to the urban context of Ulaanbaatar (UB). The 3R4UB project applies the CE and citizen science approach as a key strategy to promote waste management through the implementation of innovative processes, moving beyond the traditional linear 'produce-consume-dispose' model in favour of a CE that values the reuse and recycling of materials.

Particular attention is devoted to the creation of concrete opportunities for the development of circular supply chains at the local level by applying citizen science principles in the definition of training and awareness strategies.

Within the project, the CNR research group has defined the following objectives: 1) to identify settlement functions in relation to the waste masterplan through 3 categories of urban settlement (planned city, spontaneous city, city in transition); 2) to influence and monitor residents' behaviours through schools (students, teachers and families revolving around the educational system); 3) to identify ecological-settlement assembly mechanisms starting from the spatial reading with respect to the urban fabric, both stationary and not.

In this perspective, the use of GIS systems proves to be an indispensable analytical tool for understanding and managing the complexity of waste flows – understood as resources within the urban fabric, providing crucial support for effective and collaborative spatial planning. Indeed, the integration of spatial data enables to visualisation of critical environmental issues and to design targeted and localised interventions in harmony with the planning of the 3 city types defining Ulaanbaatar.

With this in mind, the contribution aims to investigate how a spatial approach can support sustainable waste management integrated with efficient urban planning through a collaborative GIS of visual narration and data interpretation. Within this complex framework—characterised by the intersection of environmental urgency, technological

potential, and the need for civic engagement—the research addresses a central question:

How can a spatially-informed and collaborative GIS approach contribute to transforming municipal solid waste management in transitional urban contexts such as Ulaanbaatar, by embedding circular economy principles and citizen involvement into planning processes?

This question positions the project beyond the boundaries of technical experimentation, situating it within broader scientific debates on spatial justice, post-socialist urbanism, and participatory governance. By explicitly linking geospatial technologies with inclusive planning practices, the study aims to explore new methods of urban intervention capable of producing not only operational efficiency but also cultural and institutional innovation.

In the following section, the socio-territorial context of Ulaanbaatar in Mongolia is examined (§2), followed by a description of the methodological approach (§3) 'Ulaanbaatar Spatial Sustainable Waste Management' (UBSWM). In the following paragraphs, the results in terms of the approach and spatialised data are described (§4) and the research steps are discussed in the conclusions (§5).

## 2. The city of Ulaanbaatar: an urban context in transition

Ulaanbaatar, the capital and largest city of Mongolia, is home to ca. 1,77 mln. people . As of today, it consists of six central administrative districts and three peripheral districts. Known locally as UB, it is situated in the Tuul River valley at an elevation of ca. 1,300 meters (4,300 feet), and the coldest capital in the world by average yearly temperature. As discussed below in this section, location, internal migrations, Mongolian nomadic culture, and climate contribute to UB's unique development and current urban challenges.

From a theoretical perspective, the selection of Ulaanbaatar as a case study is rooted in its significance as a paradigmatic example of a transitional urban context. The city reflects key dynamics of post-socialist transformation, where centralised planning legacies coexist with increasing informality and fragmented governance (Karthe et al., 2022; Duurenbayar, 2016). Moreover, the persistence and expansion of informal ger districts situates UB within a broader discourse on urban informality and the hybridisation of urban forms in the Global South and post-socialist Asia (Park et al., 2019; Miller, 2013). These conditions make UB an emblematic terrain for investigating how spatial tools and collaborative governance mechanisms can support more inclusive and adaptive forms of urban management. The city's extreme climate, environmental vulnerability, and rapid demographic shifts further amplify the relevance of a spatialised and citizen-driven approach to waste governance. Founded in 1639 as a nomadic Buddhist monastic center, UB changed locations 29 times before settling in its current spot in 1778. In 1924, after the establishment of the Mongolian People's Republic, it became Mongolia's capital and was renamed Ulaanbaatar. Soviet-era urban planning began in the 1950s, replacing tradi-

tional ger (portable nomadic tents) districts with Soviet-style flats. As we will see, Ulaanbaatar, a relatively young and rapidly evolving metropolis, faces significant environmental and management challenges, intrinsically linked to accelerated urbanization, the widespread presence of informal settlements without adequate infrastructure, and a municipal transport, heating, and solid waste management system that presents significant inefficiencies. To understand UB's current context, we will now briefly take a look at the city's development in the 20th century.

The "Urban Development Master Plan of Ulaanbaatar" serves as the foundational document for the city's territorial, architectural, and spatial planning policies. Ulaanbaatar's first general plan, developed in 1954 (see Fig. 1) with the Soviet Design Institute, aimed to guide growth until 1974 for a projected population of 125,000. The plan facilitated the construction of key infrastructure, including the city center, the small ring road, and sections of the large ring road. However, by 1960, the population had already reached 180,000, prompting an early revision. The second general plan (1961) projected a 20–25-year horizon with a target of 250,000 residents, leading to the development of a 3,900-hectare urban area along the Tuul River. It enabled the construction of 19 residential districts (later expanded by three more) and boosted the housing stock by 79% compared to 1960. Nevertheless, by 1975, Ulaanbaatar's population had soared to 348,700, underscoring persistent underestimations of migration, particularly from rural herders.

The third plan (1975) sought to control population growth by developing satellite cities like Nalaikh and Baganuur and introducing migration limits. Still, within two years, 100,000 new residents arrived, far surpassing the estimated 35,000. A fourth plan followed, but by 1986, with a population of 492,000 and amid political and economic transition post-1990, planning efforts weakened, and urban density management was largely abandoned.

*Fig. 1 - First general plan of Ulaanbaatar city (source: Ulaanbaatar National Archives)*

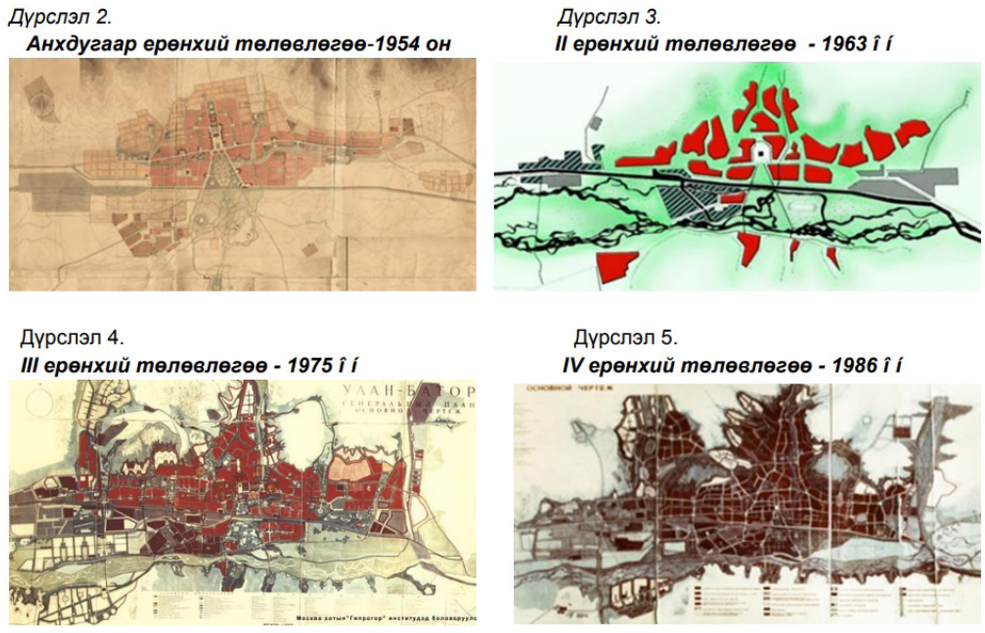



*Fig. 2 - First (1954), second (1963), third (1975), fourth (1986) general plan of Ulaanbaatar city. (source: https://development.ub.gov.mn/uploads/The-second-volume-of-UB-master-plan.pdf )*

The fifth master plan (2002-2020), the first to involve Mongolian experts significantly, proposed ambitious concepts but remained mostly theoretical. Uncoordinated growth, especially in ger districts, alongside the rise of private vehicles, strained the city's infrastructure and environment. The sixth master plan, approved in 2013, attempted to address these issues but, by 2018, had achieved only 29.6% implementation due to weak enforcement across organizational levels, resulting in few tangible outcomes . To confer an idea about the dimension of UB's urban sprawl, and the difficulties related to its management, we can take a look at the development of the city's area and perimeter (see Fig. 3a and 3b).

In fact, after Mongolia transitioned to democracy in the early 1990s, the city continued to experience rapid population growth due to migration from rural areas. Many of the new rural migrants settled in informal ger districts, contributing to their further expansion (Park et al., 2019). These districts reflect Mongolia's nomadic heritage, as many migrants continue to live in traditional gers, preserving aspects of their nomadic lifestyle despite the challenges of urbanization. Informal quarters, which make up much of Ulaanbaatar's area, spread across the flatlands around the city center and extend into the valleys to the east, north, and west, as well as climbing the steep hillsides (Miller, 2013; Duurenbayar, 2016). A blend of urban and nomadic cultures is evident in these areas, where many ger residents own cars and have electricity. However, while most ger districts have public schools and are connected to the city centre through busses (privately run companies whose network and frequency are problematic - Bayartsetseg, 2015) and one paved main road, basic infrastructure remains lacking, including sewage systems, diffused paved roads, and heating beyond carbon stoves. This fusion of modern conveniences

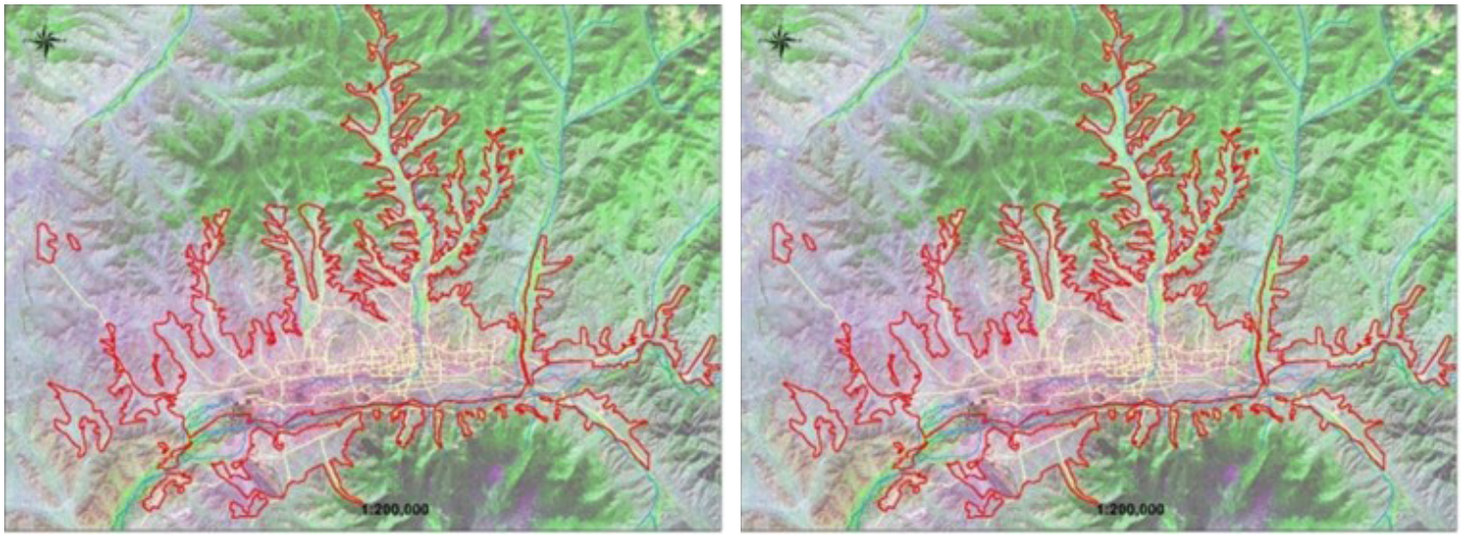



*Fig. 3a - On the left, map of the expansion of Ulaanbaatar city, 10,730 ha as of 1990 (source: Bolormaa et al., 2019).*

*Fig. 3b - On the right, map of Ulaanbaatar city expansion, 39,235 hectares as of 2020 (source: Bolormaa et al., 2019).*

with traditional living conditions highlights the complexities of Ulaanbaatar's rapid urban growth and planning efforts.

With nearly half of Mongolia's population residing in UB, the city serves as the cultural, industrial, and financial heart of the country. Yet, it continues to struggle with integrating social, environmental, and infrastructural needs amidst rapid urban growth and a history of fragmented planning (Karthe et al., 2022). Today, UB faces significant challenges from its rapid urbanization. The city can be divided into three distinct areas: the planned city (Soviet legacy), the spontaneous city (ger districts), and the city in transition (struggling to bridge the two).

The ger districts , while embodying Mongolia's nomadic heritage, also contribute to environmental issues, such as severe winter air pollution, due to a lack of infrastructure and heating systems. Ulaanbaatar's main environmental problems stem from the high

*Fig. 4 - A ger settlement area near the large ring road, March 2025 (source: author's own picture)*

levels of air pollution caused by carbon-burning domestic heating stoves, heat-only-boilers (HOBs) in ger districts, and thermal power plants, compounded by the city's location in a valley and its cold climate, as well as the increasing number of private cars, driven by the lack of an extensive public transport system and a road network designed for a much smaller population.

In January 2025, Mongolia's Parliament approved the seventh general plan for Ulaanbaatar, setting a 2040 development vision focused on sustainability, adaptability, and smart growth. This plan addresses decades of unplanned expansion that have harmed quality of life. It aligns with policies like Vision-2050 and the National Regional Development Concept, aiming to decentralize the population, promote sustainable urbanization, enhance infrastructure, and reduce pollution. Recent initiatives (2024–2028) focus on creating a "20-minute city," relocating institutions, expanding public transport, and improving green spaces and water systems. Key projects include constructing a new ring road, introducing a Metro line and tram network to ease congestion, and addressing air pollution through the construction of a fifth Thermal Power Plant, development of an off-grid energy system, and building a waste incinerator.

In this context, our research proposes the 'Ulaanbaatar Spatial Sustainable Waste Management' (UBSWM) approach, using GIS-based spatialisation of quantitative and qualitative data to construct a layered narrative of UB's socio-urban dynamics. In light of this complex and fragmented urban scenario—marked by deep socio-spatial inequalities, informal growth patterns, and infrastructural vulnerabilities—the need emerges for planning tools that can operate across multiple scales and engage a diversity of actors. It is within this frame that the 3R4UB project introduces an innovative methodological approach, aiming to spatialise waste-related dynamics and foster collaborative governance mechanisms capable of responding to Ulaanbaatar's transitional condition. The following section outlines the structure and rationale of this approach.


*Fig. 5 - Mixed urban settlement types in UB, here a ger district (right) borders with a planned city district (left) and a 'city in transition' (a new road being built and newly built high-rise buildings near school 154 – number 52 and 154 are school buildings).*

## 3. Ulaanbaatar Spatial Sustainable Waste Management (UBSWM): methodological approach

Building on the historical and spatial reconstruction of Ulaanbaatar presented in the previous section, the following chapter outlines the methodological approach developed to address the city's complex urban dynamics through collaborative and spatialised waste management strategies.

The methodological approach underpinning the research, called 'Ulaanbaatar Spatial Sustainable Waste Management' (UBSWM), aims to initiate a collaborative planning process (Healey, 2003) to map waste flows in detail within different urban areas, strategically identify waste eco-hubs (understood as new neighbourhood-level facilities) and develop concrete operational models for the implementation of CE principles adapted to the specific context of UB. The methodological framework of UBSWM can be positioned within the broader tradition of action research and participatory spatial planning. In particular, it draws on principles of collaborative mapping (Chambers, 2006) and co-production of knowledge (Turnhout et al., 2020), where spatial analysis is not only a technical tool but a catalyst for dialogue between stakeholders. The use of GIS is therefore not limited to data processing but is embedded in a broader effort of citizen science (Vohland, et al. 2021) and community empowerment. By involving local communities, schools, and institutional actors in data collection, interpretation, and restitution, the approach aims to produce shared knowledge that can inform sustainable, place-based waste governance. In this sense, the UBSWM is conceived not only as a methodological device, but also as a relational infrastructure, enabling a multivocal reading of the territory and activating new alliances between space, knowledge and decision-making.

The methodological framework (Fig. 6) of the project is rooted in the framework of the Sustainable Development Goals (SDGs) defined by the United Nations, taken as a guiding reference to orient strategic, methodological and operational choices. In particular, four SDGs were selected as priority macro-goals, by virtue of their relevance to the environmental, social and economic issues faced in the urban context of UB: SDG 8 - Decent work and economic growth; SDG 11 - Sustainable cities and communities; SDG 12 - Responsible consumption and production; SDG 13 - Climate action.

The above mentioned SDGs are operationally declined in the design of the working method: they orient the construction of the location criteria, guide the definition of the spatial priorities and inspire the design of the communication and training contents conveyed through the StoryMap platform. This methodological approach was supported by an important preliminary collection and analysis of heterogeneous data, from official sources (National Statistics Office NSO of Mongolia, UB Statistical Yearbook), direct field mapping activities, satellite data and remote sensing sources, as well as documents and technical reports produced by international cooperation and third sector organisations. In particular, materials provided by the Deutsche Gesellschaft

für Internationale Zusammenarbeit (GIZ), the Asian Development Bank (ADB), the Japan International Cooperation Agency (JICA), as well as local NGOs active in the promotion of waste separation practices and environmental awareness in marginal areas (Oppido, Ragozino, & Esposito De Vita, 2023) of the city were used.

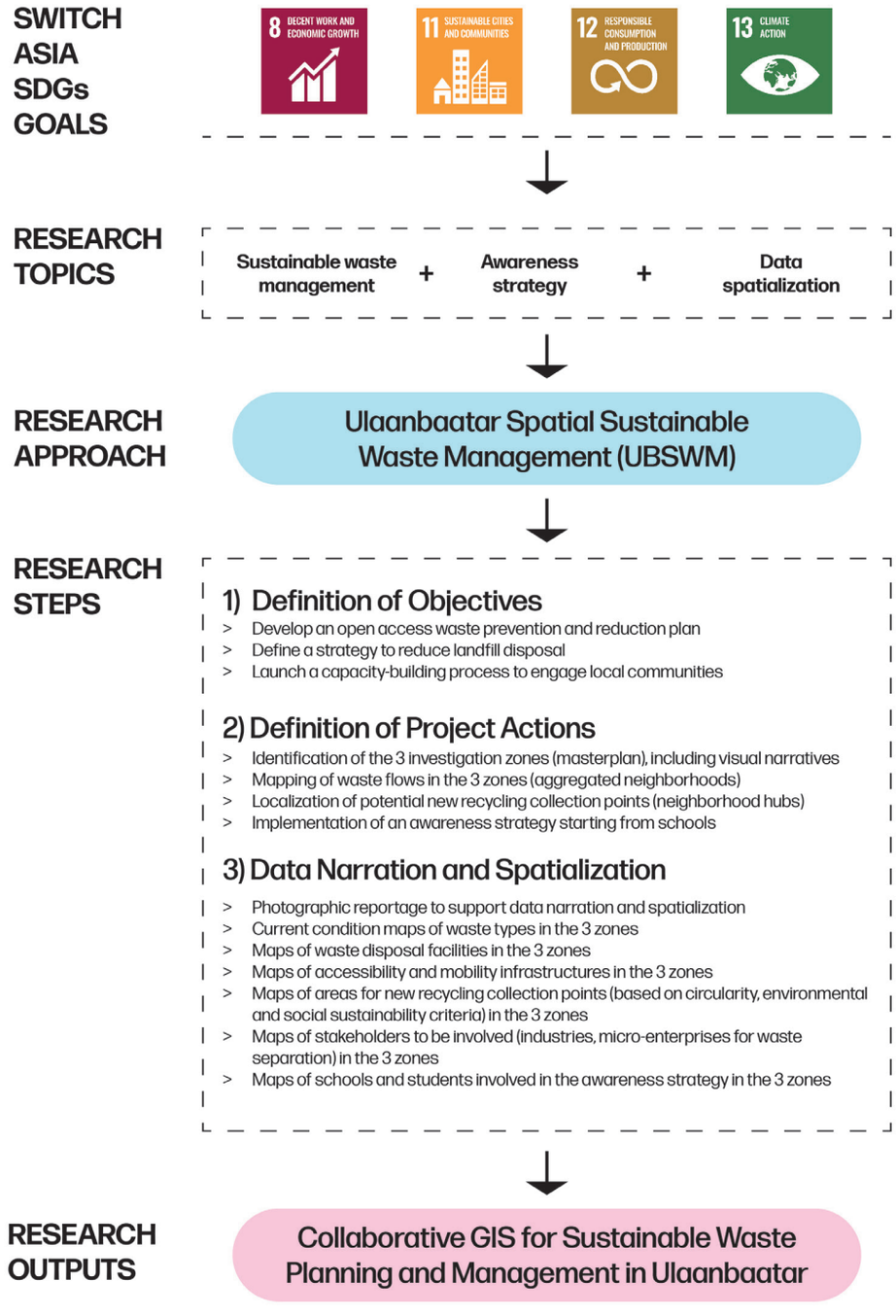



*Fig. 6 - Ulaanbaatar Spatial Sustainable Waste Management UBSWM (author elaboration)*

The central operational tool for the integrated spatial analysis has been GeoDB GIS, allowing the superimposition and combination of information layers referring to the circularity criteria defined by the project. The research path is developed according to three distinct but closely interconnected phases, which progressively define objectives, actions and restitution tools. The first phase focused on the definition of the project objectives, a founding moment through which the strategic assumptions of the plan are clarified. These include the construction of an urban plan for waste prevention and reduction that is usable in an open access format and designed to be scalable on a neighbourhood basis, alongside the formulation of a strategy aimed at significantly reducing landfill disposal. This is complemented by the activation of a capacity building process, oriented towards the active involvement of local communities in waste management processes. This approach explicitly recalls the principles underlying the co-production of knowledge (Turnhout et al., 2020), which emphasise the shared construction of knowledge through dialogue between institutional actors, technicians and inhabitants.

The second phase concerned the construction of project actions and operational mapping, starting with the identification of three pilot areas within the urban masterplan of UB, selected for their morphological and functional heterogeneity, as well as for the different incidence of phenomena related to waste production and treatment. These areas were associated with a spatial survey process supported by visual narratives, aimed at reconstructing aggregate waste flows on a neighbourhood scale. The analysis made it possible to strategically locate new waste collection points (eco-hubs ), designed to optimise accessibility and improve the efficiency of the system. At the same time, an environmental awareness strategy was defined and launched, with an initial focus on educational institutions, conceived as key presidia for the activation of virtuous practices and the dissemination of sustainable behaviour. This operational phase was guided by an approach that integrates spatial analysis and participation, according to the logic of collaborative geodesy and inclusive planning practices (Fraser et al., 2006).

Finally, the third phase (output) outlines the moment of restitution and interpretation of the results, through a data spatialisation process that combines cartographic visualisation and territorial narrative. In this phase, the photographic reportage becomes an essential tool to complement and amplify the critical reading of the collected data, favouring a multilevel representation of the observed urban conditions. The production of thematic maps - relating to the actual state of waste in the three areas, the existing plants, the mobility network and the areas suitable for the location of eco-hubs (particularly in the schools where the awareness strategy was tested) - is accompanied by the construction of a visual and interactive narrative, hosted in the StoryMap platform. In this environment, the data are also made readable to non-specialist audiences, reinforcing the communicative and pedagogical function of the project. This integration between technical data and visual storytelling draws inspiration from

the principles of urban narrative mapping (Perkins, 2008) and the experiences of urban data storytelling (Graham & Zook, 2015), which are capable of rendering the complexity of local dynamics through a dialogic synthesis between different but interdependent forms of knowledge.

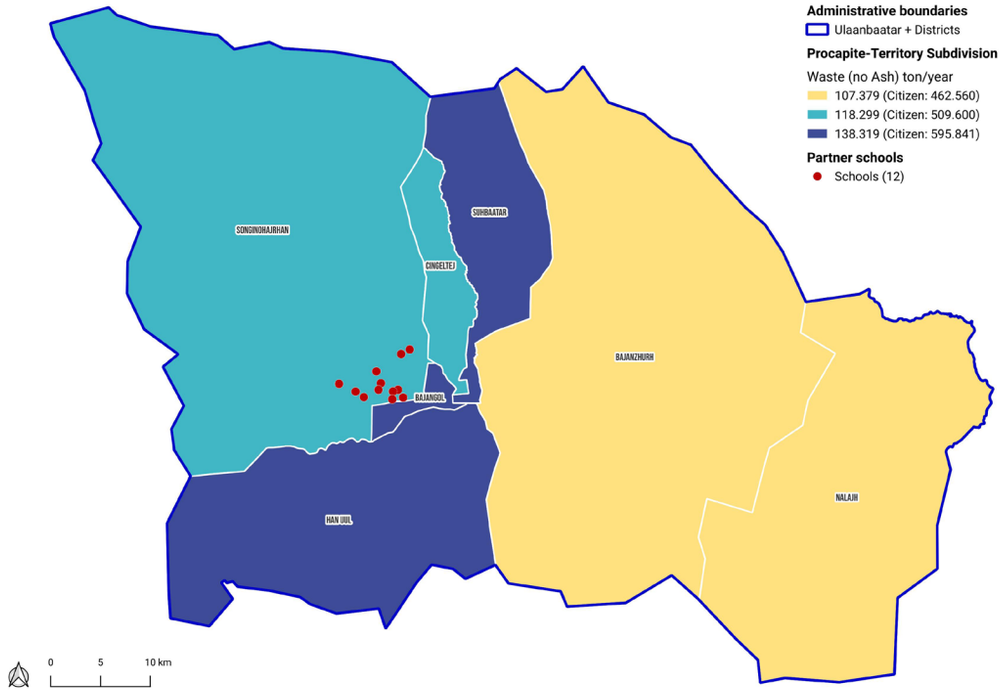
## 4. Results

Among the results of this research, to round off the methodological path, special attention was paid to the construction of a narrative device capable of rendering not only the spatial complexity of the phenomena observed, but also the cultural, social, and symbolic specificities that characterise the urban settlements of Ulaanbaatar. From this perspective, the StoryMap developed on the ArcGIS platform does not represent a simple cartographic visualisation tool, but takes the form of a true interactive storyboard, in which quantitative data, images, narratives and interpretations are interwoven to build a multi-level and shared representation of the urban context (Gurjar & Gaur, 2022; Sakshi et al., 2023). The development of the StoryMap was based on a database composed of official open-access sources, such as those of the National Statistics Office of Mongolia , the UB City Master Plan , and publicly accessible environmental databases supplemented with datasets provided by researchers from partner universities in UB. All the data collected have been previously processed in the QGIS environment, chosen to guarantee interoperability, traceability, and accessibility within an open-source logic (Gurjar & Gaur, 2022).

The use of cartographic narrative allowed us to highlight the profound heterogeneities that characterise Ulaanbaatar's ‘city within a city’: high-density neighbourhoods, ger settlements with a strong identity, and transition areas with fragmented infrastructure. The creation of a collaborative GIS specifically designed to support sustainable waste planning and management in the city of UB is one of the main outputs. The thematic maps provide a clear and detailed representation of the distribution of urban settlements and waste streams, providing a solid information base for planning targeted and localised interventions (Sakshi et al., 2023). The analysis of the overlap of the different information layers makes it possible to identify the most critical urban areas, such as suburbs characterised by ger settlements, and to suggest concrete solutions to improve the efficiency and sustainability of the waste management system. The cartographic narrative developed within the project aims to render, in visual and analytical form, the multiple spatial, social and infrastructural dimensions that make up the complex urban geography of Ulaanbaatar. The maps produced are conceived as interpretative devices capable of guiding the reading of the detected phenomena, supporting the decision-making process, and strengthening the dialogue between stakeholders, thus contributing to a more conscious and inclusive planning.

A first (data) map (Fig. 7 - Mapping Waste per Capita and Educational Engagement in Ulaanbaatar's Districts) shows the demographic distribution cross-re-

ferenced with waste generation and disposal flows, highlighting the areas of highest environmental and social concern. The data used (Tab. 1 - Definition of the collection project assumption. Procapite-Territory Subdivision (3R4UB)) is sourced from the city's official Master Plan and from open-access statistical databases, including Mongolia's national portal and the CityPopulation platform . Scaling down, in order to better observe the area where the schools involved in the project are located, a number of key maps are produced to better explore the issues addressed. Beginning with the map (Fig. 8), Ulaanbaatar's Three Urban Forms: Planned City, Spontaneous City, and City in Transition, which offers a comparative reading of the planned city, the informal city (composed mainly of ger settlements), and the city in transition. Through data collected on-site through fieldwork and integration with qualitative sources, this representation intends to capture the different urban morphologies and the relationship systems that structure them, making spatial discontinuities and levels of accessibility to services visible.




| AREA | DISTRICT | CITIZEN | WASTE (no ash) ton/year |
|---|---|---|---|
| 1 | Baganuur + Bagahangai + Bayanzurh + Nalaih | 462.560 | 107.379 |
| 2 | Bayangol + Han Uul + Suhbaatar | 595.841 | 138.319 |
| 3 | Chingeltei + Songinohairhan | 509.600 | 118.299 |
| | | 1.568.000 | 363.996 |

*Fig. 7 - Above, mapping Waste per Capita and Educational Engagement in Ulaanbaatar's Districts*

*Tab. 1 - Below, definition of collection project assumption. Procapite-Territory Subdivision (3R4UB)*

An important emphasis of the work is dedicated to infrastructure for mobility and accessibility, with a map (Fig. 9 - Mapping School Reachability and Urban Mobility: Student Distribution and 15-Min Walkable Area) describing the network of public transport by road (buses, stations, stops), mobility by rail (railway lines and stations), the distribution of car parks and airports, up to the identification of isochrones, with the starting point of the schools involved in the project, showing areas potentially reachable in fifteen minutes (Moreno, 2021) of walking. These representations allow us to assess the possibility of logistical integration of eco-hubs and the coherence between the infrastructure network and collection strategies.

Finally, special attention is devoted to the specialised land uses (Fig. 10 - Mapping Specialised Enclosures and School Networks), starting with waste disposal plants and landfills, along with other specialised enclosures, represented in relation to the settlement system to bring out how these enclosed places are grafted into the planned city and how the city in transition tends to locate itself where new facilities are built.

Together, these representations contribute to the construction of a multilevel thematic atlas, which does not merely describe the state of affairs but also suggests operational scenarios and adaptive configurations. The maps are also designed to be integrated into the ArcGIS StoryMap platform, with the aim of returning data through an accessible visual narrative, capable of generating engagement, understanding, and participation.

The work carried out in QGIS made it possible to structure the geodatabase according to thematic levels consistent with the circularity criteria, which were subsequently exported and narrated through the dynamic interface of ArcGIS StoryMap. In this environment, it was possible to integrate interactive maps, photographic content, and explanatory texts, facilitating not only a technical but also an experiential reading of the territories analysed (Neofotistos et al., 2023).

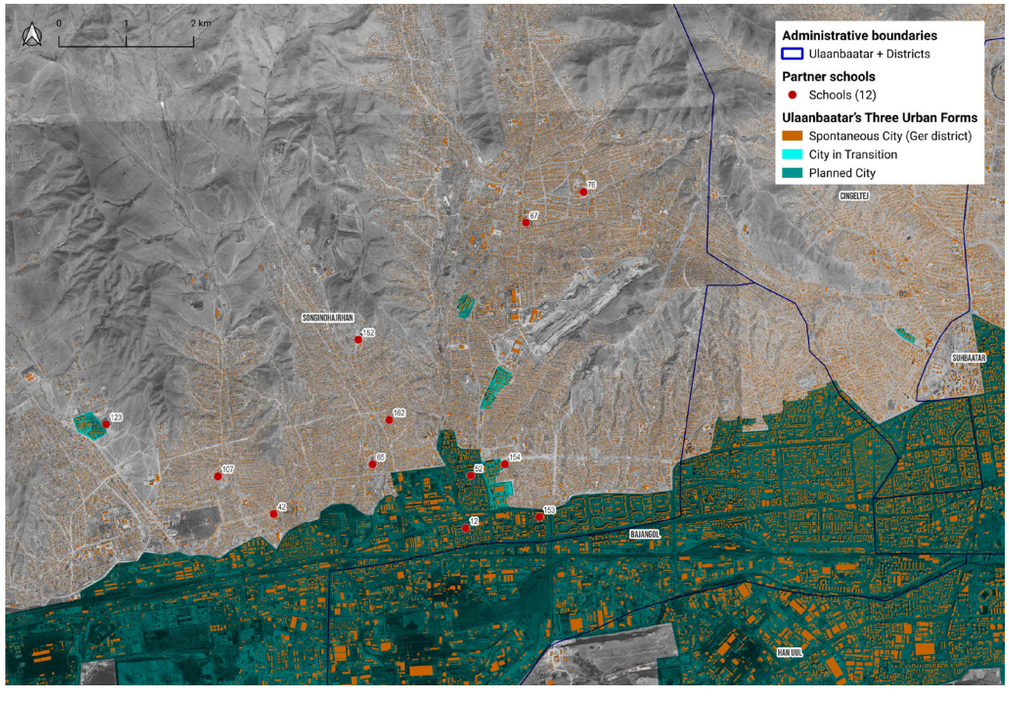



*Fig.8 - Ulaanbaatar's Three Urban Forms:Planned City, Spontaneous City, and City in Transition*

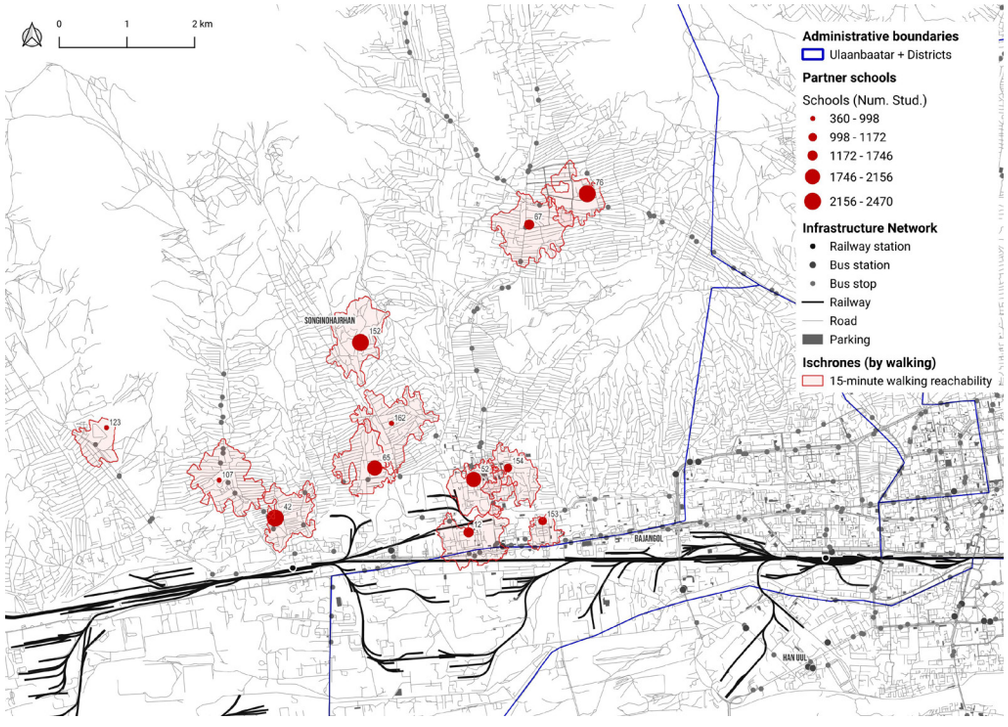



*Fig. 9 - Above, mapping School Reachability and Urban Mobility: Student Distribution and 15-Min Walkable Areas*

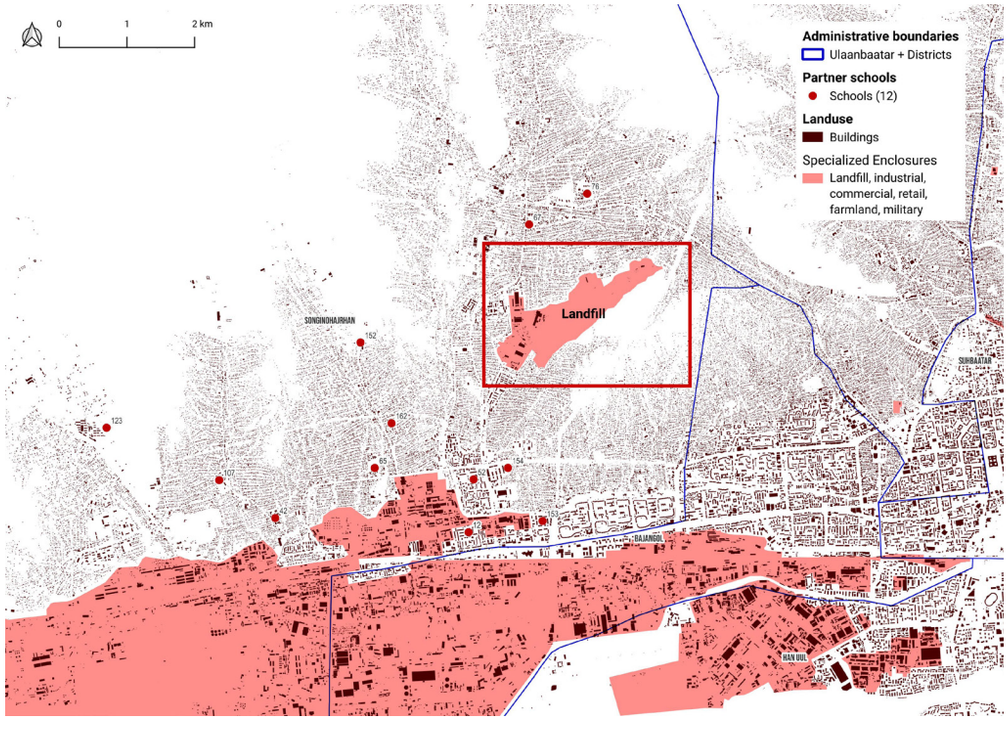



*Fig. 10 - Below, mapping Specialized Enclosures and School Networks*

The pilot project implemented at the school level represented an important test-bed for testing circular economy models in a circumscribed and controlled context. The introduction of eco-hubs in schools produced significant preliminary results, showing a considerable in-

crease in separate waste collection and greater environmental awareness in both students and their families. In parallel, a waste management plan integrating communication and participation tools was developed, managing to actively involve more than 25,000 students and their households. The awareness-raising campaigns implemented have played a crucial role in promoting the adoption of sustainable practices such as recycling and upcycling within the school community and, by extension, in the wider urban context.

Since its initial stages, the research adopted a participatory approach, with the aim of maximising local ownership of the results and ensuring the active involvement of all decision-makers in the institutional capacity-building process. Proactive collaboration was promoted between local authorities, relevant government agencies and various stakeholders, in order to jointly assess the impact of the adopted measures on the waste management sector and to raise awareness of the existing barriers and specific needs of the UB context. A significant achievement in this direction was the creation of an integrated partnership model, based on the collaboration between the Italian research institute CNR IRISS, the Municipality of Ulaanbaatar, the Mongolian government agency Fresh Water Resources and Nature Conservation Centre (FWRNCC) and the Italian technical partner Metellia Servizi. This model facilitated the broadening of the participation of all relevant stakeholders and the creation of a platform oriented towards the sharing of resources, skills and responsibilities.

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This model facilitated the broadening of the participation of all relevant stakeholders and the creation of a platform oriented towards the sharing of resources, skills, and responsibilities. The spatial tools developed, particularly the thematic maps, go beyond their descriptive function and represent a first step toward the construction of a decision support system for circular economy planning. By visually integrating quantitative and qualitative data, these maps act as a shared knowledge base that can inform local waste management strategies and foster policy-making processes aligned with collaborative planning theory, enabling more inclusive, evidence-based, and territorially grounded actions.

## 5. Concluding remarks

The overall results of the research conducted within the 3R4UB project present a potentially replicable model for addressing the complex challenges of urban solid waste management in cities with similar socio-economic and urban planning characteristics to UB. The UBSWM approach, which synergistically integrates the use of advanced GIS tools, the adoption of participatory planning practices, and the implementation of targeted outreach strategies,

shows promise for the realisation of a more sustainable, inclusive, and equitable municipal solid waste management system. The project strongly emphasises the crucial role of active local community involvement and structured collaboration between citizens and public authorities as determining factors for the long-term success of waste management initiatives. The 3R4UB project significantly contributes to local capacity building at different levels by providing technical and management skills to the relevant authorities while promoting the growth of environmental awareness within the population. The methodological framework of UBSWM can be positioned within the broader tradition of action research and participatory spatial planning. It draws on principles of collaborative mapping (Chambers, 2006) and co-production of knowledge (Turnhout et al., 2020), where spatial analysis is not only a technical tool but a catalyst for dialogue between stakeholders. The use of GIS is therefore not limited to data processing but is embedded in a broader effort of citizen science (Vohland et al., 2021) and community empowerment. By involving local communities, schools, and institutional actors in data collection, interpretation, and restitution, the approach aims to produce shared knowledge that can inform sustainable, place-based waste governance.

Future perspectives of the project include the development of multi-scalar models based on the use of GIS and the intention to extend the application of the tested model to other cities in Mongolia, with a focus on the potential role of schools as privileged laboratories for sustainability education. One of the follow-ups of this research will be the development of an ArcGIS StoryMap platform, which will integrate maps, multimedia content, and narrative text to create an interactive and engaging representation of the findings, ensuring the transparency, shareability, and replicability of the sustainable waste management model developed for UB.

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## References


- Aceves-Bueno E., Adeleye A.S., Feraud M., Huang Y., Tao M., Yang Y., Anderson S.E. (2017), "The Accuracy of Citizen Science Data: A Quantitative Review", The Bulletin of the Ecological Society of America, 98, 04/2017, Washington DC, pp 278-290.
- Adami L., Schiavon M. (2021), "From circular economy to circular ecology: a review on the solution of environmental problems through circular waste management approaches", Sustainability, 13, 2/2021, MDPI, Basel, Switzerland.
- Aristeidou M., Scanlon, E., Sharples M. (2020), "Learning Outcomes in Online Citizen Science Communities Designed for Inquiry", International Journal of Science Education, Part B, 10, 4/2020, Taylor & Francis, pp 277-294.
- Asian Development Bank (2025), "Mongolia: Ulaanbaatar Urban Services and Ger Areas Development Investment Program–Tranches 1, 2, and 3", Available at: https://www.adb.org/sites/default/files/project-documents/45007/45007-004-45007-005-45007-009-smr-en_0.pdf
- Bayartsetseg T. (2015), "Social Exclusion in the Ger Districts of Ulaanbaatar", Available at: https://blogs.ucl.ac.uk/mongolian-economy/2015/06/24/social-exclusion-in-the-Ger-districts-of-ulaanbaatar/.
- Bolormaa B., Fürst C., Buyandelger M. (2019), "Estimating the impact of urban planning concepts on reducing urban sprawl using some spatial indicators", Geographical Issues, 19, 2/2019, pp 42-61.
- Chambers R. (2006), "Participatory mapping and geographic information systems: Whose map? Who is empowered and who disempowered? Who gains and who loses?", The Electronic Journal of Information Systems in Developing Countries, John Wiley & Sons, 25, 2/2006, pp 1-11.
- Ferrara R. (2015), "The Smart City and the Green Economy in Europe: A Critical Approach", Energies, 8, MDPI, Basel, Switzerland, pp 4724-4734.
- Duurenbayar B. (2016), "Informal Settlement and It's Upgrading Ulaanbaatar's Ger District", (Master thesis) Politecnico di Milano, School of Architecture Urban Planning and Construction Engineering Master of Science in Urban Planning and Policy Design, Avilable at: https://www.politesi.polimi.it/retrieve/a81cb05c-4727-616b-e053-1605fe0a889a/2017_04_Duurenbayar.pdf
- Esposito De Vita G., Visconti C., Ganbat G., Rigillo M. (2023), "A collaborative approach for triggering environmental awareness: the 3Rs for sustainable use of natural resources in Ulaanbaatar (3R4UB)", Sustainability, 15, 18/2023, MDPI, Basel, Switzerland.
- Fraser E.D.G., Dougill A.J., Mabee W.E., Reed M., McAlpine P. (2006), "Bottom-up and top-down: Analysis of participatory processes in urban planning", Landscape and Urban Planning, 75, 1-2/2006, Elsevier, Amsterdam, Netherlands, pp 57-66.
- Ghisellini P., Cialani C., Ulgiati S. (2016), "A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems", Journal of Cleaner production, 114, Elsevier, Amsterdam, Netherlands, pp 11-32.
- Graham M., Zook M. (2015), "Visualizing urban inequalities: GIS and narrative mapping in social planning", Urban Studies, 52, 10/2015, SAGE Publishing, pp. 1883–1899.
- Gurjar S. K., Gaur, A. (2022), "Application of remote sensing and GIS in integrated solid waste management-a short review", Advanced Organic Waste Management, Elsevier, Amsterdam, Netherlands, pp 351-362.
- Hawkins G. (2006), The Ethics of Waste: How We Relate to Rubbish, Rowman & Littlefield Publishers, Dublin, Ireland.
- Herodotou C., Sharples M., Scanlon E. (2018), "Introducing citizen inquiry", in AAVV Citizen Inquiry: Synthesising Science and Inquiry Learning, a cura di Herodotou Christothea, Sharples Mike, and E. Scanlon Eileen, Routledge, Taylor & Francis.
- Healey P. (2003), "Collaborative planning in perspective", Planning theory, 2,

2/2003, SAGE Publishing, 101-123.
- Karthe D., Lee H., Ganbat G. (2022), Fragmented Infrastructure Systems in Ulaanbaatar, Mongolia: Assessment from an Environmental Resource Nexus and Public Health Perspective, in AAVV Urban infrastructuring: reconfigurations, transformations and sustainability in the Global South, a cura di Deljana Iossifova, Gasparatos Alexandros, Zavos Stylianos, Gamal Yahya, Long Yin, Urban Infrastructuring, Sustainable Development Goals Series, Springer, Singapore.
- Knickmeyer D. (2020), "Social factors influencing household waste separation: a literature review on good practices to improve the recycling performance of urban areas", Journal of Cleaner Production, 245, Elsevier, Amsterdam, Netherlands.
- Memon M. A. (2010), "Integrated solid waste management based on the 3R approach", Journal of Material Cycles and Waste Management, 12, Springer, pp 30-40.
- Miller E.J. (2013), "Nomadic and domestic: dwelling on the edge of Ulaanbaatar, Mongolia" (Phd thesis), University of California, Available at: http://gradworks.umi.com/35/55/3555240.html
- Mitchell N., Triska M., Liberatore A., Ashcroft L., Weatherill R. & Longnecker N. (2017), "Benefits and challenges of incorporating citizen science into university education", Public Library of Science PLOS ONE, 12, 11/2017, San Francisco, California.
- Moreno C., Allam Z., Chabaud D., Gall C., Pratlong F. (2021), "Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities", Smart Cities, 4, 1/2021, MDPI, Basel, Switzerland, pp 93-111.
- Neofotistos M., Hanioti N., Kefalonitou E., Perouli A. Z., Vorgias K. E. (2023), "A real-world scenario of citizens' motivation and engagement in urban waste management through a mobile application and smart city technology", Circular Economy and Sustainability, 3, 1/2023, Tsinghua University Press and Elsevier, pp 221-239.
- Obakhavbaye M., Burden K. (2023), "Inclusive Circular Economy: Promoting Young Adult's Participation Through Citizen Inquiry and Creative Participatory Research Methods in a Developing Country", Social Sciences & Humanities Open, Elsevier Ltd, Oxford, UK.
- Oppido S., Ragozino S., Esposito De Vita G. (2023), "Peripheral, Marginal, or Non-Core Areas? Setting the Context to Deal with Territorial Inequalities through a Systematic Literature Review", Sustainability, 15, 13/2023, MDPI, Basel, Switzerland.
- Ostertun Geirdal A., Ruffolo M., Leung J., Thygesen H., Price D., Bonsaksen T., Schoultz M. (2021), "Mental health, quality of life, wellbeing, loneliness and use of social media in a time of social distancing during the COVID-19 outbreak. A cross-country comparative study", Journal of Mental Health, 30, 2/2021, Taylor & Francis, pp 148-155.
- Park H., Fan P., John R., Ouyang Z., Chen J. (2019), "Spatiotemporal changes of informal settlements: Ger districts in Ulaanbaatar, Mongolia", Landscape and urban planning, 191, Elsevier, Amsterdam, Netherlands.
- Perkins C. (2008), "Cultures of map use", The Cartographic Journal, 45, 2/2008, Taylor & Francis, pp. 150-158.
- Sakshi, Neeti K., Singh R. (2023), "Diverse Applications of Remote Sensing and Geographic Information Systems in Implementing Integrated Solid Waste Management: A Short Review", Engineering Proceedings, 56, 109/2023, MDPI, Basel, Switzerland
- Sharma H. B., Vanapalli K. R., Samal B., Cheela V. S., Dubey B. K., Bhattacharya J. (2021), "Circular economy approach in solid waste management system to achieve UN-SDGs: Solutions for post-COVID recovery", Science of the Total Environment, 800, Elsevier, Amsterdam, Netherlands.
- Singh A. (2019), "Remote Sensing and GIS Applications for Municipal Waste Management", Journal of Environmental Management, 243, Elsevier, Amsterdam, Netherlands, pp 22-29.
- Springer T. L. (2012), "Biomass yield from an urban landscape", Biomass Bioener-

gy, 37, Elsevier, Amsterdam, Netherlands, pp 82-87.
- Tauginienė L., Butkevičienė E., Vohland et al. K., Heinisch B., Daskolia M., Suškevičs M., Prūse B. (2020), "Citizen science in the social sciences and humanities: The power of interdisciplinarity", Palgrave Communications, 6, 1/2020, Palgrave Macmillan, Springer Nature, pp 1-11.
- Turnhout E., Metze T., Wyborn C., Klenk N., Louder E. (2020), "The politics of co-production: participation, power, and transformation", Current Opinion in Environmental Sustainability, 42, Elsevier, Amsterdam, Netherlands, pp. 1-10.
- Vohland et al. K. et al. (2021), AAVV The science of citizen science, a cura di Katrin Vohland et al., Anne Land-Zandstra, Luigi Ceccaroni, Rob Lemmens, Josep Perelló, Marisa Ponti, Roeland Samson, Katherine Wagenknecht, Springer, Cham, Switzerland.

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