Research Training Group
Urban Green Infrastructure
Technische Universität München

RTG Urban Green Infrastructure

Training Next Generation Professionals for Integrated Urban Planning Research

Updating on current Results

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Results Brochure of the Research Training Group *Urban Green Infrastructure – Training Next Generation Professionals for Integrated Urban Planning Research*

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Abstract

The Research Training Group *Urban Green Infrastructure* at the Technical University of Munich is investigating new types of urban green infrastructure to improve the sustainability, resilience and quality of life of cities. The focus is on training young researchers in urban planning, urban ecology, engineering and environmental medicine. The consortium works in three research clusters on Transformation of Urban Spaces with UGI, Improving Urban Indoor and Outdoor Climate, and Sustainable Urban Stormwater Management, divided in 13 subprojects. In the first funding period until September 2026, 14 principal investigators, 14 doctoral candidates, a post-doctoral researcher, a coordinator and more than 20 associated researchers, Mercator fellows and visiting researchers are involved in this inter- and transdisciplinary research project.

Keywords

Ecosystem services; Indoor and Outdoor Climate; Nature-based solutions; Stormwater Management; Transdisciplinary Research; Urban Space; Urban Transformation

Content

Figures

Tables

Introduction

Background

The aim of the DFG-funded Research Training Group *Urban Green Infrastructure (RTG-UGI)* is to inspire and to train young researchers on novel solutions for Urban Green Infrastructures (UGI). By developing networks of green and blue open spaces with multiple ecosystem services (ES), the sustainability, resilience and quality of life of cities shall be improved. Doctoral candidates undergo a specific and innovative qualification program that enables them to conduct UGI-related research in their disciplines at the highest academic level, while training them in inter- and transdisciplinary research within a system thinking approach. They collaborate with, and receive support and guidance from, researchers in the fields of urban planning, urban ecology, engineering and environmental medicine. The RTG-UGI represents a cornerstone in the education and upcoming careers of young scientists towards integrated urban research.

Aims and objectives

The RTG-UGI integrates research, planning and design of urban infrastructure and ecosystems, and human health to address current challenges in urban environments. The RTG seeks to gain a deeper understanding of the interrelationships between the Social, Ecological and Technological domains of the urban System (SETS) for the design of innovative UGI (Figure 1). The UGI graduate program conducts transdisciplinary research that is organized in three clusters on Transformation of Urban Spaces with UGI, Improving Urban Indoor and Outdoor Climate, and Sustainable Urban Stormwater Management.

Based on the SETS framework, the operationalization, substitution and integration strategies are motivated by linkages between research clusters and subprojects that will provide successful solutions for adapting cities to global change by improving their sustainability and resilience. The strategies are process-oriented, i.e. they focus on social cooperation and exchange between different social actors (*operationalization*), or outcome-oriented, i.e. achieving specific goals through UGI design and implementation (*substitution* and *integration*).

Objectives of the RTG-UGI:

1. Comprehensive scientific training in urban SETS and practical hands-on experience with UGI through participation in internships with city governments;
2. Engage doctoral candidates in interdisciplinary research in UGI through interacting research clusters that span social, environmental and technological domains;
3. Conducting research to respond to current societal needs for UGI;
4. Promote scientific careers by offering high quality training for (inter)national doctoral candidates and affiliate researchers.

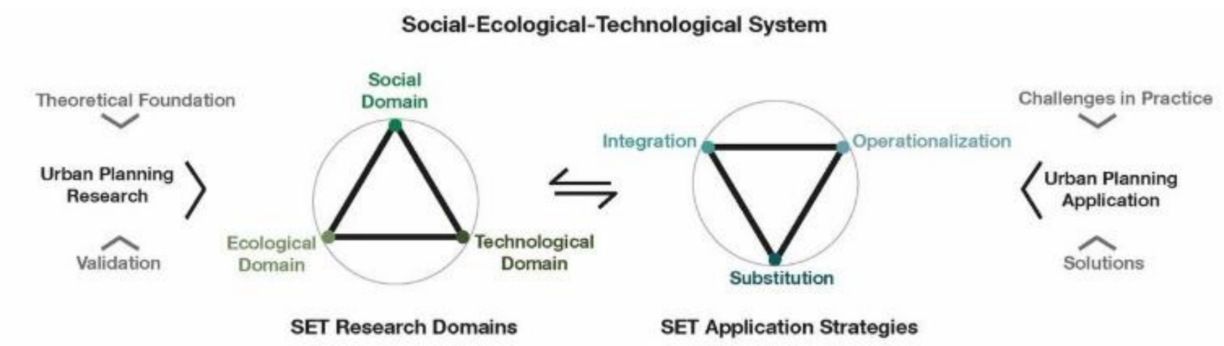

Figure 1: Research and application on social-ecological-technological systems (SET) in urban environments.

System Model

Roland Reitberger, Farzan Banihashemi, Nayanesh Pattnaik, Leila Parhizgar, Carolin Trost & Mohammad Rahman

One goal of the RTG is to develop a systems model that captures the multiple interactions of UGI and its surrounding environment. With this model, the inherent complexity of the urban system is explored. To develop such a model, a weekly meeting (Journal Club) was held during the summer semester 2023. The doctoral candidates of the RTG-UGI presented scientific papers related to their research to the whole group and connections to other subprojects were discussed. This provided a basic understanding of relevant interactions and was a starting point for developing qualitative causal-loop diagrams within each cluster. This development is currently in progress. On completion, it is planned to establish the interrelationships between the subsystems of the three Clusters.

As an example of the ongoing work, Figure 2 shows a causal-loop diagram for interactions within Cluster 2 on Indoor and Outdoor Climate. Main indicators within its subsystem refer to the interactions between urban tree growth, buildings, pollen concentration and outdoor thermal comfort. The model currently contains 41 indicators and identifying their connections is in progress. The goal is to develop an assessment of the indicator connections based on scientific sources and expert knowledge. This will allow to identify the most interacting indicators and influencing factors and form the foundation for quantifying interactions in the next step.

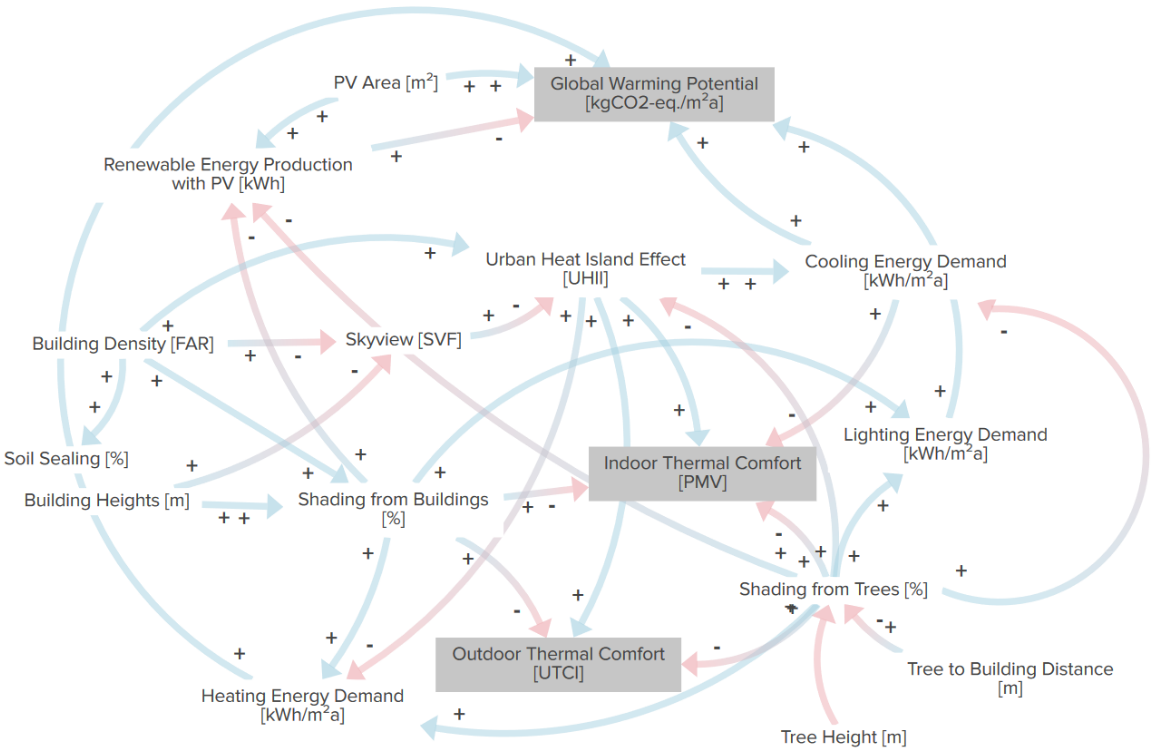

Figure 2: Excerpt from the current development a causal-loop diagram of building- and vegetation-related positive and negative feedbacks within Cluster 2 (work in progress).

Urban Typologies

Julia Micklewright, Roland Reitberger, Nayanesh Pattnaik, Mahtab Baghaie Poor, Leila Parhizgar, Hadi Yazdi & Mohammad Rahman

Background

Urban typologies were developed to characterize and simplify the urban fabric of Munich thereby enabling the scholars to assign various experiment sites to types and compare results originating from different locations of the city. Having these overarching typologies will also contribute to a common nomenclature within the RTG and help to connect the subprojects. The decision was to develop the typologies using the city of Munich's planning documents. This was done to enhance the practical usability of the typologies. The approach is further grounded in an understanding of urban landscapes as reported in previous studies, for instance, in Pauleit and Breuste (2011), Bartesaghi Koc et al. (2017) and Breuste et al. (2021).

The overall goal is to provide all RTG members with a GIS layer set representing those urban typologies that enhance the incorporation of each subproject findings into a comprehensive urban systems model. The simplification of the urban form into typologies is seen as a useful tool for extrapolating those results at a local scale to the whole city surface. Additionally, it can serve as a basis to identify the most common types. This will allow to select the most scalable urban labs for further investigation.

Methodology

Similar to the work of Bartesaghi Koc et al. (2017), the developed typologies combine built structure, land use and vegetation characteristics. These typologies rely on two main pillars, the “Block type” which includes the building and the open space typologies and the “Network type”, which includes the streets typology and the railway network (Figure 3). The land cover and the canopy cover percentage which stands for the vegetation cover is then applied as a further sub-categorization of these typologies.

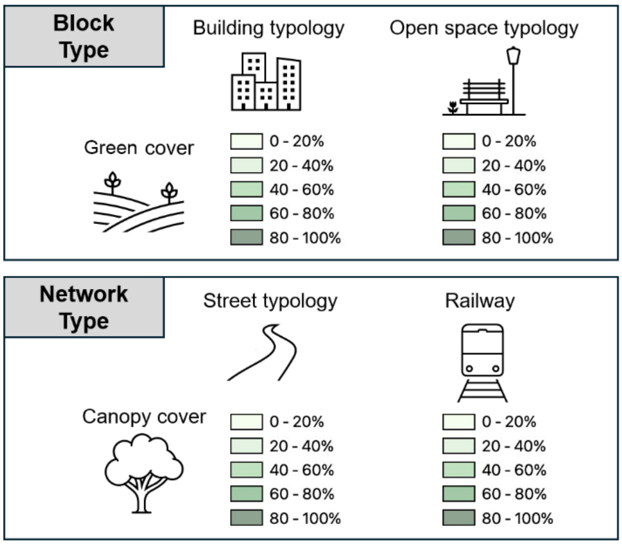

Figure 3: Typology classification logic of UGI

The spatial datasets were developed based on GIS data sets which were gathered from the following sources: the building and open space types were provided by the city administration of Munich and further simplified to seven types; the vegetation map originates from the land use and land cover (LULC) map of Munich developed by Dr. S. Bae at the chair of Prof. Dr. W. Weisser and the street classification is still under development.

Outlook

Urban typologies are being finalized and will be unrolled across the RTG for the first spatial and statistical analyses (Figure 4 - Figure 5). Collaboration possibilities with other spatial mapping institutions have been explored to use more recent data sets and further improve the data quality and resolution. This will support the further development of the urban typologies.

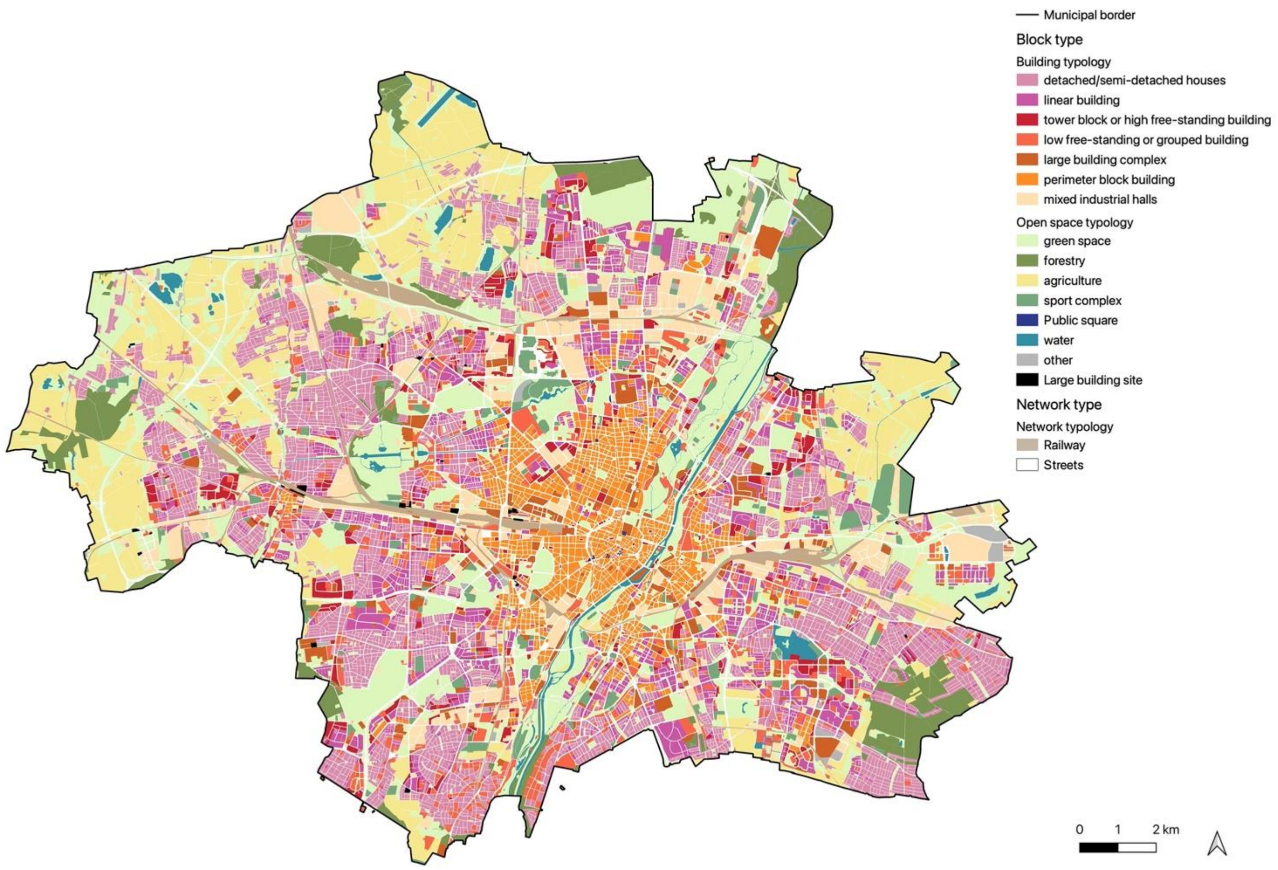

Figure 4: Spatial representation of "Block type" Typologies in Munich

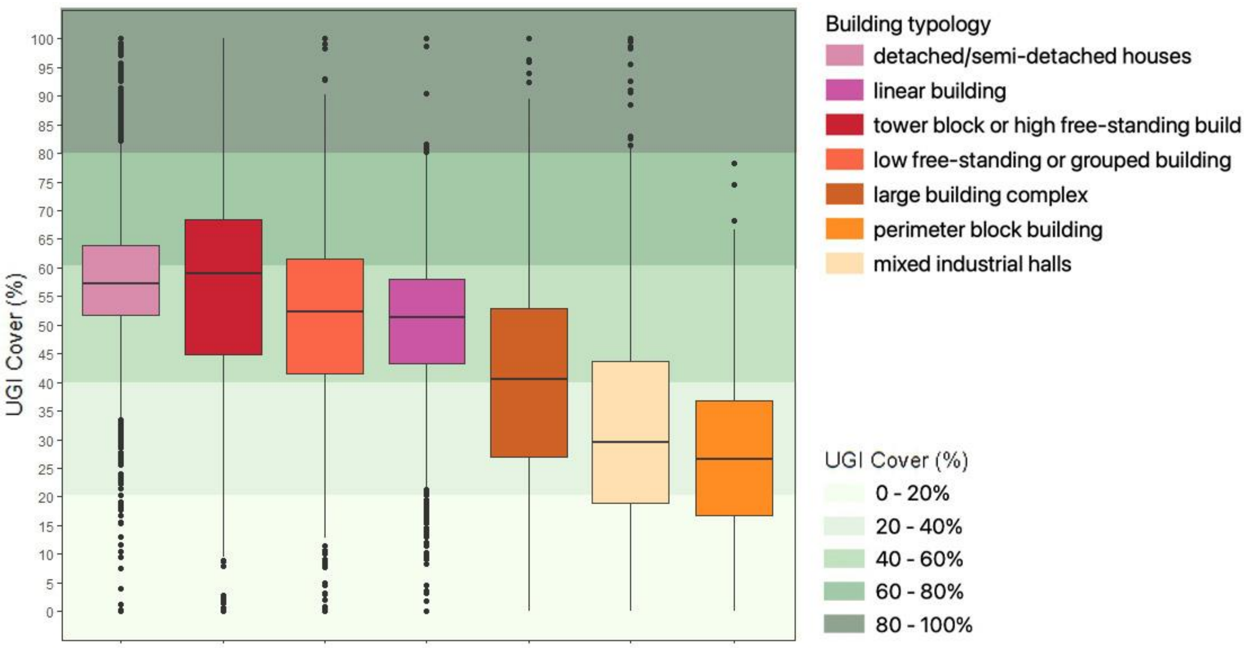

Figure 5: Distribution of UGI cover values within building typologies

SP1.1: Urban Green Spaces as Hotspots for Biodiversity

Andrew J. Fairbairn, Sebastian T. Meyer & Wolfgang W. Weisser

Background and objectives

The world's population is approaching 8.5 billion and is expected to reach nearly 10 billion by 2050 (UN 2019). With cities already housing nearly half of the world's people (Grimm et al. 2008) and future population growth expected to occur almost exclusively in cities (UN 2018), the pressures on urban green spaces will continue to increase (Haaland and van den Bosch 2015). Large swaths of land have already been converted due to urban growth and densification (Mcdonald et al. 2018), resulting in a concentration of human activity and increased habitat fragmentation (Haaland and van den Bosch 2015). As a result, urban development has been identified as a major driver of global biodiversity loss (Maxwell et al. 2016). As such, there is a growing agreement on the importance of urban biodiversity (Elmqvist et al. 2019, European Commission 2019, Mata et al. 2020, Grabowski et al. 2023), especially as people are becoming increasingly aware of biodiversity's role in providing important ES (Haase et al. 2014) and its impacts on human health (Methorst et al. 2021). However, our understanding of what drives biodiversity in urban areas is still limited and most urban greening projects only aim to increase the amount of green without taking into consideration what impact quality of green may have on biodiversity.

Here we aim to understand the distribution and drivers of urban biodiversity so that cities can better plan and design multifunctional UGI to not only meet the needs of people but also wildlife. To meet this aim, we break our work down into the following objectives:

O1: Analyze the role of UGI elements for different animal taxonomic and functional groups.

- To begin understanding the effects of urban design and UGI on urban biodiversity, we examine the impact of design elements on biodiversity in urban squares by synthesizing measurements from several different taxonomic groups that were taken on 103 public urban squares in Munich, Germany, and analyze how they are affected by features of those squares.
- We have generated methods and workflows for monitoring the contribution of UGI to biodiversity using AI-driven and advanced technology-based biodiversity assessments. To understand the drivers of urban biodiversity at a city scale, methods for monitoring biodiversity at spatial and temporal scales not possible with traditional methods are required. While passive acoustic monitoring is well established in bird monitoring, the ability to use it at large scales presents similar bottlenecks to traditional schemes because of limitations in human resources. Therefore, automated approaches are needed. We aim to develop a workflow using passive acoustic monitoring with species identification using deep learning as part of a semi- or fully automated monitoring scheme. However, species identification with deep learning is a novel technology and the efficacy of these models is not fully understood. Utilizing expertly identified acoustic recordings gathered in Munich, we assess the efficacy of the publicly available deep neural network, BirdNET (Kahl et al. 2021), in classifying bird species. Our aim is to ascertain whether BirdNET can generate species lists comparable to those of an expert ornithologist in an urban setting.
- We investigate the contribution of UGI to the occurrence of animals: Using the automatic species identification methods tested above, we quantify the urban bird commu-

nity across the city and investigate the contribution of different local and regional UGI elements to the occurrence of species.

O2: Explore the chances of operation, substitution and integration in enhancing animal biodiversity in cities.

- Using the models developed in O1, we predict how changes in UGI impact bird diversity in the city.

O3: Develop strategies for multifunctional design of UGI including the promotion of wildlife.

- Here, we synthesize the results of this project and other projects to explore opportunities for including biodiversity in existing UGI as well as developing guidelines for wildlife-inclusive UGI design.

Methodology

O1: To understand how features of the urban environment affect biodiversity, we identified 103 public urban squares in Munich and quantified their features and biodiversity of seven different taxa (arthropods, bats, birds, mosses, pollinators, small mammals and spontaneous vegetation). Using a combination of linear models and random forests, we identified what features of the squares were most important for the abundance (or activity) and richness of each taxonomic group.

To develop a semi-automated monitoring workflow, we first investigate how automatic species identification compares to an expert ornithologist. Using expertly identified acoustic recordings collected in Munich, Laim, using a Frontier Labs BAR recorder, which was placed in the courtyard of one of apartment buildings between May and October 2021, we compared to the output of BirdNET, a deep convolutional neural network developed by Cornell Labs (Kahl et al. 2021). By varying different BirdNET parameters, we made comparisons between the two datasets and calculated species richness, created species lists and the machine-learning performance metric F1 score. Thereby, we derived recommendations for the best settings to use BirdNET for biodiversity monitoring in an urban setting and establish a workflow for monitoring bird diversity in Munich at a large scale.

To investigate the influence of different UGI elements on bird diversity at a city scale, we select gradients in different features of interest (e.g. NDVI, vegetation composition, brownfield sites, vegetation structure etc.) accounting for location in the city (distance to Marienplatz) and deploy Frontier Labs bioacoustics recorders on lampposts or trees at each site for a period of one week. Recordings are then ingested into our data storage server and run through BirdNET to get species lists per site. Using linear models, we modelled the relationship between bird species richness, diversity, activity and the targeted urban features. We calculated bird activity as a vocal activity rate, or the number of BirdNET detections over the recording period.

Results and discussion

In the 103 squares in Munich, we found that the design features of those squares strongly determined the occurrence of different taxa (Fairbairn et al. 2023). We found that both richness and abundance generally increased with increasing greenness (NDVI) (Fairbairn et al. 2023). However, we found that different taxa are affected by different square features: For example, the density of trees and the proportion of lawn. Disturbance features, such as the number of humans or artificial light at night had a negative impact of several taxa but were positively related to pest mammal activity and the presence of pigeons (Fairbairn et al. 2023).

Interestingly, we found old trees to be unimportant to all taxa measured, despite their importance globally (Lindenmayer and Laurance 2017). This could be due to the intense management that urban trees undergo in the name of public safety (Le Roux et al. 2014). Deadwood is one of the most important features of old trees for biodiversity (Lindenmayer et al. 2014) and its removal may reduce the importance of old trees in cities. Our results demonstrate that the human design of urban spaces has great impact on the other species that may also occupy these spaces (Fairbairn et al. 2023). As such future urban development aiming to increase human–nature interactions (McKinney 2002, CBD 2012) or improve ES need to not only consider the needs of humans but also those of the other taxa coinhabiting cities (Fairbairn et al. 2023).

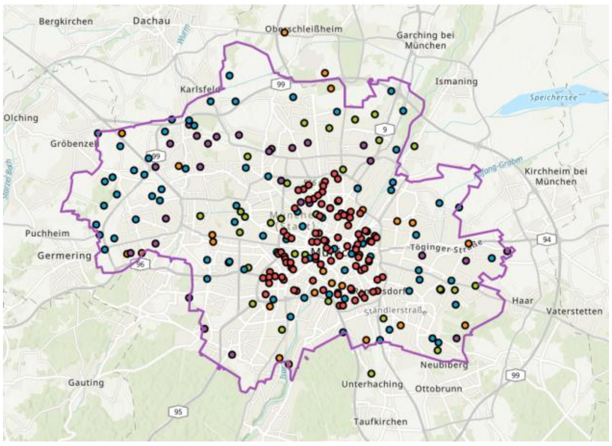

Figure 6: Bird acoustic monitoring sites in Munich. Each point represents one of 250 sites where acoustic monitoring of birds was undertaken in Munich between March and September 2023. Purple line is the city limits of Munich.

An analysis of the comparison between BirdNET and expert identification of acoustic recordings is ongoing. However, we have developed a workflow for large scale urban bird monitoring using BirdNET for automatic species identification.

Between March and September 2023, we monitored 250 sites throughout Munich (Figure 6). This monitoring was undertaken within several smaller projects investigating the effects of different urban features on bird diversity, for example NDVI, vegetation composition, brownfield sites and vegetation structure. In initial results investigating the relationship between NDVI and bird diversity, we detected a total of 61 bird species from 72 sites. The most common species (species found on the most sites) were *Corvus corone* (Carrion crow, n = 62), *Dendrocopos major* (Great spotted woodpecker, n = 55), *Picus viridis* (Eurasian green woodpecker, n = 51) and *Carduelis carduelis* (Eurasian goldfinch, n = 45). The most active species (most detections) were *Phylloscopus collybita* (Common chiffchaff, n = 54,951), *Apus apus* (Common swift, n = 51,450), Eurasian goldfinch (n = 35,101) and Great spotted woodpecker (n = 29,374). Species richness increased significantly with both NDVI and distance to the city center (NDVI $F_{1,65} = 9.11$; $p \leq 0.004$; distance $F_{1,65} = 8.88$; $p \leq 0.004$). Activity also increased significantly with increasing NDVI ($F_{1,65} = 3.14$; $p \leq 0.032$; Figure 7).

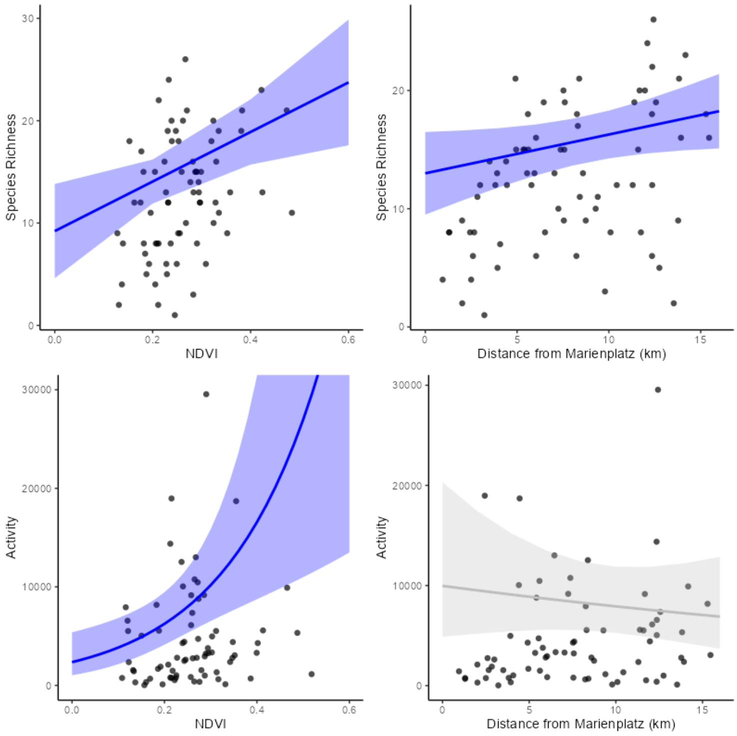

Figure 7: Effect of NDVI and distance from the city center (Marienplatz) on bird species richness and activity from 72 sites in Munich. Blue indicates a significant relationship, grey insignificant.

However, there was no significant relationship with activity and distance to the city center. This may suggest that activity is mainly driven by very common species and additional, more rare species have less of an impact. Our results add to the body of evidence that there is a strong relationship between greenness of location in the city and bird diversity (Bino et al. 2008, Ikin et al. 2013, Leveau et al. 2018, Leveau 2020, Mühlbauer et al. 2021, Nava-Díaz et al. 2022, Benedetti et al. 2023).

Outlook

Regarding Objective 1, we have made substantial progress. We show that greenness both in urban squares and throughout the city influences birds and other taxonomic groups. We also show that local features greatly impact the diversity and abundance of different taxonomic groups on public urban squares. However, there are some features we did not consider yet, for example, building height or distance to major features such as the Isar river. These features may have profound effects on the biodiversity occurring at a specific location in the city.

Additionally, our public squares data may only be representative of that urban feature, and other factors may be at play in the rest of the city. Therefore, we plan to use the 250 sites monitored looking at different urban features and additional sites yet to be monitored to cover additional features and continue to improve our data basis to investigate the drivers of urban biodiversity. Finally, we will use this data to produce a species distribution model for birds in Munich enabling us to represent urban biodiversity spatially explicit for the whole city.

For Objective 2, we will investigate how via operation, substitution or integration, UGI can be used to improve urban biodiversity. The species distribution models to be developed in Objective 1 could be used for predicting changes in bird communities following an urban greening intervention.

For Objective 3, we will work with the other members of Cluster 1 and the RTG collectively to develop guidelines for the design of wildlife inclusive, multifunctional UGI.

SP1.2: Urban Green Space Inequality and its Relationship with Biodiversity

Xia Yao, Fabio Sefanjo Timothy Sweet, Tobias Leichtle, Hannes Taubenböck, Andrew J. Fairbairn, Stephan Pauleit & Wolfgang W. Weisser

Background and objectives

Green space provides various ES and benefits for humans, such as climate regulation services (Masoudi et al. 2021), biodiversity conservation services (Gao et al. 2021), shading and cooling areas (Cummins and Jackson 2001), a sense of peace and tranquility (Kaplan and Kaplan 2003), reducing stress (Ulrich 1981), and so on. However, the distribution of green spaces in cities has been found to be unjust (Byrne et al. 2009, McConnachie and Shackleton 2010, Zhang et al. 2020). Age, gender, race, income, education level, and other factors stratified the access to green spaces (Wolch et al. 2014). It has been recognized as an environmental justice issue, also known as green justice (Wolch et al. 2014). It makes the inequality in green space accessibility, and further potentially results in translating into inequalities in mental and physical health (Chen et al. 2022). Still, our understanding of green justice is limited, and most research determines green justice by investigating the relationship between green areas (2-dimensional perspective) and socio-economic factors (Shen et al. 2017, Wüstemann et al. 2017, Sikorska et al. 2020). However, this fails to consider that urban green exists in three dimensions. Furthermore, the distribution of ownership of the green spaces is rarely considered (Shanahan et al. 2014). The ownership of green spaces usually determines their availability to humans, such as private green spaces are always open to individuals (Lachowycz and Jones 2013), while the public is open to all residents (Shanahan et al. 2014). To better understand green justice and maintain the opportunity of access to green space and biodiversity for citizens, this study identifies green inequality in Munich and understand its impact on bird diversity from a 3-dimensional perspective. Our objectives are:

O1: Identify urban green space inequality in Munich and its driving factors.

O2: Explore the impact of the urban green space inequality in Munich on bird diversity.

O3: Develop strategies for green justice and biodiversity equality.

Methodology

To identify urban green space inequality in Munich, we first acquired green volume data (2019.02) for the city of Munich from the German Aerospace Center (DLR), then the socioeconomic data (2019) obtained from the Infas 360 company. After that, spatial analysis will be carried out based on the green volume data and socioeconomic data by using the Geographic Information System (GIS). We then aim to build a model by R to work out the relationship between green volume data and socioeconomic data. Then, the green volume inequality and its driving factors in Munich will be figured out.

To explore the impact of the urban green space inequality on bird diversity, we will use the bird data collected by project SP1.1. The bird species richness and occurrence at the 250 bird acoustic monitoring sites will be used to explore whether the bird species richness or occurrence at the monitoring site is affected by the green volume inequality.

Based on the key factors driving green justice and its impact on biodiversity, combined with the socio-economic and natural materials of Munich, we will provide suggestions and guidelines for developing strategies to improve green space inequality and promote biodiversity, thus enhancing the human well-being and health in Munich. Our study also will provide the methods and experience for other cities.

Results and discussion

At this stage, the project has just collected green volume data and socio-economic data, currently undergoing analysis.

Outlook

In 2024, we will finish the O1, write a manuscript, and present the results at the 2024 GfÖ conference in Freising, as well as continue collecting biodiversity data, and then investigating the relationship between the urban green space inequality and bird diversity. Another manuscript is expected to be finished before the end of the year.

SP2: Breathable Corridors. Mobility in Multifunctional Urban Spaces

Mahtab Baghaie Poor & Gebhard Wulfhorst

Background and objectives

Increasing urbanization and global climate change necessitate the transition towards sustainable modes of transport more than at any time now which is included in the Sustainable Development Goals of the UN as well. The transportation system in cities holds great potential to mitigate air pollution, GHG emissions and, enhance the overall quality of urban life. The most sustainable transport modes, walking and cycling, also known as *Active Mobility*, have a great potential to be encouraged by UGI as the users of these modes have direct exposure to their surrounding environment (Figure 8). Despite existing research, there is a notable gap in understanding the nuanced role of UGI as a multifaceted system encompassing various elements and services. Existing literature predominantly treats 'greenery' as a singular factor, overlooking the diverse components within UGI.

The main goal of this research is to understand the share of UGI in active mobility comfort. In doing so, this research aims to discover how differently UGI elements play a role in these two modes of transport at different times of the day, week and year. In that regard, the objectives of the research are:

O1: To understand the general perception of comfort in active modes;

O2: To understand user-specific perceptions of UGI in active modes' comfort; and

O3: To reveal the differences between walking and cycling in terms of UGI provisions in addition to temporal differentiations.

To understand the effects of UGI on the cycling experience, we need to investigate the complex of urban built environment, natural environment, and personal characteristics of people. In this trilogy, the third pillar, subjective factors, and their relations to the other two pillars are often overlooked due to the infinite complexity of human beings and the difficulty of capturing psychological details of movement perception in the city. Consequently, the difference in the contribution of each UGI element to the walking and cycling experience for various people has been left undiscovered and is the knowledge gap that this research aims to address. In doing so, we introduce the User Experience (UX) data collection methods as a way of capturing the sensations and variables of active mobility comfort.

Figure 8: Components of Active Mobility Experience.

Methodology

Using a mixed-methods approach, the study is shaped in the following phases:

1. **Quantitative phase:** A tailored Comfort survey for walking and cycling is designed and distributed in Munich. Together with the data provided by previous surveys run by the City of Munich, these investigations build the quantitative phase of the research. This will reveal a general understanding of the share of comfort factors and set the ground for the next phase.
2. **Qualitative phase:** In this phase, we will pursue a qualitative approach using User Experience (UX) study methods. These methods

are suitable for the purpose of this research which aims to capture the subjective and abstract concept of comfort by omitting the researcher's interpretation from the results. This research starts with the social group of young adults who work or study in Munich. This group includes internationals who come from different mobility cultures and their moving to the new city could act as a life event that triggers behavioral shifts. People in this group are known to have the most agility and readiness to ride in less comfortable conditions, change their mobility behavior, and are more likely to learn and adapt to their new environment. The data collection essentially consists of **route tracking** and **experience tracking** facilitated by introductory workshops and daily monitoring and validation. Through the means of think-aloud protocol and voice/video recordings, participants (divided into two cohorts: walking, and cycling) are asked to capture and reflect on their personal (pleasant and unpleasant) feelings during their journeys, and the causing factors and document them.

3. **UGI-focused walk-along interviews:** To further narrow the focus of data collection down to UGI elements, semi-structured walk-along interviews are held with all participants of the walking and cycling cohort on certain routes consisting of various street-UGI typologies. A focus group workshop at the end of this phase is designed to validate the data collection and shed light on the ranking of the effect of UGI elements for active mobility comfort.
4. **Comparative study:** The data gathered through quantitative and qualitative phases for two modes of walking and cycling in Munich and a second European city, opens the doors to an enhanced understanding through comparative studies. In this step, we focus on the interpretation of results to reveal the contributions that various UGI elements can have to pedestrians and cyclists in Munich. Comparing the results with similar data in other EU cities sheds light on differences in geographical and social aspects.

Results and discussion

This subproject focused on developing the theoretical framework and methodological approaches in the first year. The results encompass the formulation of street typologies adaptable to the broader research group's objectives, the development and refinement of innovative research methods through a dedicated course and workshops, and the supervision of master theses focusing on finding the potential of connected green corridors for cyclists in Munich.

1. *Development of contextual street typologies for UGI*

In alignment with other RTG projects, a new street typology was developed based on the existing literature, existing road regulations, and classifications in Munich and Germany. A new approach for street classification is developed based on combining function, greenery, and human scale, suggesting a range of car-only to Active Mobility-only realms.

2. *Testing and refinement of research methods in an applied classroom setting and workshops*

A dedicated course was introduced to use and refine the User Experience methods in mobility, including methods like UX mapping, Think-aloud protocol and walk-along interviews. The successful establishment of this class paved the way for incorporating robust methodologies in the subsequent phases of the research project. Mobility User experience workshops were also held several times in classroom and neighborhood settings to refine the practicalities of the data collection phase.

3. *Master thesis projects*

Two master's theses have been supervised, exploring the potential of green corridors for a connected network of cycling. Using network analysis, surveys, scenarios, and UX workshops, the findings shed light on the high preference among young adults to cycle along parks. An interesting result was that 28% (n = 100) of riders were willing to reroute up to 2 km for work and

40% of riders were willing to reroute up to 5 km for leisure trips to have more greenery on their commute. This already reveals the great potential of UGI for changing travel patterns in Munich.

Outlook

Spring 2024 will witness pivotal surveys, including a PPGIS survey, offering rich insights into pedestrians and cyclists' preferences and spatial perceptions. Qualitative data collection, commencing in autumn 2023 for round 1 and summer 2024 for round 2, will provide depth to a user-based understanding of UGI benefits for active modes.

After gaining insights at an individual level about the perception of UGI by pedestrians and cyclists, the future orientation of the research can develop toward upscaling the findings at a network level. This outlook encompasses finding the gaps and overlaps between the mobility network and UGI network and suggesting integrations based on the findings of the current research.

SP3: Key Urban Structures for Green Urban Reconstruction Processes

Julia Micklewright, Ishika Alim & Mark Michaeli

Background and objectives

To develop a continuous network of UGI in our dense cities, it is necessary to leverage all open spaces regardless of their ownership status. Private spaces in cities represent a large share of potential green spaces and are therefore central in ensuring a continuous UGI network (Cameron et al. 2012, Hanson et al. 2021), but these surfaces still remain less explored by research (Haase et al. 2019). Whether these spaces are vacant land or maintained unsealed spaces such as gardens, frontages or courtyards, it is necessary to understand these typologies and plan strategically on a city scale to integrate them in UGI strategies.

Project 1 (J. Micklewright)

Objectives

The aim of this research project is to analyze the potential of private frontages to increase the continuity of UGI along mobility networks. In this study, private frontages are understood as the private space lying between the building façade and property border along the street space – when a green space, it is colloquially named a front garden. Systematically, the study will (1) characterize and quantify the typology of frontages in Munich, (2) demonstrate the multifunctionality of these spaces and their potential to support the continuity of the UGI, and (3) evaluate the operationalization potential of the identified benefits (Figure 9).

Methodology

The research project is carried out with a first phase designed as a quantitative approach based on a spatial and statistical analysis in order to map and quantify the potential of considering front gardens to strengthen the continuity of UGI. This is then complemented with a second qualitative phase focusing on the promotion of the ES provided by these spaces and the exploration of potential public-private partnership scenarios harvesting these benefits. In the third phase, the feasibility of these scenarios will be analyzed thanks to qualitative semi-structured interviews to ensure a complete understanding of synergies and potential barriers in such scenarios.

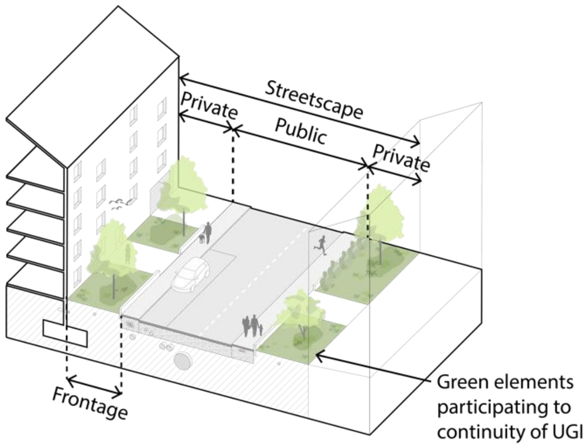

Figure 9: Project scope and definitions.

Results and discussion

Preliminary results of the statistical analysis show that, in the case of Munich, frontages are found across all urban typologies with a prevalence in the (semi)-detached housing, as this could be expected considering that this urban typology has the highest UGI cover percentage and covers a large area of Munich's municipality (cf. Section Urban Typologies). Predominantly in the detached/ semi-detached housing typology, frontages have also been found to overlap with city-defined green corridors, which hints at their importance when it comes to supporting the continuity of the UGI.

Based on this mapping, the surfaces are categorized in a framework developed to cluster frontages into typologies based on morphological, contextual and functional criteria. The results of this first phase will allow identifying predominant types of frontages, their ubiquity and role in the continuity of the UGI network.

Outlook

The results of the first phase will be assembled in a scientific article publication entitled: “The latent potential of front gardens: measuring the surface potential of private front gardens in Munich within the UGI and identification of typologies”. The findings of phase one will inform the scenario development and outline potential barriers for public-private partnership scenarios which will be verified in the last phase of the research project.

Project 2 (I. Alim)

Objectives

This research project focuses on urban vacant land, which are understood here as unplanned, not maintained, and unsealed spaces originating from abandoned uses or left-over spaces. The aim of this study is to evaluate the significance of urban vacant land in supporting the continuity of the UGI and the conditions under which these spaces can be planned strategically in the short term (Drake and Lawson 2014) or long term to support urban regeneration. This research addresses the need for further definition of typological differences in urban vacant land, reaching a better understanding of their spatial location within the urban context to serve as UGI step-ping stones (Luo and Patuano 2023) and achieving synergies with their surroundings on a short- and long-term basis. The research revolves around the following questions:

Q1: Which specific activation potentials are linked to the various typologies of vacant land?

Q2: How does the spatial location of vacant land within the urban context influence the potential to offer complementarity and synergy with the surroundings?

Q3: Which strategic measures can be taken to speed up processes of activation of vacant lots and integrate them in the short and long term into the UGI and urban context?

Methodology

The initial stage consists of a spatial analysis of the location specificities of vacant land and the qualification of their surrounding context based on a Land Use and Land Cover map using Geographical Information Systems (GIS). This will allow for a further definition of vacant land typologies, outline their potential to improve UGI continuity and identify challenges linked to socio-ecological aspects.

Results and discussion

The project is in the initial phase of clarification of the project scope based on the establishment of the literature status quo and identification of goals.

Outlook

Further research is expected to be conducted after the research break.

SP4: Transformative UGI-Governance

Elizaveta Weber & Stephan Pauleit

Background and objectives

To develop UGI as a coherent network in the context of diminishing availability of public urban land where UGI is most commonly implemented (Brokking et al. 2021), it is essential to extend implementation of UGI also to private land. However, due to the complex and constantly changing landscape of social ownership, it is almost impossible for a single actor to plan, develop and coordinate UGI (Erickson 2006). More and more academics recognize collaborative governance - where the state relies on collaborative efforts with non-state actors – as a means of UGI development (Frantzeskaki et al. 2019).

This research aims to test this assumption based on the city of Munich to understand whether collaborative actions are an appropriate solution. The strategic research goal of the thesis focuses on how the current UGI governance system in Munich can be altered by shifting the roles in decision-making in order to understand opportunities to integrate UGI into existing built infrastructures of different types across both state and non-state-owned property. Thus, the objectives of the study are the following:

O1: To find the barriers and enablers towards collaborative actions for effective UGI implementation;

O2: To explore possible solutions for overcoming the selected identified barriers; and

O3: To determine opportunities for the application of possible solutions within the current system of UGI governance in Munich.

Methodology

To reach the objectives of the study we use the city of Munich as a case study. The research is divided into three phases and relies on mixed methods.

1. Barriers and enablers: identification of the research units, stakeholder analysis, focus groups, secondary data analysis, semi-structured interviews.
2. Learning: Comparative case study analysis
3. Forecasting: Focus group methods and scenario workshop

Results and discussion

The first stage of the research is seeking to answer the research question: What factors played the most significant role in hindering and ensuring collaborative actions in the process of UGI development across both public and private lands?

To answer the question eight units of research were chosen for in-depth analysis based on the selection matrix and set of predefined criteria (Figure 10). A total of 18 semi-structured interviews have been conducted to date. For each unit, a detailed profile encapsulating insight into stakeholder interactions across different phases of UGI development was created. The gathered information is currently in the process of analysis based on the adapted Environmental Governance Framework (Driessen et al. 2012).

Preliminary analysis revealed, in a sense, a paradox. In practice, in number of units, collaborative action is absent in multiple or all UGI development phases, but this has not affected the integration of UGI. Such units emphasized that the main obstacle to collaborative action was the lack of need for collaboration due to independence in resources and decision-making power, which were directly dependent on land ownership type, funding capacities and type of UGI. Some units identified mechanisms for the exclusion of actors by the state. The final discussion will reflect on how well UGI can be governed depending on land ownership.

Outlook

The thematic analysis results will serve as the foundational basis for the first paper, titled "Collaborative governance arrangements for UGI in the context of complex urban land ownership patterns".

Concurrently, drawing on the insights from these analyses, the second phase "Learning" will be started. This phase is designed to gain insights from various contexts, helping to understand how to overcome the identified barriers hindering collaborative UGI governance in Munich.

Figure 10: Selection matrix on Transformative UGI-Governance.

SP5: Designing UGIs as Dynamic Processes

Hadi Yazdi & Ferdinand Ludwig

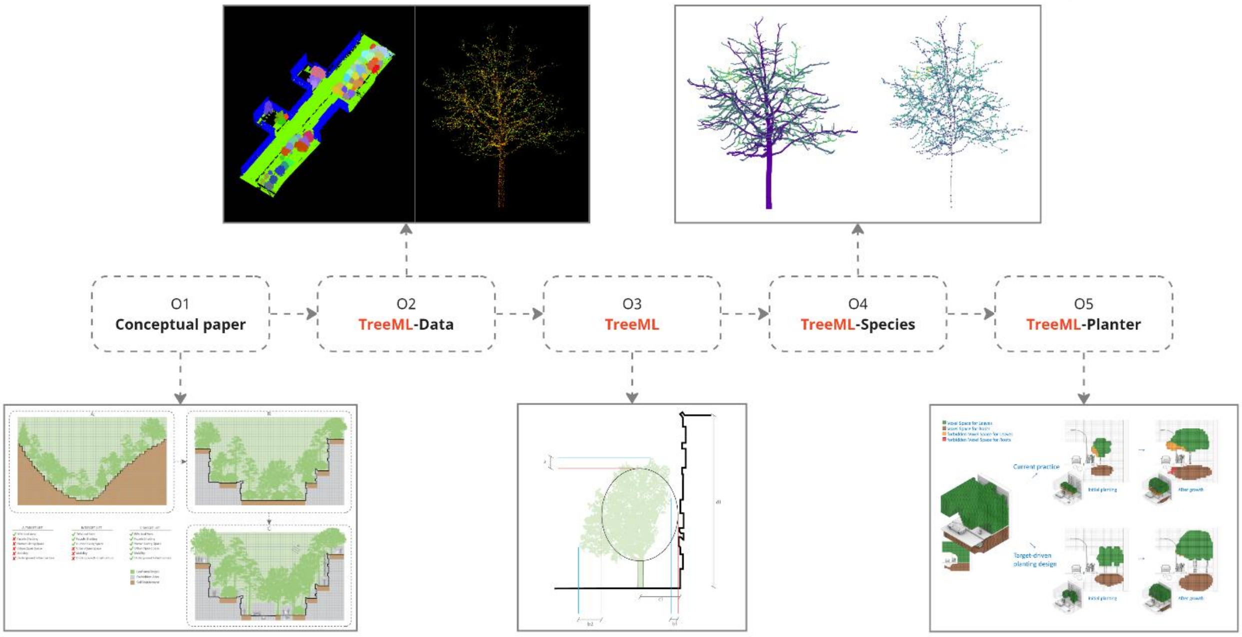

Figure 11: A visualization of all objectives and steps in subproject 5.

Background and objectives

In light of the growing trend of urbanization and the impact of climate change, the concept of UGI has gained prominence as a mean to enhance human health and wellbeing in urban areas (Konijnendijk et al. 2013). Given their significant role in UGI, it is crucial to thoroughly examine and research trees. Hence, maintaining an updated and precise inventory of individual urban trees is essential for conducting comprehensive urban forestry studies and supporting decisionmakers in strategic planning processes (Wallace et al. 2021).

Professional arborists usually have been responsible for compiling tree inventories, capturing a diverse range of variables such as location, species, vitality status, height and diameter at breast height (Nielsen et al. 2014). However, due to the time and quality efficiency of data collection by arborists and the intensive human work involved, alternative methods are being employed to conduct much more up-to-date tree documentation in a shorter time, such as remote sensing techniques (Roman et al. 2017, Seiferling et al. 2017). These novel approaches help to ensure the speed, quality and efficiency of inventory updates. Therefore, the utilization of high-resolution remote sensing data has emerged as a novel approach for accurately mapping individual trees within urban areas (Parmehr et al. 2016, Ucar et al. 2018, Erker et al. 2019).

These highly accurate and detailed urban tree data facilitate the evaluation and understanding of the tree crown growth, automated species recognition, and tree location optimization. Based on these goals, we developed a framework in five steps (Figure 11):

O1: Target-driven tree planting and maintenance (conceptual paper);

O2: TreeML-data: a multidisciplinary and multilayer urban tree dataset;

O3: TreeML: a machine-learning prediction model for tree canopy growth based on local environmental factors;

O4: TreeML-species recognition: automated tree species recognition based on quantitative structure models (QSM) and graph structures; and

O5: TreeML-Planter: a tree planting design tool based on the tree growth model in Objective 3. The model uses the 3D voxel model Objective 1 as a target leaf area for achieving the goal ES.

Methodology

The key used method of each step is explained based on their objective:

O1:

- Literature review and summary, and
- Flowchart for design processes.

O2:

- Remote sensing data gathering with TLS laser scanner,
- Automated semantic segmentation of urban point clouds, and
- Quantitative structure model and Graph structure model.

O3:

- Machine learning prediction models.

O4:

- Graph neural network classification models.

O5:

- Optimization model for locating the trees for specific targets.

Results and discussion

The result of **Objective 1** was published in the *Journal of Digital Landscape Architecture* entitled "A target-driven tree planting and maintenance approach for next generation Urban Green Infrastructure (UGI)" (Yazdi et al. 2023). This paper proposed a conceptual novel approach for designing UGIs from a 3D voxel point of view in cities to maximize the leaf area considering existing spatial conditions and objectives (Figure 12).

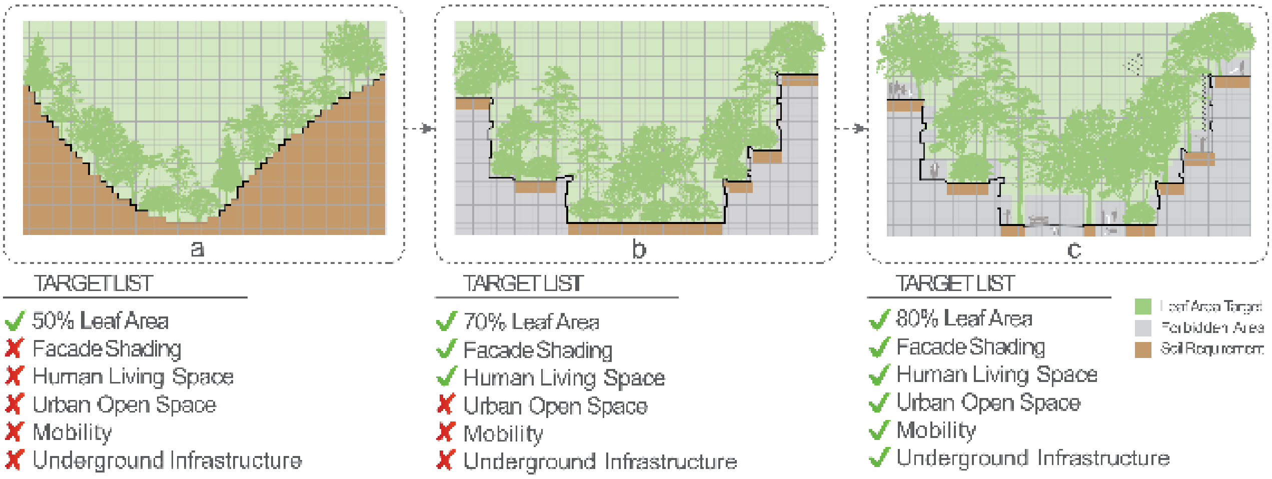

Figure 12: A conceptual framework of the target-driven tree planting and maintenance (Yazdi et al. 2023).

The result of the **Objective 2** was a data paper (Yazdi et al. 2024), which was published at the *Nature Scientific Data* journal. The dataset encompasses labeled point clouds derived from 40 scanning projects conducted on streets in Munich. Additionally, it includes 3,755 leaf-off (winter scans) point clouds specific to individual trees. Further dataset components include quantitative structure models (QSM), detailed tree structure measurements, and tree-graph structure models representing the trees located within these streets (Figure 13).

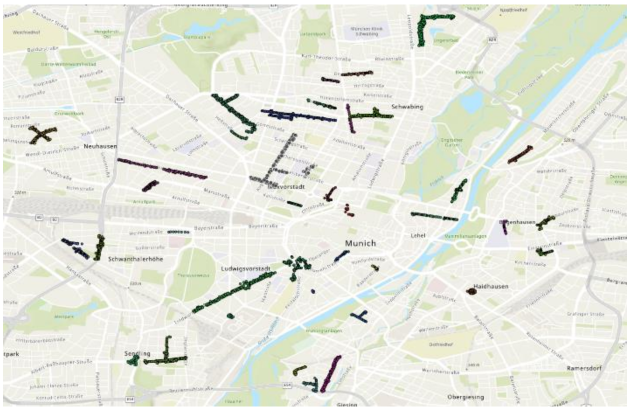

Figure 13: Open-source data of the 3755 measured urban trees in TreeML-Data paper (Yazdi et al. 2024).

Outlook

The results of the three remaining objectives are planned to be reported in:

O3: The TreeML model is under development, and the result will be submitted in January 2024 to the journal *Sustainable Cities and Society*;

O4: The TreeML-Species recognition model is under development, and the result will be submitted in winter 2024 to the journal *Remote Sensing of Environment*; and

O5: The TreeML-planter will be developed and submitted by the end of 2024.

SP6: Indoor Comfort and Energy Consumption of Buildings

Roland Reitberger, Farzan Banihashemi & Werner Lang

Background and objectives

As the impacts of urban heat islands (UHI) and climate change become increasingly apparent, there is a growing focus on implementing resilience strategies and enhancing buildings' climate adaptation (Grafakos et al. 2019). UGI has been identified as a promising intervention in this context, but its integration into the built environment is still lacking (Leone et al. 2023).

Buildings and UGI act as highly interconnected parts of the complex urban system. As the sustainable urban transformation requires a holistic approach, such interactions play a decisive role in finding well balanced solutions (Sharifi 2020). However, capturing and utilizing this complexity is a challenging task in research and urban planning.

Our goal is to study the interactions between built and green elements of urban systems and make them usable in urban planning. For this, we aim to:

- Quantify the influence of urban trees on buildings (energy, indoor comfort) in a bottom-up approach on city level;
- Investigate the potential of vegetation to improve several aspects synergistically (e.g. indoor / outdoor thermal comfort, energy demand); and
- Capture trade-offs between UGI and buildings to propose decision support methods for planners in such situations.

Methodology

To implement a bottom-up approach for energy simulation on city level, it is necessary to develop a methodology that allows capturing the influence of vegetation while being computationally highly efficient. Therefore, we use a machine learning (ML) model based on artificial neural networks. Training data is generated through 100,000 parametric building energy simulations. We establish a coupled workflow including the UHI and building energy simulation. For these simulations, we utilize the Urban Weather Generator (Bueno et al. 2013) and the Ladybug Toolbox (Roudsari and Pak 2013), respectively. This allows us to build a model that accounts for shading from trees as well as the effect of building density and evapotranspiration on the microclimate. The resulting ML model is then deployed to 3D CityGML data features. The dataset contains all trees in Munich (Münzinger et al. 2022) and their shading effect on buildings (Willenborg et al. 2018). We retrieve building geometries in the city of Munich from (LHM 2014). This dataset also contains the construction years and allows differentiating the cooling effect from trees for different building age classes (BAC). Figure 14 gives an impression of the combined datasets.

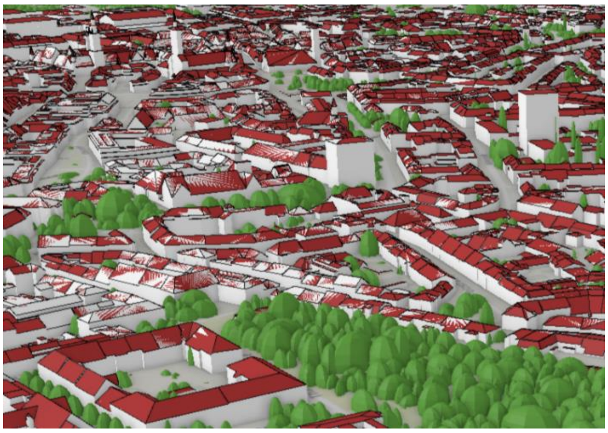

Figure 14: Combination of building and vegetation data in CityGML format. Building data: LHM (2014), tree data: Münzinger et al. (2022).

To investigate the synergy potential of UGI, we developed a sophisticated urban simulation model that captures various sustainability aspects, including energy demand, photovoltaics, wind, outdoor thermal comfort, and indoor thermal comfort. This model is a basis for further expansion and can also be used in subsequent trade-off studies. Furthermore, a generic process for exploring these urban planning trade-offs was established. It consists of the four main steps: data acquisition, model building, trade-off investigation, and decision support derivation (Reitberger et al. 2024).

Results and discussion

Preliminary training of the ML model and its application to the whole city of Munich revealed the reduction of cooling energy demand of buildings by urban trees. Figure 15 shows the results for approximately 67,000 residential buildings in Munich, grouped by their BAC. We considered two scenarios: the status quo and the building stock without any trees.

All BACs show a reduction in cooling demand due to the urban tree stock. For very old buildings (BAC 1, before 1918) the reduction is the smallest with 6.6% in average. This typology is frequently present in densely populated city centers, where the vegetation ratio is low, resulting in minimal impact on buildings. However, this also means that there is room for improvement in terms of cooling demands and indoor thermal comfort in these older typologies. The maximum relative reductions are found for BACs 2 to 6 with average values of 10–12%.

The bottom-up approach has limitations, especially regarding the level of detail (LoD). The buildings are only available at LoD 2, necessitating assumptions, such as window-to-wall ratios or attic utilization. Additionally, user behavior is difficult to predict. Hence, it was integrated as a feature in the ML model. This enables us to derive uncertainties associated with user behavior on a city scale.

Regarding the synergistic improvement of multiple aspects through UGI, we conducted a case study that accounts for indoor and outdoor thermal comfort, heating, and lighting energy demand. Figure 16 shows the results of the developed urban simulation model when the percentage of available planting spots occupied by trees was increased. A synergistic behavior of indoor (Predicted Mean Vote, PMV) and outdoor (Universal Thermal Climate Index, UTCI) thermal comfort can be observed. This synergy is contradicted by trade-offs with heating and lighting energy demands. The study showed that the magnitude of interaction between the aspects depends on the specific building conditions, e.g. refurbishment standard.

High energy standards work well together with high tree coverage in our case study. Thereby, increased heating requirements due to additional shading remain low, while trees can significantly improve indoor thermal comfort. Nevertheless, the case study showed that the assessment of synergies and trade-offs needs to be context specific.

Such simulation intensive approaches are limited in several ways. Wind flow, evapotranspiration, and tree shading are examples for simulation parts that are computationally expensive and thus only allow a limited number of evaluations. Further simplification and validation are therefore necessary. The results were published in a conference paper and presented at the SBE Conference 2023 (Reitberger et al. 2023).

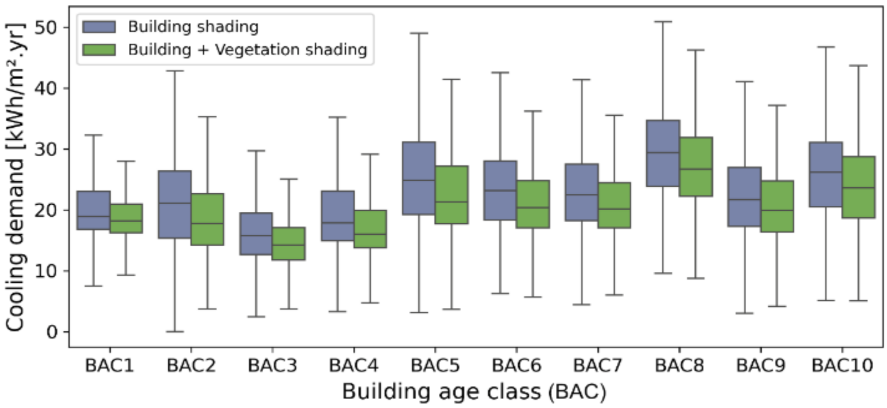

Figure 15: Preliminary results for potential cooling demand per building age class (BAC) for two scenarios: with and without vegetation shading (for approximately 67k residential buildings in Munich). The BACs refer to (Loga et al., 2015), with BAC 1 representing buildings built before 1918 and BAC 10 referring to buildings built between 2010 and 2015.

Outlook

Our next steps include deriving typological properties from the final energy model and publishing the application of the ML-approach. Thereby, we want to integrate the building energy perspective in the RTG's typologies of Munich (see section Urban Typologies).

To expand our currently energy focused consideration of the built environment, we are working towards the integration of ecological Life Cycle Assessment. As UGI will not be enough to compensate greenhouse gas emissions caused in the lifecycle of buildings (Theilig et al. 2023), a holistic approach consisting of sufficiency, consistency, and efficiency, must be taken. To this end, we started investigating combinations of grey and green measures to achieve synergy effects and manage unavoidable trade-offs in a targeted manner. In order to quantify such interactions, we aim to develop coupled simulation approaches.

One example is the usage of the microclimate software ENVImet to determine hourly air temperatures in front of green façades. These results can be implemented in subsequent indoor thermal comfort simulation, which allows to compare façade greening scenarios. A publication for the CISBAT 2023 conference is currently. in the publishing process, describing the methodology and its application in detail (Marx et al. 2023).

Model simplification and validation is another important part of future work. To validate the outdoor simulations, we started collaboration within the RTG and use measured data from the other subprojects. This will contribute to the efficient usage of the Urban Weather Generator, as the optimal radius for considering the UHI at a local scale with this tool is currently unclear.

Furthermore, we are working towards a more detailed exploration of trade-offs in urban typologies. This is important in two ways: firstly, urban planners learn in which corridor of possible solutions they can move and what they can expect as optimal trade-offs. Secondly, it allows us to derive control options for urban and UGI planning to move in a targeted manner within the space of optimal solutions.

The results achieved so far and the next steps planned are aimed at contributing to a systemic understanding of the urban environment across the RTG subprojects. The interrelationships uncovered in this way should help us to develop solutions to the challenges of sustainable transformation of our urban environment.

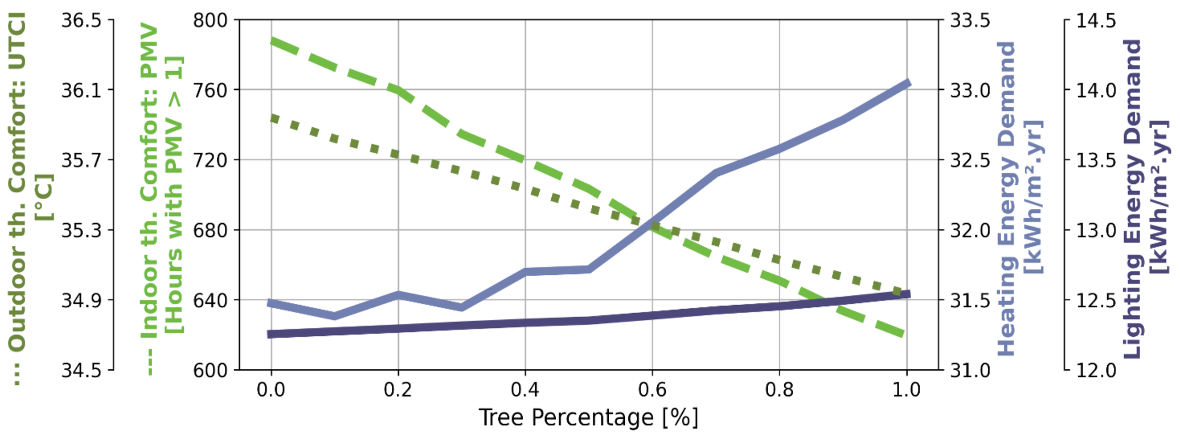

Figure 16: Dependence of mean heating and lighting energy demands and indoor (PMV) / outdoor (UTCI) thermal comfort on increasing tree percentage in a generic neighborhood. Indoor thermal comfort is evaluated by the number of hours with PMVs above +1 (slightly warm) throughout one year.

SP7: Microclimate-Green Infrastructure Interactions

Nayanesh Pattnaik, Mohammad Rahman & Stephan Pauleit

Background and objectives

Global climate change and rapid urbanization have significantly altered the energy balance within our cities (Chapman et al. 2017). This shift has resulted in a range of environmental issues, most notably the UHI effect. The UHI phenomenon has influenced regional climate patterns, vegetation growth, and the quality of water and air, all of which intricately shape the wellbeing of urban inhabitants (Zhou et al. 2018). UHI poses heightened threats to public health, particularly in temperate cities (Monteiro et al. 2019). Consequently, strategies for mitigating these challenges are imperative to safeguard human thermal comfort amid rising urban temperatures.

UGI is increasingly acknowledged for its capacity to counteract elevated heat levels in urban areas while concurrently enhancing the health, wellbeing, and thermal comfort of residents (Pauleit et al. 2011). Among a variety of plant elements, trees have attracted widespread attention for their ability to cool down the urban environment (Rahman et al. 2020). However, the thermal comfort provided by different strata and combinations of vegetation are yet to be explored. The ES offered by this multilayered vegetation depends heavily on their growth and eco-physiological responses to the highly heterogeneous urban surroundings. Hence, developing a holistic understanding of the contributions and influences of different types of vegetation towards mitigating heat in urban areas remains a challenge.

Our aim is towards improving outdoor human thermal comfort through the integration of multilayered UGI in cities. Specifically, we want to understand the following:

- The interactions of different types of surface coverage and the microclimate;
- The spatio-temporal variation of energy and water fluxes of different strata of vegetation as well as impervious surface; and
- Plant characteristics that control the extent and intensity of different ES provisioning.

The results of this subproject can effectively guide the planning and design of greening strategies in urban areas to improve thermal comfort.

Methodology

The research approach for the subproject involves two parts. First, the empirical part, which focuses on analysis of data collected through ground-based observations and field measurements at the study sites. Second, in the later stage, the experimental approach will be complemented by a modelling approach to scale up the findings from a plot level to a neighborhood or city scale. The study sites for the subproject will be the public squares of Munich. Public squares are a focal point for social life in a city as they offer space for different uses such as recreation, commercial activities, sport and social activities (Zölch et al. 2019). Therefore, it is of paramount importance to provide users comfortable thermal conditions in such spaces. Additionally, public squares feature a variety of surface combinations, giving us the chance to use scenario analysis to investigate how various surface cover (green and grey) interact with one another.

Results and discussion

The first stage of this study investigated the influence of surface coverage on outdoor thermal comfort, with a particular emphasis on understanding the cooling effect provided by shrubs. To achieve this objective, a field measurement campaign was conducted in 15 public squares of varying green coverage in Munich during warm, summer days. Initial results show that public squares with high tree and high grass coverages showed lowest mean radiant temperatures (Tmrt), 7K and 9K lower than fully sealed squares respectively (Figure 17). Results also indicate the effect of shrubs on the Tmrt with a mean decrease of 6.6 K compared to sun exposed measurements. Shrubs having almost three times less latent heat exchange than trees of similar crown volume and species. The four examined species also significantly differed from one another in terms of leaf physiology indicating that species level differences in ecophysiology and the importance of species selection for the objective of outdoor thermal comfort. Additionally, quantifying the effect of each of the vegetation structure, we found that heat stress is reduced to moderate level (Tmrt <55 °C) by either 35% Tree cover or 60% shrub cover or 75% grass cover.

Outlook

Our initial findings emphasize the significant role of tree cover in mitigating heat stress. Our subsequent focus will delve into understanding the impact of tree function when combined with the different vegetation elements and how these combinations might influence the human thermal comfort.

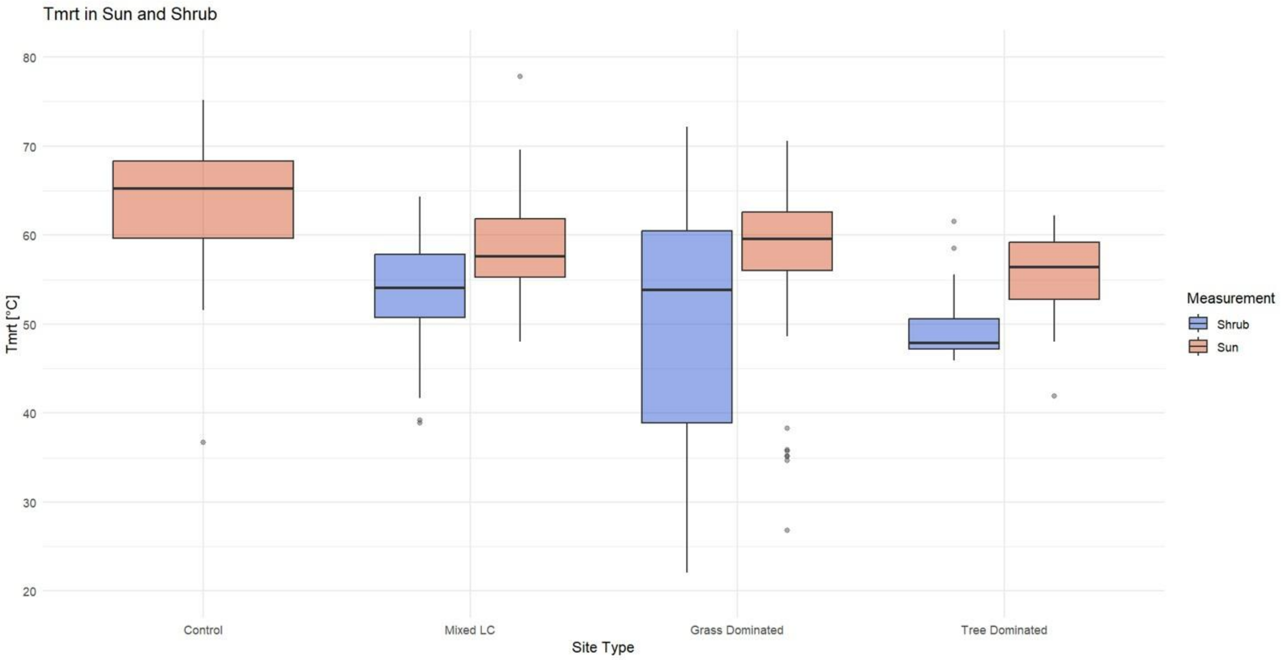

Figure 17: Mean radiant temperature (Tmrt) of four different settings (control, mixed, grass, trees) with shrubs or sun exposure in 2023.

SP8: Structure, Functioning and Ecosystem Services of Urban Trees

Leila Parhizgar, Thomas Rötzer & Hans Pretzsch

Background and objectives

As urbanization grows by 2050 the majority of the world's population is expected to reside in cities (UN 2008), urban areas confront diverse challenges, including the adverse effects of climate change on urban environments. Urban trees as a vital component of urban green spaces play a critical role in mitigating these challenges by offering multiple ES, such as regulating air quality, increasing shade and cooling (McPherson et al. 1994, Moser et al. 2018). Several studies have proposed models as tools to assist urban planners in the sustainable management of urban tree stocks and their ES at a city or quarter level (Pretzsch et al. 2021, Poschenrieder et al. 2022). However, due to limited data, **tree mortality** is only vaguely represented in models so far. Furthermore, while many studies such as Rötzer and Pretzsch (2018), have focused on European native urban tree species, the **structure, growth, and mortality of non-native/introduced species** have been neglected, although they might support climate change adaptation of urban tree stocks. We finally see a severe lack of **models for urban tree stocks**; they would support both the integration of existing knowledge and the sustainable management of urban tree stocks and the related ES. This background suggested the following three objectives of our study.

O1: Mortality of urban trees

Calculate annual mortality rates for urban trees and address questions: i. To what extent do these mortality rates differ across various size classes in two functional species groups a) coniferous and broad-leaved b) drought-tolerant and intolerant? ii. How do these rates change throughout different size classes? iii. What are the most important reasons for tree mortality in cities? iv. Is there a statistically significant relationship between tree mortality rates and the local climate conditions of cities, as determined by the de Martonne Index (dMI)?

O2: Growth & drought resistance of promising, future urban tree species

Evaluate the growth rate and drought resilience of five non-native EU species (*Corylus colurna*, *Gleditsia triacanthos*, *Populus nigra*, *Sophora japonica, Sorbus intermedia*) through dendrochronological analysis. To explore: i. How has climate change affected the basal area growth of these species since the beginning of the present millennium? ii. Are these species (compared to the species most common native species) more drought resistant? iii. Do individuals in Würzburg with low precipitation have a higher drought resilience than trees in Munich with more rainfall?

O3: Modeling approach. How to plan, achieve and control a sustainable stock of urban trees based on species and size class specific?

Integrate existing knowledge to develop a matrix model predicting mortality and growth rates of selected urban tree species, including simulated ES using the CityTree model (Rötzer et al. 2019).

Methodology

O1: For this objective, a database is created using the tree cadaster of five major cities in Germany over a seven-year period from 2016 to 2022. Utilizing R Studio, tree cadasters will be analyzed, employing logistic regression model, via generalized mixed model (GLM) designed for binary classification (0,1), mortality rates will be explored for different tree species and size classes. Additionally, other variables such as tree growing site and dMI will be incorporated into the analysis.

Q2: For the second objective, a comprehensive database is compiled from 274 cored trees across two selected cities (Munich and Würzburg). The evaluation of growth rate and drought resilience for the selected trees (Figure 18) will be conducted through dendrochronological analysis. The method involves analysis of tree rings using the LINTAB measuring device. The crossdating will be implemented using R Studio, DplR package (Bunn and Korpela 2021) (Bunn and Korpela 2021). Additionally, optical analysis, detrending via the ring width index (RWI), Superposed epoch analysis (SEA), and Linear Mixed Models (LMM) are employed to investigate basal area (BA) growth, with a focus on the impact of climate change since 2000.

Gleditsia triacanthos *Populus nigra* *Sophora japonica*

Corylus colurna *Sorbus intermedia*

Figure 18: Selected tree species of objective 2.

O3: The primary goal of this objective is to develop an inclusive matrix model that integrates the findings from objectives one and two, concentrating on aspects like growth, mortality, and the simulation of trees ES using the CityTree model (Rötzer et al. 2019). It is aimed to develop a predictive model to forecast urban tree mortality across diverse urban settings, species, and size classes. This would provide a structured approach to enhance the sustainability of urban tree populations.

Results and discussion

For the first objective, we used the cadaster data of five cities in Germany, encompassing seven years of tree monitoring. Preliminary findings indicate variability in annual mortality rate among cities, yet a consistent trend across all cities from 2016 to 2022. Notably, street trees exhibited an average mortality rate of 0.4% higher than the non-street urban trees. Furthermore, as result of the GLM logistic regression model we found a significant correlation ($p < 0.001$) between tree mortality and DBH size classes. We identified a Type III - Survival Curve, revealing elevated mortality rate among young and small trees, and reduced mortality among middle, large DBH size classes (Figure 19). Our analysis of the survival curve aims to pinpoint factors influencing high mortality rates, which shift as trees age and mature. The insights gained will serve as the foundation for the modeling approach in the third objective.

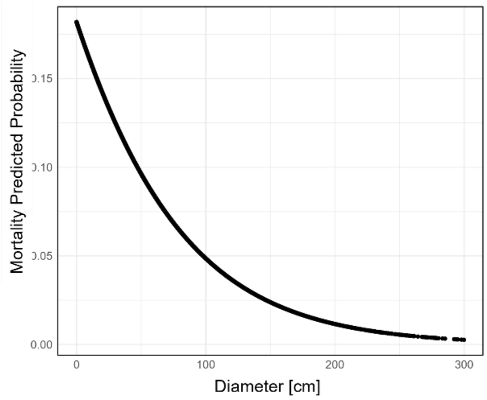

Figure 19: Predicted mortality rate in association with diameter size classes (Type III survival curve).

Outlook

The result of the objective one will be published in the first half of 2024, titled as “Understanding Mortality Rates and Associations with Tree Species and Diameter Size classes”. Also, it will be presented at the IUFRO conference, Stockholm in June 2024.

Overall, the study will utilize a variety of methods, including comprehensive mortality analysis, assessment of future drought-tolerant tree species and provided ES. Our aim is to bridge gaps in understanding mortality rates, discover drought-resistant urban tree species, and develop a model for understanding and aiding urban planning, enhancing tree management, and urban ES and sustainability.

SP9: Spatio-temporal Patterns of Pollen and Fungal Spores and its Impact on Health and Disease

Carolin Trost, Maria Pilar Plaza Garcia & Claudia Traidl-Hoffmann

Background and objectives

In times of increasing population densities and the associated expansion and densification of cities, the importance of the topic air pollution is growing (Hoesly et al. 2018). Green spaces and urban forests are needed in cities to improve the UHI effect (Maimaitiyiming et al. 2014) or the air quality by e.g. mitigating particulate particles (Beckett et al. 1998). However, negative effects are often neglected. These include the emission of allergenic pollen, which can lead to respiratory diseases such as allergic rhinitis and asthma (Pawankar 2014, Cariñanos et al. 2017, D'Amato et al. 2020). To avoid exposure to aeroallergens, aerobiological information tools can be used to produce maps showing the presence of pollen from ornamental trees, thus preventing unnecessary exposure, and showing sufferers healthy itineraries through the city (Quevedo-Martínez et al. 2022).

The general idea of this project is to focus on the verification of the risk of aerobiological origin in space and time for Augsburg and Munich. To achieve this, the following objectives will be considered:

1. Analyze the pollen spectrum of Augsburg using data obtained from aerobiological sampling at different points in the city;
2. Create regional geographic pollen gradients and plot the characteristics of the main pollination period in each of the cities;
3. Adapt existing aerobiology indexes to Augsburg to create risk maps and relate different aerobiological parameters with aspects such as geographical characteristics and intrinsic differences in the urban characteristics of each city, including the presence of buildings and differences in urban planning.
4. Create Augsburg aerobiological risk maps for the genus *Betula sp.* using Kriging and based on LiDAR data;
5. Develop healthy urban itineraries to avoid areas of greatest aerobiological risk; and
6. Correlation between microscale urban climate on pollen and spores concentration.

Methodology

To create an aerobiological information tool to help identify healthy itineraries based on urban ornamental trees, airborne pollen grain concentrations and build environment multiple technologies will be used.

The remote sensing technique LiDAR (Light and Detection and Ranging) is used to determine the exact position of objects, in this case buildings and trees, to create a high-resolution digital surface model (DSM) of the environment. The processing of this model is done with GIS (Geographical information systems).

In combination with pollen data collected with different instruments (volumetric 7-day Burkhard pollen trap, pollen monitor HUND, Swisens-Poleno and portable pollen traps) risk maps for Augsburg and Munich can be created. To create these risk maps, the potential for allergenicity from ornamental trees must be calculated. For this purpose, the AIROT index (Pecero-Casimiro et al. 2019) will be used. This index considers both geography and the built environment to determine the allergenicity of an area individually for each city (Pecero-Casimiro et al. 2020). In addition, the IUGZA index (Cariñanos et al. 2014) is taken into account, in which biological parameters such as the height, width and distribution of trees are considered in more detail. Both are to be adapted to Augsburg and possibly serve as a template for a separate index.

These indexes are applied to the genus *Betula*, since these trees have highly allergenic pollen and are one of the predominant pollen species in Europe (Smith et al. 2014, Caillaud et al. 2015). Furthermore, the geolocations of *Betula* for Augsburg were recorded by previous mapping. In addition to the locations, these also include the height and width of the individual trees (Figure 20).

Further factors like meteorological parameters (e.g. temperature, wind and precipitation) and pollutants (e.g. CO_2, PM_{10}, $PM_{2.5}$, NO) will be included in the model to reflect reality as close as possible and to detect possible correlations between these parameters.

The evaluation and presentation of the results is carried out using GIS, with the help of which both risk maps and a model of the city are possible.

Results and discussion

As this work was only started in June 2023, the expected results will be described here.

The indexes will provide spatial data on the strength of allergenicity, which will be displayed in risk maps as already mentioned. With the help of these it is possible to recognize which areas have a high allergenicity and which itineraries must be chosen to get through the city as healthily as possible. This data can not only serve as information for professionals from the public and private sectors, but can also be made available to the general public in order to avoid high exposure times or locations.

Outlook

In the future, these aerobiological tools will prevent people with allergies from being harmed by entering areas with a high pollen load. The risk maps will provide a healthier itinerary through the city, improving health and reducing the cost of medical care.

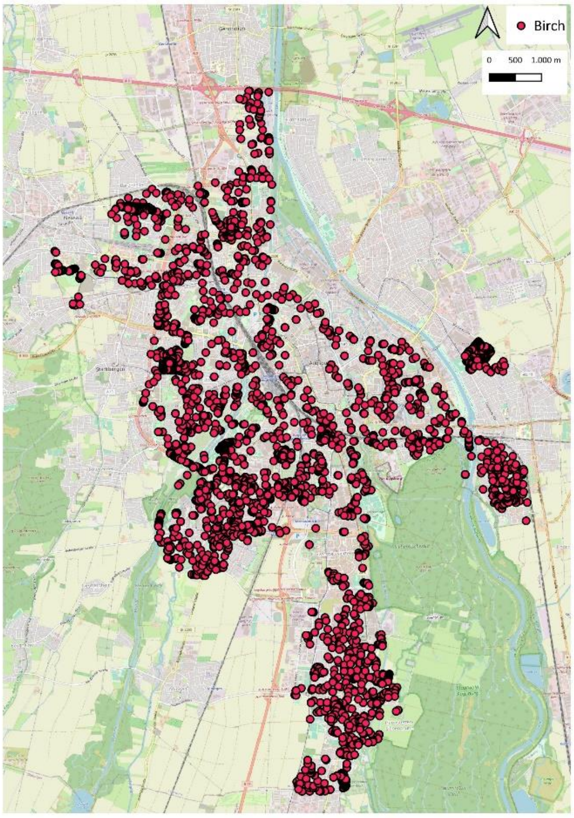

Figure 20: Geolocations of birch trees within the city of Augsburg.

SP10: Effects of Sustainable Urban Drainage Systems on Water Quality

Natalie Páez-Curtidor & Brigitte Helmreich

Background and objectives

Urban runoff carries many contaminants that impact waterbodies that affect human health and ecosystems (Brudler et al. 2019, Müller et al. 2020). This is the case with heavy metals and biocides, which are in relatively high concentration in urban stormwater and are highly mobile and bioavailable (Huber et al. 2016, Wicke et al. 2021). As climate change will intensify the frequency and intensity of extreme weather events – including rainfall and flooding (Intergovernmental Panel on Climate Change (IPCC) 2022), it is increasingly crucial to mitigate this source of diffuse pollution in cities.

A city-wide implementation of SUDS is an alternative to address this issue (Boehm et al. 2020). In particular, green SUDS are gaining more attention as they can serve as habitats for biodiversity enhancement, climate-change mitigation and adaptation, and resilience enhancement against extreme weather events (Prudencio and Null 2018). This is the case with bioswales, which are underground depressions with different topsoil mixtures and vegetation where stormwater infiltrates. While conventional bioswales can effectively remove particles from stormwater runoff and particulate-bound pollutants, they can fail to remove dissolved pollutants over their life cycle (Gavrić et al. 2019, Boehm et al. 2020, Bork et al. 2021).

This project aims to investigate the use of biochar, a carbonaceous porous material produced from the pyrolysis of organic waste, as a component of the topsoil in bioswales. Biochar is attractive for its potential to remove a broad set of pollutants while being readily available, having relatively low production costs and providing favorable conditions for plant survival (Mohanty et al. 2018). Specifically, the goals of this project are:

- To investigate the effect of biochar amendments in enhancing the removal efficiency and long-term retention of dissolved pollutants (heavy metals: copper and zinc; biocides: diuron, mecoprop and terbutryn) in bioswales; and
- To assess the immobilization of pollutants concerning changing runoff conditions (e.g. varying rain intensities and dry periods, Natural Organic Matter concentration, pH, presence of deicing salts) in biochar-amended bioswales.

Methodology

The tested biochars were procured from a local supplier accredited by the European Biochar Certification (EBC). A preliminary run of batch adsorption experiments was conducted to screen four green-waste-derived biochars produced through different pyrolysis temperatures (Figure 21). The adsorption capacity of biochar mixtures was also tested to assess any increase in the removal of the considered pollutants. In all cases, the adsorption performance of the biochars was compared with that of granular activated carbon (GAC).

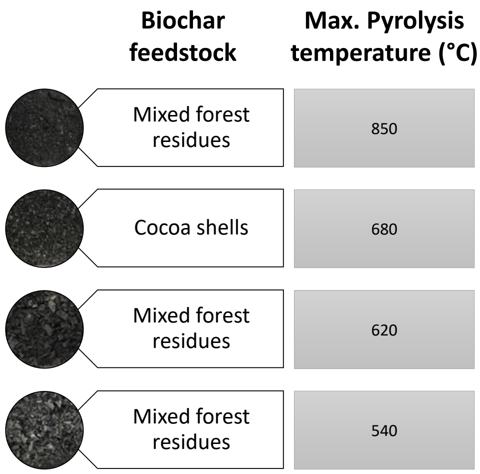

Figure 21: Selected biochars for adsorption screening experiments. All biochars have the European Biochar Certification (EBC).

Following the screening, the best-performing materials were used in batch isotherm and kinetic experiments using a synthetic stormwater matrix, as used by (Spahr et al. 2022), with an addition of 7 mg/l of humic acid. In these experiments, the adsorption and desorption processes of the selected pollutants was assessed following the procedures detailed in the OECD (2000) guidelines. In general, the pollutants' concentration ranged from 20 to 1000 µg/l and an adsorbent dose of 4 g/l was used.

Results and discussion

The screening adsorption experiments showed that only the high-temperature (850 °C) biochar from mixed forest residues has a removal of most pollutants comparable to granular activated carbon (GAC) (>50% removal of heavy metals; >95% removal of diuron and terbutryn). In contrast, the tested combinations of biochars did not show an improved removal of the contaminants of interest in the presence of humic acid. Given this result, a further adsorption experiment using the same high-temperature biochar with a larger particle size was conducted. Interestingly, the coarser biochar achieved a higher biocide removal. This is shown in Figure 22, where the LogKd coefficient for the adsorption of biocides is presented. These results suggest a better suitability of the coarse, high-temperature biochar for an improved pollutant retention in bioswales.

Outlook

The adsorption and desorption performance of the high-temperature biochar will be studied in further adsorption experiments. Here, an additional analysis of the influence of changing runoff conditions (i.e. pH, humic acid content and salts content) will be performed in a fractional factorial experiment. The selected biochar is also tested in combination with the regular soil matrix used by the City of Munich for gardening works, as well as in combination with compost and skeletal subsoil to explore their potential for circular resource use in bioswales. Here, its impact in the saturated hydraulic conductivity of the soils and the influence of the other soil components in the adsorption capacity is studied. This will guide the selection of biochars to improve the ES of urban bioswales.

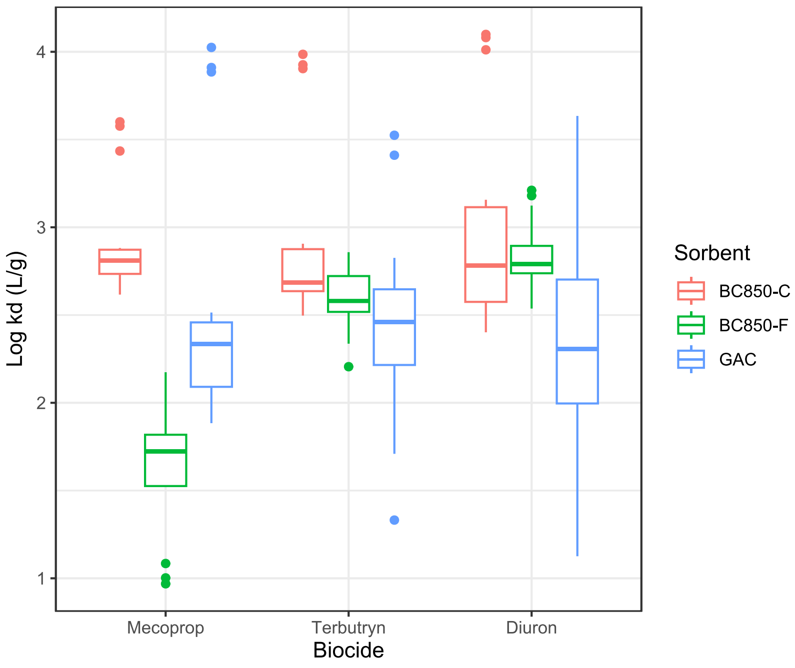

Figure 22: LogKd (L/g) of biocide removal for the tested sorbents. A larger LogKd value indicates a better adsorption performance. BC850-F: high-temperature, fine biochar. BC850-C: high-temperature, coarse biochar. GAC: Granular activated carbon.

SP11: High Carbon Organic Amendments Improving Soil (Multi-)Functionality

Lauren Porter, Monika Egerer & Ingrid Kögel-Knabner

Background and objectives

The global water cycle is intensifying, its increased variability projected to cause both more extensive flooding and severe droughts. Through this oncoming crisis, the obsolescence of current grey infrastructure is becoming clear. The use of constructed soils in UGI is endorsed by the European Parliament in efforts towards a circular economy and involves reusing and recycling materials otherwise classified as waste, both organic and inorganic, to build a functional soil. Dewatering and pollutant adsorption are two functions of constructed substrates that are of primary importance in managing urban stormwater.

To enhance pollutant retention, organic matter can be added, with recent studies focusing on upcycled pyrogenic materials, such as biochar, as a more sustainable amendment when compared with industrially produced components. As a soil's structural development impacts both dewatering potential as well as pollutant retention capacity, the effect of high carbon organic amendments (HCOAs) on bulk density, aggregate formation and stability, as well as porosity – especially in comparison with other soil binding agents – deserves deeper investigation.

Our objectives are the evaluation of the functionality of mixing HCOAs with subsoil waste (Table 1) to serve as:

1. Dewatering systems;
2. Pollutant retainers and water filters;
3. Fertile habitats for native biodiversity; and
4. Carbon sinks.

Table 1: High Carbon Organic Amendments tested

HCOA	Pyrolysis Temp. (°C)	Feedstock	% Particles < 0.315mm	OC (mg/g)	C/N Ratio
HT.FR Biochar	850 (HT)	Mixed forestry residues (FR)	46 %	700	268
MT.CS Biochar	680 (MT)	Cocoa Shells (CS)	20 %	570	26
LT.FR Biochar	560 (LT)	Mixed forestry residues (FR)	12 %	810	136
Activated carbon	-	Industrially processed	-	880	no N
Compost	-	City green waste	-	260	17

Methodology

Substrate mixtures were constructed by weight: 96% mineral soil material with only 4% addition of organic material in order to comply with German regulations for infiltration swales (DWA 2020). All material was air-dried for a minimum of five days before being sieved through a <2 mm mesh size.

Two mineral subsoils were acquired from developing urban areas within two of Bavaria's largest cities and are internationally classified as a sand and a sandy clay loam (SCL, sandy clay loam, Munich; S, sand, Augsburg).

Select soil properties serving as indicators for various urban drainage substrate services were characterized and compared between substrate mixtures. These properties included bulk density, water content at field capacity as well as nutrient contents (C, N, K, Ca, Mg, Na). Furthermore, a one-month incubation cycle was conducted to evaluate initial, rapid structural development of the substrates, as well as to get first impression of the substrates carbon cycling potential.

Shortly, the incubation consisted of 300 g of an air-dried substrate mixture (homogenized by hand for three minutes) being filled into a microcosm and placed onto a suction plate (plastic suction plate with polyamide membrane, pore size 0.45 µm, EcoTech Umwelt-Messsysteme, Bonn, Germany) at a water tension of -150 hPa in a closed hydraulic system.

During the first three days of the experiment, 30 ml of a 1:10 diluted Hoagland's solution (pH 5.5, Hoagland's No 2 basal salt mixture, Sigma-Aldrich, Steinheim, Germany) was administered per day to assure all pores were filled and that the samples could then equilibrize to -150 hPa, thereafter 10 ml were administered after each respiration measurement (every 48–72 h) to counteract evaporation, leading to a total input of 368 mg of nutrient powder per microcosm. Five replicates of each mixture were incubated for a total of 30 days in the dark at a constant temperature of 20 °C.

Results and Discussion

In dry mixing HCOAs of an economical and practical percentage with two subsoils native to urban spaces in Bavaria (SCL, sandy clay loam, Munich; S, sand, Augsburg), all substrates see a shift towards macroaggregation within 30 days of incubation. The initial structural development in all constructed soils can be attributed to primary particle size distribution, mineral composition and original state of aggregation, with HCOAs inputs, microbial activity and residual available mineral binding surfaces having minimal to no effect (Figure 23). In this first short-term study, there is evidence that the type of HCOA incorporated will not impact initial soil structure development, allowing for flexibility in construction and practitioners' choices. Studies incorporating native vegetation as an influencing factor are now underway.

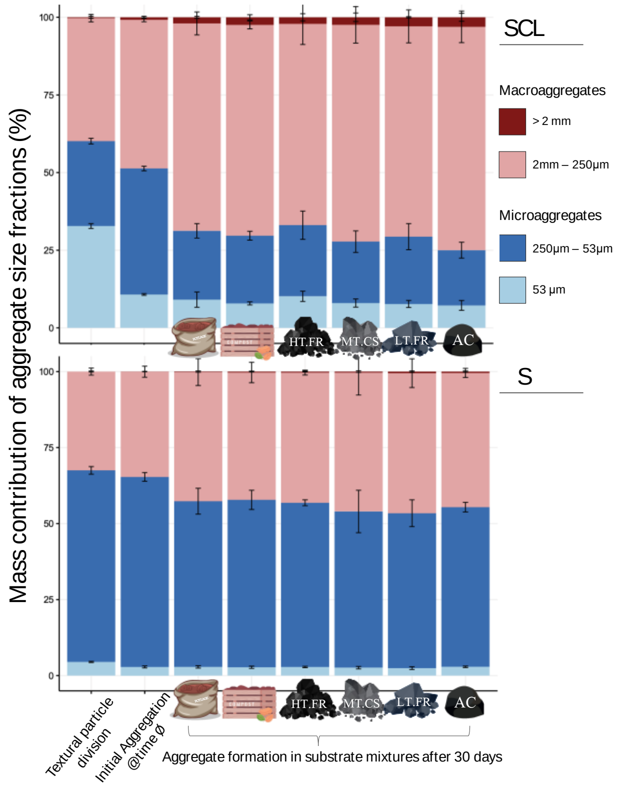

Figure 23: Development of mass contribution of aggregate size fractions after one month of incubation

Outlook

Following these initial investigations and those of Subproject 10 determining the organic amendments' pollutant adsorption potential, a follow-up experiment was planned implementing the newly, informed substrate combinations. These substrates were tested for their ability to support native plant diversity under infiltration swale conditions (cyclic flooding and drying) across one growing season. In this greenhouse experiment the multifunctionality of swale systems as carbon sinks will be primarily evaluated based on the initial carbon allocation patterns between the plant, rhizosphere and bulk soil.

SP12: Soil Microbiomes as Drivers for Environmental and Human Health

Swanandee Nulkar, Stefanie Schulz & Michael Schloter

Background and objectives

Microbiomes have critical roles in ecosystem functioning and carry out essential functions that support planetary health, including nutrient cycling, climate regulation and water filtration. Microbiomes are also associated with humans, and most microbiota, which are part of the human microbiome complex, can be considered an important health-determining factor, as microbiota provide functions essential to life (Berg et al. 2020). Recent research strongly points to the fact that microbiomes between different environments (including humans) are strongly interrelated and influence each other (Sessitsch et al. 2023).

Thus, an increase in the diversity of environmental microbiota could also increase the diversity and functionality of the human microbiome and, subsequently, human health. However, an increase in microbes in our direct surroundings is also associated with certain risk factors, including the development of specific microbial genotypes to adapt microbiota to urban environments. One of the highest risks, which has been frequently discussed in this respect, is the increase in abundance of antibiotic-resistant microbiota, which could transfer their resistance genes to human and animal pathogens as a consequence of the co-selection of genes which code for heavy metal and antibiotic resistance. Therefore, the aims of our subproject are:

1. Develop strategies to improve microbial biodiversity and functionality in soils of urban environments; and
2. Reduce the risk of emerging new antibiotic-resistant microbial genotypes in soils of urban environments.

Methodology

We performed a greenhouse experiment with SP10 and SP13 where we tested the effect of different plant–soil mixtures and different levels of heavy metal contamination on the community composition of the soil microbiome. We selected the heavy metal accumulating plant *Deschampsia cespitosa* ssp. *cespitosa*, which was grown either in soil with sandy soil texture or in soil amended with brick materials, which is considered a good adsorbent of heavy metals. The pots were artificially contaminated with $ZnCl_2$ and $CuCl_2$ solutions and then watered with water (control) or heavy metal solution (treatment) twice a week for 15 weeks. Bulk and rhizosphere soil samples were then taken and stored at -80 °C. The samples were processed for microbial carbon and nitrogen content using the chloroform fumigation extraction. For the analysis of the microbiome in the samples, we performed a molecular barcoding approach. Therefore, DNA was extracted from the bulk and rhizosphere soil. Post extraction, the DNA was used to quantify bacteria by measuring the number of the 16S rRNA gene copies using quantitative PCR. 16S rRNA amplicons were then sequenced on the Illumina sequencing platform to determine the prokaryotic community composition and diversity. The microbial biomass and sequencing results were analyzed using the phyloseq package in R. Moreover, core microbiome analyses were performed to identify unique taxa of heavy metal treatments. The results are discussed below. The obtained data will be cross analyzed with the results obtained from SP10 and SP13, where plant responses and heavy metal concentrations in soil and plants have been analyzed.

Results and discussion

We selected infiltration swales here as high loads with heavy metals have often been detected due to traffic and house building. On the one hand, this hinders the development of high microbial diversity in soil with negative consequences for ES provided by infiltration swales, while on the other hand, it increases the risk of the increase of antibiotic-resistant microbes as a result of co-selection.

As expected, applying heavy metals to soil strongly affected bacterial abundance independent from the added amendments in the bulk and rhizosphere soil (Figure 24).

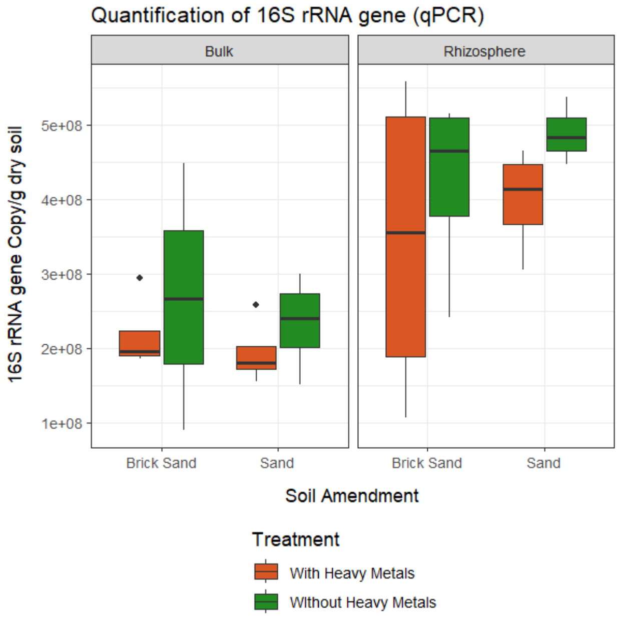

Figure 24: Bacterial abundance in the bulk and rhizosphere soil depending on treatment with heavy metals.

Additionally, we found a strong reduction of N in the microbial biomass, mainly in the treatments amended with sand, indicating that the heavy metal application strongly influenced microbial communities involved in N turnover. Analysis of the microbial community confirmed these results. A prominent decrease in the alpha diversity of the bulk soil community treated with heavy metals was also observed here (Figure 25). Moreover, the sand amendment also showed a reduction in bacterial alpha diversity.

On comparing the diversity between amendments, brick sand showed a greater reduction in diversity, which could be attributed to the greater retention capacity of clay-like brick sand particles. The core microbiome analysis revealed that the Microscillaceae and Streptosporangiacea families were unique to sand amendment under heavy metal treatment. Whereas the families Sutterellaceae, Nocardioidaceae, Gaiellaceae, Vicinamibacteraceae and unclassified JG30-KF-CM45 and AKYG1722 (order Thermomicrobiales) and TRA3-20 (order Burkholderiales) were unique to heavy metal treatments in brick sand.

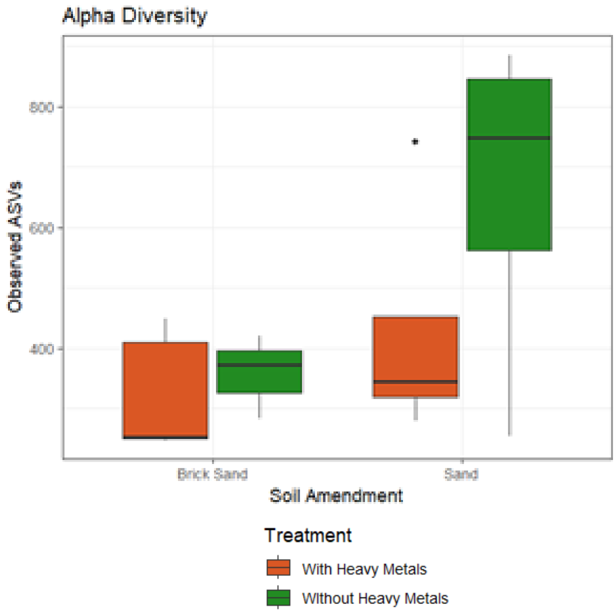

Figure 25: Alpha diversity of the bulk soil community depending on treatment with heavy metals.

The presence of greater shared taxa in brick sand could be attributed to the retention properties of the amendment. Moreover, among the observed taxa, AKYG1722 is known to be positively correlated to the presence of heavy metals, particularly zinc (Qian et al. 2022). Members of the family Sutterellaceae exhibit vancomycin resistance (Morotomi 2014). Streptosporangiacea (Otoguro et al. 2014) and Nocardioidaceae (Tóth and Borsodi 2014) are associated with antibiotic production. Analysis of the alpha diversity in the rhizosphere soil and the resistome profiles are still under investigation. As expected the application of the heavy metals to soil strongly effected microbial biomass independent from the amendments added, mostly in bulk soil as well as at the plant soil interface. We found a strong reduction of N in the microbial biomass, mainly in the treatments amended with sand, indicating that the heavily metal application strongly influenced microbial communities involved in N turnover. First data from the analysis of total microbial communities confirmed these results. The resistome profiles are still under investigation.

Outlook

Based on the outcomes of the first experiment (short-term effects), we want to assess the long-term consequences of heavy metal addition to soils using samples from sites that have been contaminated for >10, >50 years, and >200 years. Therefore, we plan to implement soils into our studies, which underwent long-term contamination with HMs as a result of mining. Further, we want to study the microevolutionary pattern of microbes when confronted with heavy metals and the role of the horizontal gene transfer by transduction and conjugation, which includes the co-selection of genes which induce antimicrobial resistance.

SP13: Novel Plant Systems for Storm Water Management

Nadja Berger & Johannes Kollmann

Background and objectives

The importance of urban storm water management is increasing, as acknowledged by innovative urban planning and new research initiatives. This is seen in infiltration swales that could provide means for more effective drainage of sealed surfaces. They must facilitate dewatering and pollutant retention, but could become novel elements of UGI. However, they provide challenging conditions for plants, due to flooding during heavy rainfall, subsequent erosion, periodic drought, and pollution with particle-bound or dissolved substances, e.g. organic biocides and heavy metals. Current approaches focus on functional substrates, species-poor lawns, non-native ornamentals or shrubs with aesthetic value, while enhancement of native biodiversity is largely ignored.

As near-natural habitats are rare in urban environments and space is limited, we investigate multifunctionality of urban infiltration swales with the goal to improve their technical functionality while simultaneously creating novel habitats for urban wildlife based on native plant species.

Four overarching objectives guide Subproject 13 on basic and applied aspects of novel plant communities for improved infiltration swales:

1. Investigate which plants tolerate the ecological stress of infiltration swales and support certain ES, i.e. pollutant retention, erosion control and stormwater mitigation, while providing habitat and resources for urban wildlife;
2. Study which above- and belowground plant traits help to achieve these ecosystem functions;
3. Design native plant communities**,** based on traits but also the species' ecological niches, to be tested in urban environments; and
4. Create a guideline for practitioners, which allows for design and selection of novel trait-based plant communities for infiltration swales to achieve the above ecosystem functions.

Methodology

To study different native plants for their potential use in urban drainage systems as described in Objectives I and II, a greenhouse experiment was conducted in 2022–23. Five species of the grass family, originating from habitats with low to high soil moisture, were subjected to conditions similar to those in infiltration swales, and above- and belowground traits were measured after three months of treatments, which included different substrates, heavy metal pollution and cyclic flooding/drying.

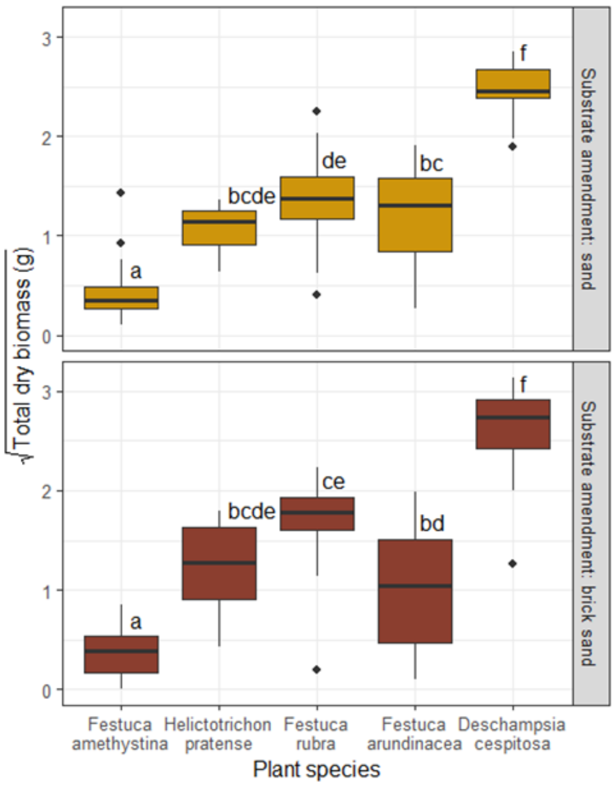

Figure 26: Biomass production of different grass species with habitats ranging from low (left) to high (right) soil moisture on substrates amended with sand or brick sand.

A second greenhouse experiment was conducted in collaboration with SP11 in 2023 to investigate plant-substrate relationships. Here, four selected herbaceous plant species of different functional types and communities on four different substrate mixtures, partially amended with biochar, were subjected to flooding.

To further our knowledge on the significance of plant community design and therefore objective III, a third experiment started within the climate chambers of the ecotron facility TUMmesa (https://tummesa.wzw.tum.de). Here, a gradient of species from contrasting plant communities is realized, ranging from mesic to fluctuating soil conditions, that are exposed to roadside pollution, flooding, drought, and heat waves in 2023–24.

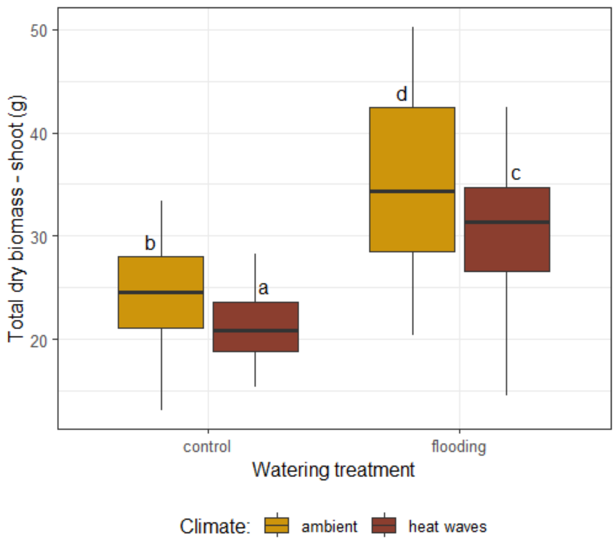

Figure 27: Biomass production of plant communities under different climate conditions (simulated ambient climate without or with heat waves) and different watering treatments (control and flooding).

Results and discussion

We found that grasses from habitats with either fluctuating or continuously higher soil moisture showed higher biomass production, while sand or brick sand as a substrate amendment had no effect, as shown in Figure 26. Flooding, as expected regularly in dewatering swales, showed different effects on individual plants compared to plant communities, if contrasted with irrigation amounts based on natural precipitation scaled to pot size as control watering regime. While plant communities did better under flooding conditions (cf. Figure 27), individual plants did show lower growth if stressed by flooding. We hypothesize that water availability under outside precipitation conditions is a limiting factor to plant growth in communities with high plant density, but not in individuals planted separately.

This would mean that the flooding conditions found in infiltration swales can be beneficial for plant growth in targeted plant communities. Additionally, we found a negative impact of heat waves on biomass production of plant communities, which was less pronounced in communities that received flooding treatment. This could suggest that plant communities would suffer less from heat wave events as expected more frequently in the future due to climate change, if they also experience flooding events like in infiltration swales. We also found no significant effect of heavy metal pollution on grass species and of heavy metal and biocide pollution on plant communities, indicating the tested species' suitability for use in infiltration swales.

Outlook

The results of the abovementioned experiments will be used to identify the effects of plant traits on the performance of novel communities under current and future urban settings. Therefore, results on individual plant species gained in the completed experiments in collaboration with SP 12 and SP 11 respectively will be compared to the currently ongoing experiment on plant communities which include the same species.

Summary and Outlook

Mohammad Rahman

The development and implementation of novel UGI solutions based on the concept of social-ecological-technological systems (SETS) is considered imperative for transformation of cities toward sustainability, climate resilience and livability. Within the framework of Research Training Group – Urban Green Infrastructure at the Technical University of Munich, 15 doctoral candidates are undertaking an innovative qualification program in their respective disciplines while considering inter- and transdisciplinary research.

In its first phase, research of the respective doctoral candidates is carried out within three thematic clusters related to 1. Transformation of urban space with UGI; 2. Improving indoor and outdoor thermal comfort; and 3. Sustainable urban storm water management.

A system model will be developed to establish the interdependencies between the different researches. Moreover, urban typologies were developed using Munich's planning documents. The overall goal is to provide all RTG members with a GIS layer set representing those urban typologies to enhance the incorporation of each subproject findings into a comprehensive urban systems model.

While there are existing topical models to map ES with scattered empirical findings; integrating several benefits to provide recommendations for future nature-based/ES-oriented planning is still very limited. Moreover, existing UGI planning methods and approaches lack quantitative analyses of ecological services at different spatial scales. Characterizing the spatial distribution of multiple ES of urban greenspaces to further develop a systematic approach to facilitate the integration of UGI is very important. Therefore, a holistic system approach to spatially quantify major ESs, namely, heat mitigation, biodiversity, active mobility, runoff reduction, health and wellbeing and so on as well as to identify complementarity and tradeoffs between services is of utmost importance. Ultimate goal of the model is to show what we can achieve with the UGI i.e. the limits of substitution with technology or grey infrastructure and how can we achieve those. This will further apprehend the selection of appropriate multifunctional UGI strategies, in particular, in areas where multiple strategies are suitable. Finally, the system model approach will support UGI planning not only in a particular city, rather can be applicable globally.

Assuming each SP within each cluster are interconnected with two-way connections, makes the whole model extremely complex. For example, with one cluster consisting of four subtopics, will have eight unilateral interconnections, which leads to there being 28 (256) different potential states of the system even within one cluster. Simultaneously, exponential growth (such as distance of tree from nearest building and tree growth) or decreasing relationships (like distance of tree from nearest building and indoor comfort) are already evident. As a next step, specific indicators will be quantified using more empirical data from each SP, the initial conceptual causal loop diagram will be tested and linked to all the clusters.

Further Activities of the RTG-UGI

Astrid Reischl

Since the start of the Research Training Group *Urban Green Infrastructure* in April 2022, we have formed a colloquium from the enthusiastic group of doctoral students, principal investigators, associated researchers, Mercator Fellows, secretaries and other members. In total, the RTG colloquium group currently has more than 80 members!

Since the beginning of the RTG, we have held more than 90 events until March 2024, including cluster meetings, workshops, working group meetings, courses, and exchange talks with visiting scientists.

The most important were the following:

1. **Kick-off event on 02nd–03rd June 2022**

For two days the consortium of the RTG came together to define the principles of the group, to present the individual subprojects, to discuss the next steps and the expected results of the first months and of course to get to know everyone! The kick-off event was a successful start for the research and the work of the RTG-UGI (Figure 28)!

Figure 28: Consortium of the RTG-UGI in June 2022

2. **PhD Proposal Presentations on 26th September 2022**

On 26th September 2022, the consortium met again to evaluate the progress of each doctoral candidates and their subprojects. The doctoral candidates presented the development of their research questions and the goals of their projects. Also, the logo of the RTG was designed (Figure 29) and together they discussed what should be the next steps in the RTG.

Figure 29: The logo of the RTG-UGI

3. **System Modelling Workshop on 05th–06th December 2022**

To further investigate how the overarching system model of the RTG-UGI should be structured, the consortium met again in early December 2022 (Figure 30). The system modeling experts Prof. Dr. Gebhard Wulfhorst and Prof. Dr. Hans Pretzsch led through the days and explained the background of system modeling and system thinking approaches. With the participation of Mercator fellow Dr. David Iwaniec, the consortium discussed the goals and indicators of the system model, different scenarios and the basic need for the model. A working group has since continued work on the system model.

Figure 30: Consortium of the RTG-UGI in December 2022

4. Reflection Day 22nd September 2023

No overall consortium meeting has been held yet in 2023. However, during the summer semester of 2023, the doctoral candidates and post-doc Dr. Mohammad Rahman met weekly in a journal club format to present and discuss important research literature for the RTG. In addition, the doctoral candidates participated in the teaching module *Urban Ecosystems*.

To hold a consortium meeting in 2023 and discuss the current status of the RTG-UGI overall, the clusters and the SPs in detail, on 22nd September 2023 we held the first RTG-UGI Reflection Day. Here we reflected on the progress and outcomes of the RTG to date. Next steps for the second half of the first cohort have been set.

5. RTG-UGI Retreat from 04th–06th March 2024

Figure 31: Exchange at the RTG-UGI Retreat in March 2024

In March 2024, the consortium met for an internal retreat (Figure 31). Since almost two years of the first cohort have passed, we discussed the individual progress of each doctoral candidate within the consortium and within the clusters. Also, a Paper Clinic will provide a platform for the doctoral candidates to present and discuss their manuscript drafts for a first or second successful publication. The final year of each doctoral candidate was discussed and the structure of the renewal proposal was set up.

Scientific Guests of the RTG-UGI:

During the first one and a half years, the RTG profited by the visits of several research guests. So far, we had common seminars and exchange with:

- Dr. Maha Deeb, Mercator Fellow, stay in October 2022 and July 2023
- Dr. Zbigniew Grabowski, former post-doctoral researcher of the RTG and Mercator fellow, stay in June 2022 until December 2022
- Prof. Dr. David Kendal, guest, visit in June 2022
- Prof. Dr. Sarah Bekessy, Visiting Researcher in April & May 2023
- Prof. Dr. Maria Ignatieva, guest, visit in July 2023
- Prof. Dr. Alessandro Ossola, guest, visit in July 2023
- Prof. Dr. Thomas Hauck, guest, visit in August 2023
- DAAD exchange students Margaret Spriggs and Cyrus Lee visited the RTG-UGI, SP11&13 in May, June, July and August 2023
- Dr. Tatyana Vahklamova, Mercator Fellow, stay from November 2023 until March 2024
- Prof. Dr. Anne Nillesen, guest, visit in December 2023
- M.Sc. Wenxi Liao, guest, visit in December 2023
- Prof. Dr. Adam Millard-Ball, guest, visit in March 2024
- Dr. Ian Thornhill, guest, visit in March 2024

Further exchange has been conducted with Dr. Chao Ren (Mercator Fellow) and Dr. David Iwaniec (Mercator Fellow). Both have attended hybrid RTG workshops and seminars of the Technical University Munich.

More Information and Contact

There are multiple ways to learn more about the RTG-UGI and connect with members. Thus, further information and contact options can be found at:

- RTG-UGI Homepage - www.gs.tum.de/grk/ugi/
- X - TUM UGI Research Training Group (@TUM_UGI_RTG) / X (twitter.com)
- LinkedIn - (14) TUM UGI Research Training Group | Gruppen | LinkedIn
- TUM Wiki - https://collab.dvb.bayern/display/TUMurbangreeninfrastructure/Profile+of+the+RTG-UGI

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