Cartographing Urban Ecosystems

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More than half of the human population live in cities. The rapid and exponential urbanization processes lead to the destruction of ecosystems, which, in turn lead to dysfunctional urban ecosystems.

The project Cartographing Urban Ecosystems (COE) is a global study to spatially understand the effects of architecture in conjunction with human behavior on urban and natural ecosystems.

This project develops innovative methods to chart the mutual relationships between architecture, urban design, and human behavior within urban ecosystems. The goal is to understand how these behaviors create feedback loops that transform the urban ecosystem over time. The methodology combines large-scale real-world data collection with deep learning-based parsing to uncover the spatial syntax of urban areas, human behavior patterns, and their impact on adjacent ecosystems.

The spatial syntax of cartographing Urban Ecosystems comprise four fundamental components:

1. **Toolset Development:**
   Creation of tools for gathering relevant on-site data.
2. **Spatial Analysis:**
   Deep analysis of spatial relationships revealed in the data.
3. **Cartographic Representation:**
   Development of visualizations to represent spatial dynamics.
4. **Interpretation and Solutions:**
   Insight generation and the development of solutions to address challenges within the urban ecosystem.

The study's method for collecting and analyzing real-world data highlights the role of technology in developing spatial solutions that reconcile urban growth with the preservation of nature. By utilizing a data-driven approach, the research offers valuable insights into formal and informal urban environments. It tries to understand transcultural collective behavior patterns, and data-driven architectural design solutions for the conservation of ecosystems.

This study aims to: (1) conduct a comprehensive real-world data collection effort, utilizing high-definition imaging to enhance deep learning-based systems for the detection, mapping, and analysis of spatial and environmental conditions (2) Gain an in-depth understanding of how spatial behaviors shape urban ecosystems by analyzing plastic litter data, movement patterns, typologies, the interplay with vegetation and environmental conditions. (3) Explore the potential of technology, in conjunction with urban design, architectural strategies, and decision-making processes, to effectively mitigate pollution and protect natural ecosystems.

In pursuit of these objectives, the project incorporates the development of a scalable digital machine learning tool, the project is dedicated to the continuous development of new analytical methods to effectively manage and extract insights from the growing amount of data gathered.

Principles for Analyzing the Morphology of Urban Ecosystems

This study develops a framework and tools for investigating the symbiotic relationship between urban ecosystems and the built environment. The focus is on understanding how spatial design shapes patterns of human behavior. The project generates maps and graphics to illustrate connections and interactions between environmental layers, highlighting the diverse properties of their configuration.

The task for the creation of a holistic understanding is immensely difficult, as geographically or culturally incongruent urban topographies and typologies embody unique spatial cultures. The organization of space is far from passive, it is dynamic, constantly influencing and being influenced by the working of its own dynamic system.

The research needs to address the resilience of urban systems and to understand cities as integrated social-ecological systems, bridging the ancient dichotomy between human and ecological systems. The idea of ecological services is crucial, as it pinpoints how cities are dependent on local ecosystems and the wide range of services they provide for their welfare and survival.

Within complex urban ecosystems, the intersection of architecture, human behavior and local ecosystems poses a significant challenge to the environmental health. The relation of environmental health to human behavior is a key element, as cities and urban centers tend to grow to a scale with no precedent. All these problems which are becoming more frequent every day are being called "Urban Pathology". It is absolutely necessary to face this pathology in order to tend towards more healthy cities.

The decay of quality of urban greenery is a global one. In Spite of clear contribution to improve urban life quality and in spite of the existence of world demands for urban sustainability, a methodological data driven approach on representing the complex intricate nature of urban configuration, environmental conditions and human behavior needs to be developed yet.

Cartographing the Spatial Syntax of Urban Ecosystems.

The applied study methods should rely on credible research and analysis. Following the paradigm of Space Syntax theory, space is an inherent element within society and the key generator for cities. The analysis should establish a connection between the configuration of space and its social outcomes and the effects that these mechanisms play on local ecosystems.

Cartographing Urban Ecosystems tries to understand the environmental conditions of urban space, described in terms of discrete spatial elements, manifested in built and unbuilt, planned and unplanned geometrical actors, that relate to human behavior. The study tries to understand the unique geometric and configurational properties of the network created by these elements.

In Principle Urban Design is about using built form to structure and shape urban spaces, for the intention of supporting and directing different urban processes into certain trajectories. We consider these processes as typically social, including economic, cultural & technological. What is considered outside of this scope, is often natural systems, and in particular ecosystems, due to the strong dichotomy between society and nature. However, typically social and ecological systems are intertwined, given the current ubiquitous call, it does not seem far to expand urban design into social ecological urban design. In a Space Syntax context this implies an aim to develop knowledge about how the spatial configuration of cities, not only influences a series of processes of a social kind, but also a series of ecological processes. Potentially not aiming for a social logic of space, but a socio-ecological logic of space.

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Figure 1 On Site, plastic litter measurement with portable camera – Palolem - India

Figure 3 Heatmap of Plastic litter in Palolem, India

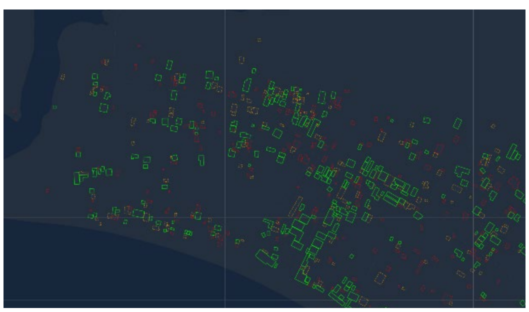

Figure 2 Image Detection Results for housing shapes of the informal settlement in Palolem, India, generated from satellite imagery

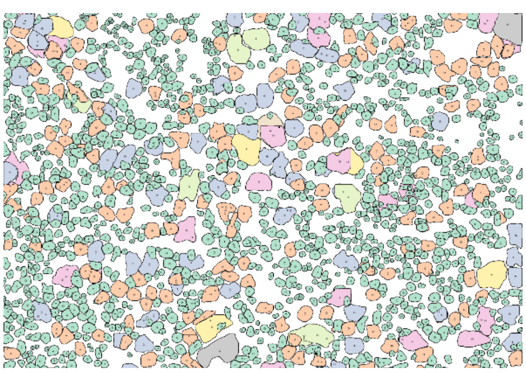

Figure 4 Deep learning parsed Tree top extraction based on Satellite Imagery

The concept that the built environment leaves a substantial human footprint is well-established. However, while the impact is broadly discussed, a more granular analysis is needed to understand the specific ways architecture influences human behavior and the local environment.

This study employs scalable data collection techniques to reveal nuanced spatial interactions within different geographical contexts. It will consider diverse scenarios of data collection to ensure its findings are robust.

A specialized hardware-software tool will be developed to measure real-world data. This tool will rely on deep learning to create, map, and evaluate geotagged images and videos.

The tool is designed for flexibility, with deployment options on mobile, stationary, and drone-based systems. This will facilitate large-scale data collection across challenging terrains, from moving vehicles, and via remote surveys.

The developed tool will be used to gather, process, and evaluate data for this study. Additionally, a lightweight version will be made publicly available for citizen science initiatives. This aims to democratize deep learning-based cartography, empowering thousands of individuals to explore and contribute to the understanding of urban ecosystems.

1. Litter Detect

A Pytorch based Machine Learning Vision Model, utilizing the YOLOv5 Architecture, That is being transfer learned on a pretrained COCO Dataset model to detect Plastic Litter in multiple environments.

2 Localizer

Localizer consists of a number of python tools that allow the geotagging of the parsed results of Litter Detect. It is directly embedded in the detection process of Litter Detect and is utilizing the metadata of the Images and Videos for the creation of CSV and Geojson files that will further be processed.

3. Observable Ecosystem

Observable Ecosystem is providing the visual cartographic representations of the collected data. The strength of this component consists in the use of HTML and Java as fast and flexible method for creating mobile friendly interfaces and applications, for the communication and creation of cartographic representations.

Observable Ecosystem provides an accessible, frictionless tool to explore spatial ecosystem data. It is interactive and is created for visually communicating complex spatial relations.

The goal of Observable Ecosystem, is to gain understanding, intuition, and insights of how a local ecosystem is affected by environmental stress.

It will be the main tool of the study for the cartographing the measured research, in addition it will be provided as a lightweight mobile tool for the use of gathering "citizen science" and for individuals and communities, the tool is meant as a communication vehicle for bridging the contact to authorities and municipalities

4. ML Cartograph

This system utilizes a chain of deep-learning based image segmentation models to generate rich cartographic data from open-source satellite imagery. This approach addresses a critical challenge in understanding urban ecosystems,

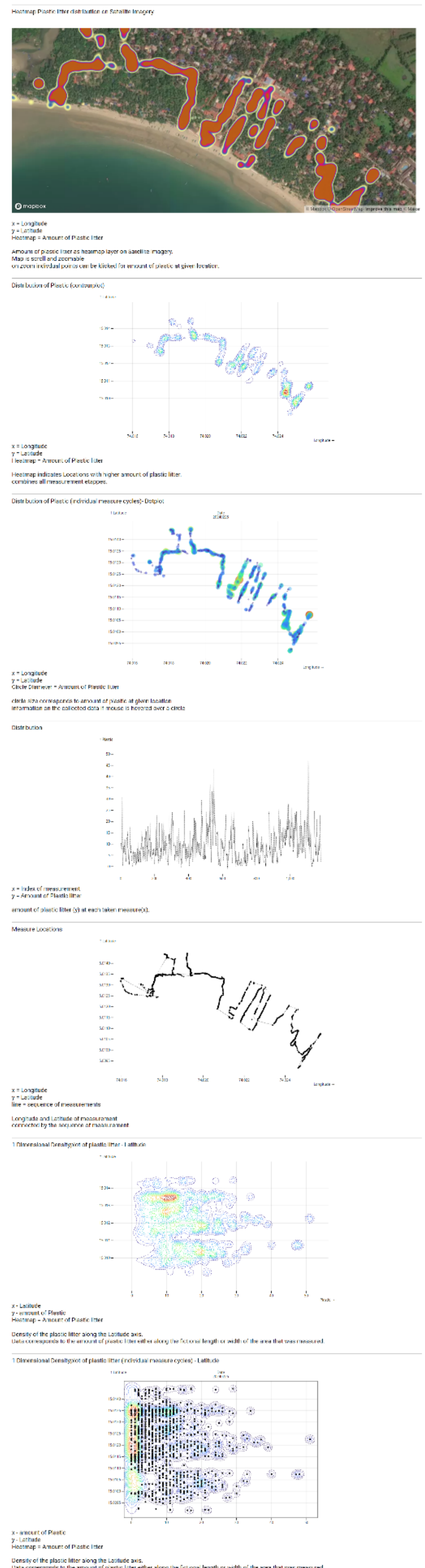

Figure 6 The results of the measure process in the village of Palolem, India.

especially in the Global South, where high-quality cartography is often lacking or difficult to produce due to factors like the dynamic nature of informal settlements.

ML Cartograph Capabilities:

1. **Building Boundaries**

Precisely delineates the footprints of individual structures.

2. **Tree Crown Boundaries & Vegetation Analysis:**

Identifies boundaries of trees, determines tree types, classifies general vegetation types, and assesses vegetation health.

3. **Litter Detection:**

Pinpoints areas with litter accumulation, supporting environmental analysis.

4. **Streets, Roads, Paths:**

Maps out the network of formal and informal pathways.

5. **Behavior Studies & Movement Patterns:**

Provides tools to track and analyze movement patterns within the urban environment.

5. **Vienna OGD Tools**

For collecting and mapping of data within the city of Vienna, the project utilizes a toolset that consists of a series of python scripts for processing requests to retrieve geometric data from the Open-Source datasets of the City of Vienna. The toolset facilitates the automated extraction and parsing of the data, utilizing the geographic locations of the gathered data.

6. **Brancher**

Is a functionality within Observable Ecosystems. This will serve as the branching tool that allows for the comparing of different measurement cycles and site, for a big data study on the accumulated data.

7. **Origin**

Origin will organize the file and data structure of the survey. For selecting measurement cycles Origin will be used for selecting, parsing and organizing the subsets of individual measurements and combines them for cartographing with “Observable Ecosystem”. Origin consists of a number of python scripts that rely heavily on the Pandas and Geopandas library.

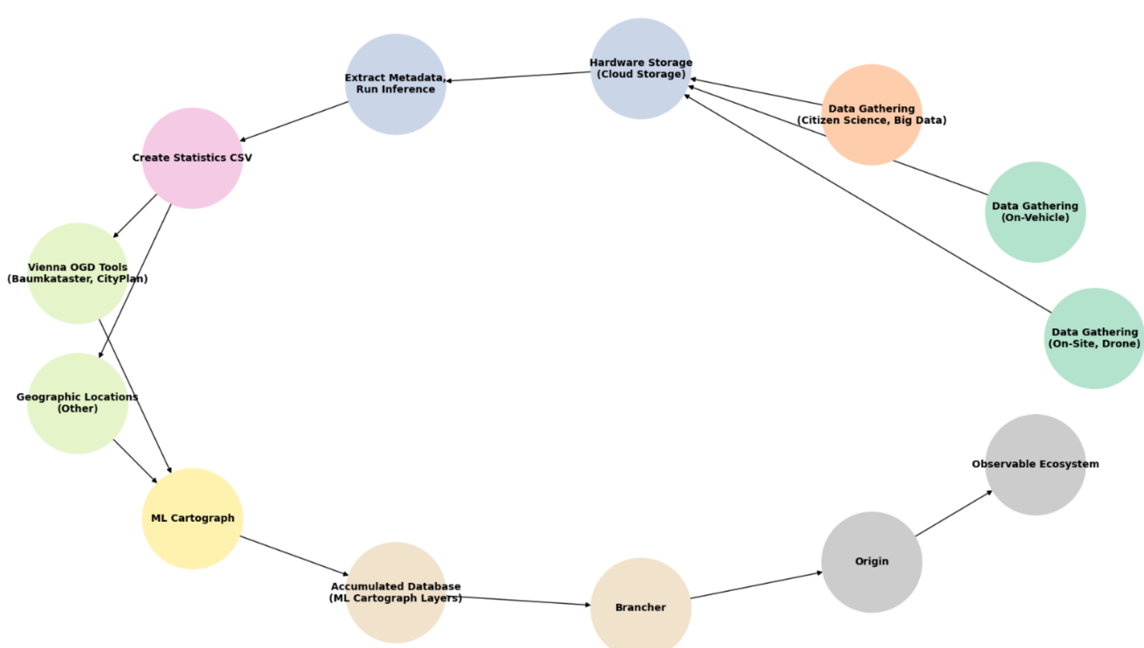

Figure 7 Bubble Diagram of the flow of processed data from data gathering on site to data illustration on server

Observable Ecosystem – Layer Illustration

(Fig.8)

Important for the cartographing will be the combination of Layers with the ML Satellite Image Segmentation method, from Mercator projected spatial distributions to quantitative representations of gathered data.

Observable Ecosystem – Wienfluss Example

(Fig.9)

The graph shows the distribution of Plastic Litter among a measured area. Locations with multiple Piles of Waste are cartographed with a density plot. This layer serves as the foundation layer for the cartographing of Plastic Litter Waste.

Figure 8Graphical Illustration of the cartographic layering, combining spatial and abstract data

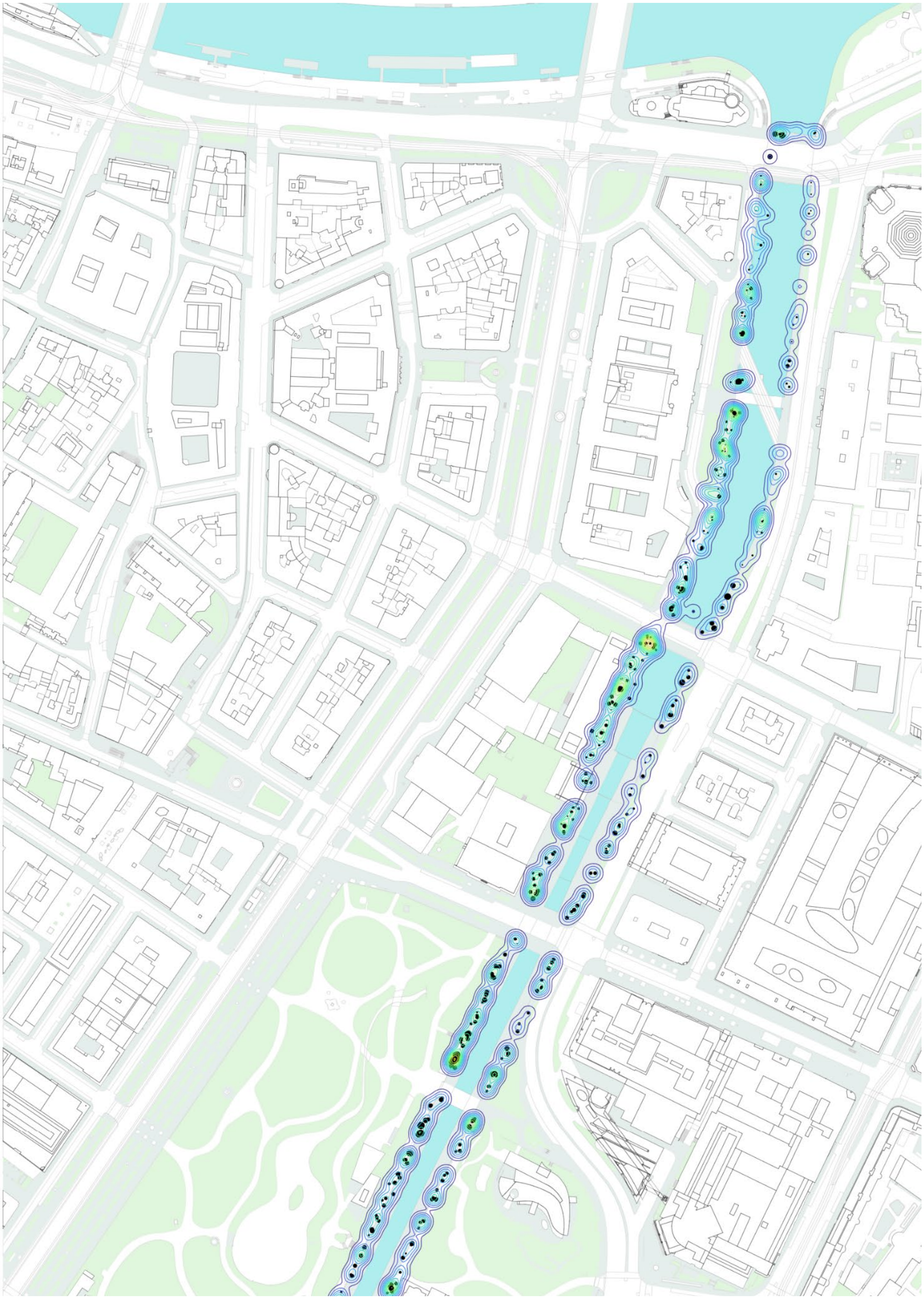

Figure 9 Observable Ecosystem Layer for the Plastic Pile distribution at the Wienfluss, Vienna.

Gathering of Plastic Litter Data

The tools developed for data processing enable evaluation and cartographic representation across three distinct methods:

1. On-Site Data Collection
2. Remote Data Acquisition
3. Reverse Engineering of Existing ML Datasets for Geospatial Information Extraction

Today, hundreds of millions of individuals possess remarkably accurate geospatial data collectors, facilitating the mapping of geospatial information. This potential for crowdsourced data, known as Citizen Science and Volunteered Geographic Information (VGI), represents a fundamental transformation in the way knowledge – particularly geospatial knowledge – is generated and disseminated within society.

The on-Site data gathering methods allow for the utilization of different cameras with geotagging compatibility. Dependent on the scale and circumstances of the data gathering location, the software will allow the reading and creation of high-definition geotagged images and videos by the usage of cameras mounted on drones, moving vehicles, or on-foot measurements. The usage of drones allows the cartographing of large terrains and environments (for example a mountain or a complete network of roads). With this technology, the scale of investigation can be radically enhanced. In this sense, the usage of measuring devices also follows the investigated scale.

Smartphones are a powerful tool for remote data collection. To gather high-quality spatial data across diverse geographic and cultural contexts, this project will release a streamlined version of the Observable Ecosystem as open-source. This will enable individuals and communities to collaboratively contribute data, introducing a gamified element to urban ecosystem mapping. The outcomes of this effort will facilitate effective communication with local authorities and stakeholders.

Consequently, the gathered data naturally benefits the study.

The third data collection method involves reverse engineering existing databases of plastic litter, accumulated for various purposes such as image recognition tasks. This includes making use of accessible crowdsourced and scientific data that is available for download.

Many projects have disproportionately focused on marine litter, neglecting its pre-marine, terrestrial, and corporate origins. To enhance our understanding of and response to plastic pollution, it is crucial to emphasize crowdsourcing and generating detailed, accessible knowledge on the geospatial characteristics of plastic pollution. This includes cities, riverbanks, beaches, coastlines, and areas surrounding schools, hospitals, national parks, and protected areas — essentially, anywhere plastic litter is found.

The initial starting point for the study will be a spatial evaluation of the Open Litter Map database, an open-source resource. The advantage of this dataset lies in its verification process; all images undergo verification before being made freely available for download. As of 2024, the platform has gathered data on 759,781 pieces of plastic litter across 484,288 geotagged images. Another significant benefit of this dataset is its global scope, encompassing diverse geographic, cultural, and climatic contexts.