Research Training Group
Urban Green Infrastructure
Technische Universität München

RTG Urban Green Infrastructure

Results Brochure as of September 2023

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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. By developing networks of green and blue open spaces with multiple ecosystem services, the sustainability, resilience and quality of life of cities will be improved. Doctoral candidates undergo a specific and innovative qualification program that enables them to conduct UGI-related research in their respective disciplines at the highest academic level, while training them in inter- and transdisciplinary research within a systems thinking approach. They collaborate with, and receive support and guidance from, leading researchers in the fields of urban planning, ecology, engineering, and environmental medicine. The RTG-UGI therefore 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 based on the concept of social-ecological-technological systems (SETS) to address current challenges in urban environments (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 either 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 SET's 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.
4. Promote scientific careers by offering high quality training for (inter)national doctoral candidates, researchers and users.

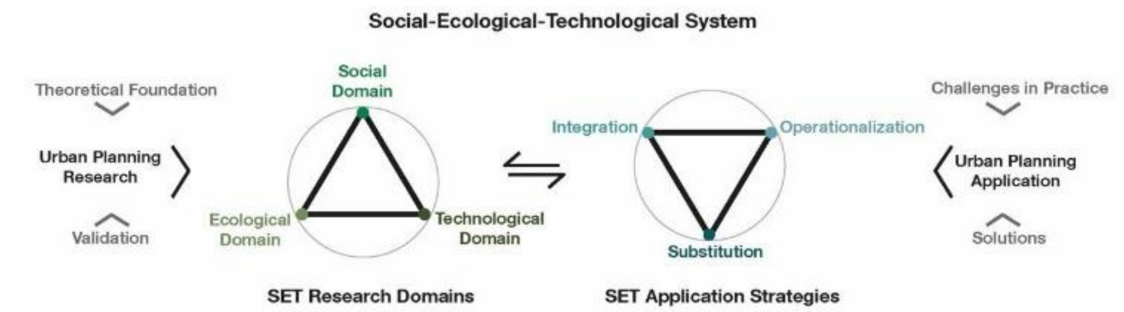

Figure 1: Research and application on social-ecological-technological systems (SET)

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 intense interactions of urban green infrastructure and its surrounding environment. With this model, the inherent complexity of the urban system shall be investigated. To develop such a model, a weekly meeting (Journal Club) was held during the summer semester 2023. The doctoral candidates of the RTG-UGI were presenting scientific papers related to their research to the whole group and connections to other subprojects were discussed. This provided a base understanding of relevant interactions and was a starting point for developing qualitative causal-loop diagrams within each cluster. This development is currently in progress. After the clusters have finished their work, the collected information will be brought together for the whole RTG to represent a collection of identified interactions and to form the foundation for further quantification and analysis.

Cluster 2 identified the main indicators within a part-system that refers to the interactions between urban tree growth, buildings, pollen concentration, and outdoor thermal comfort. The list currently contains 41 indicators and identifying their connections is in progress. Figure 2 shows an example of the planned visualization of interactions using a causal-loop diagram. 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.

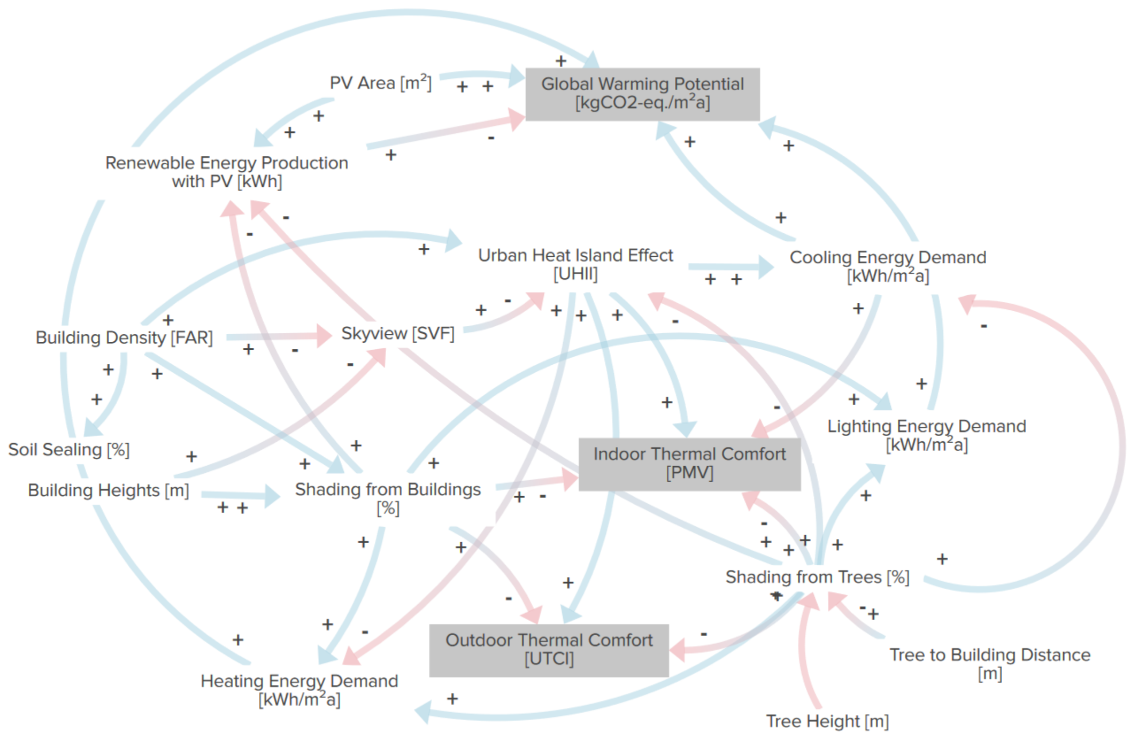

Figure 2: Excerpt from the development status of the cluster 2 causal-loop diagram regarding building aspects (work in progress).

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 exposed, 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 to enhance the incorporation of each sub-project 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.

Method

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.

Block type

Land cover	*Building typology*							*Open space typology*						
	1	2	3	4	5	6	7	10	20	30	40	50	60	70
0-20%	1.1	2.1	3.1					10.1						
20-40%	1.2	2.2	3.2											
40-60%	1.3	2.3	3.3											
60-80%	1.4	2.4	3.4											
80-100%	1.5	2.5	3.5											70.5

Network type

Canopy cover	*Streets typology*							*Railway*
	110	120	130	140	150	160	170	180
0-20%	110.1	120.1	130.1					180.1
20-40%	110.2	120.2	3.2					
40-60%	1.3	2.3	3.3					
60-80%	1.4	2.4	3.4					
80-100%	1.5	2.5	3.5					

Figure 3: Typology classification logic

The spatial datasets were developed based on GIS data sets which were gathered from the following sources (Figure 4 - Figure 7): the building and open space types were provided by the city administration of Munich and further simplified to 7 types; the vegetation map originates form the land use and land cover (LULC) Map of Munich developed by S. Bae at the chair of Prof. Dr. W. Weisser and the street classification is still under definition.

Outlook

Once the street typologies will be finalized, these typologies will be shared with the whole RTG and the first statistical analyses will be run based on sub-project results. After a first exchange with the German Aerospace Center (DLR), collaboration possibilities (e.g. shared data) have been identified. The DLR is currently checking their requirements for sharing data with the RTG. If better quality or more recent data gets available through this collaboration, the urban typologies can be updated.

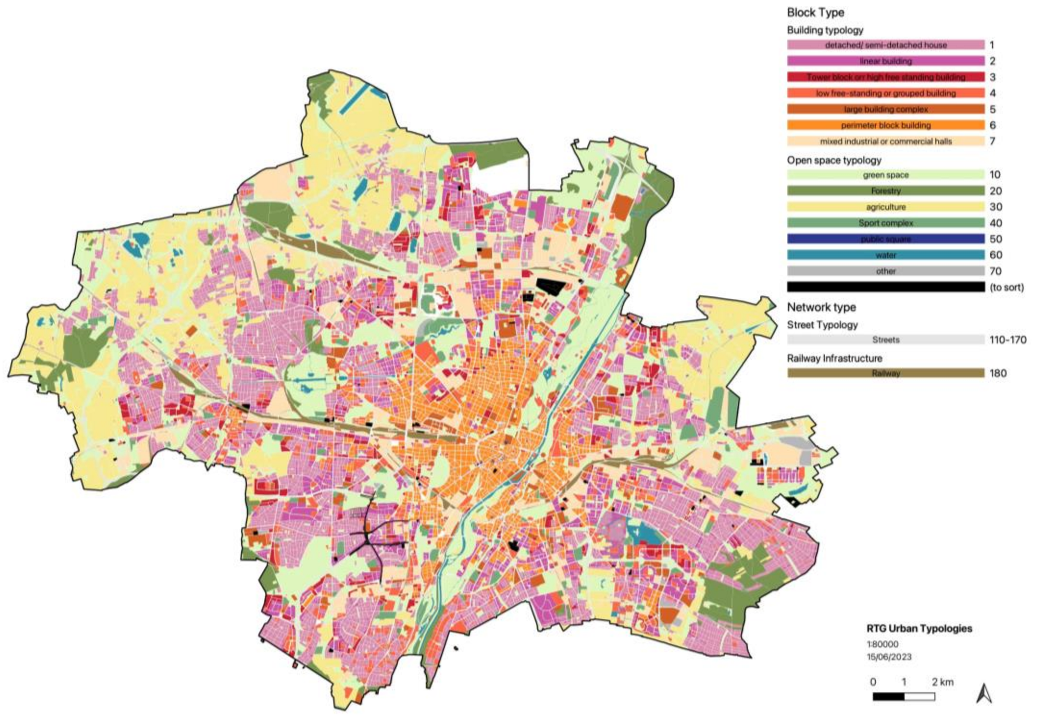

Figure 4: Spatial representation of "Block type" Typologies without sub-categorization

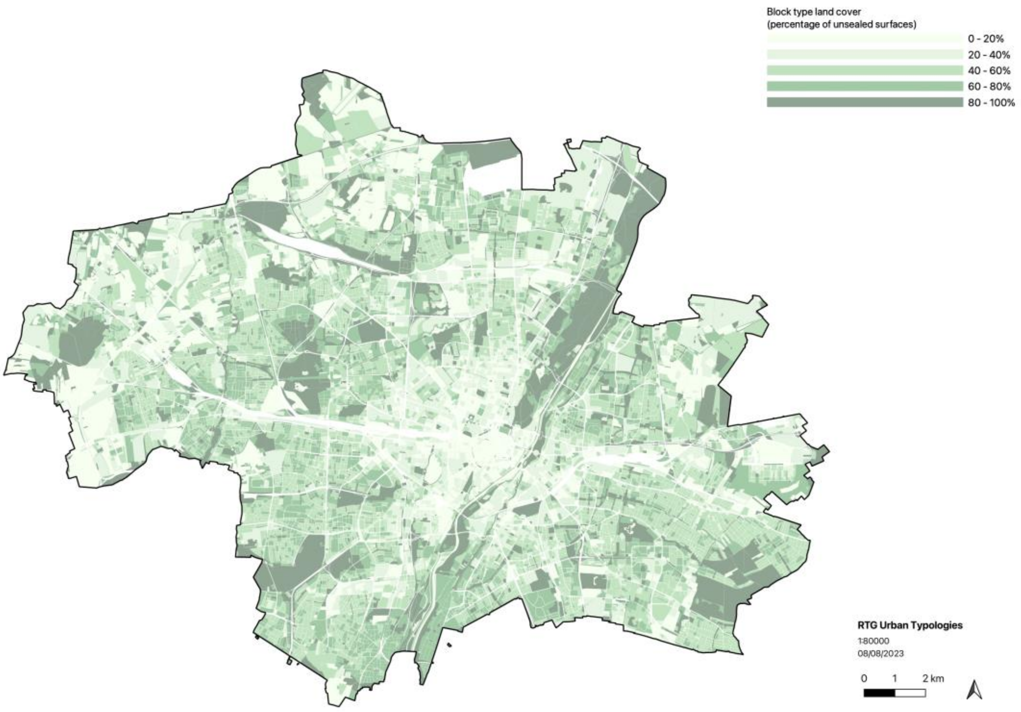

Figure 5: Spatial representation green cover for the "Block type"

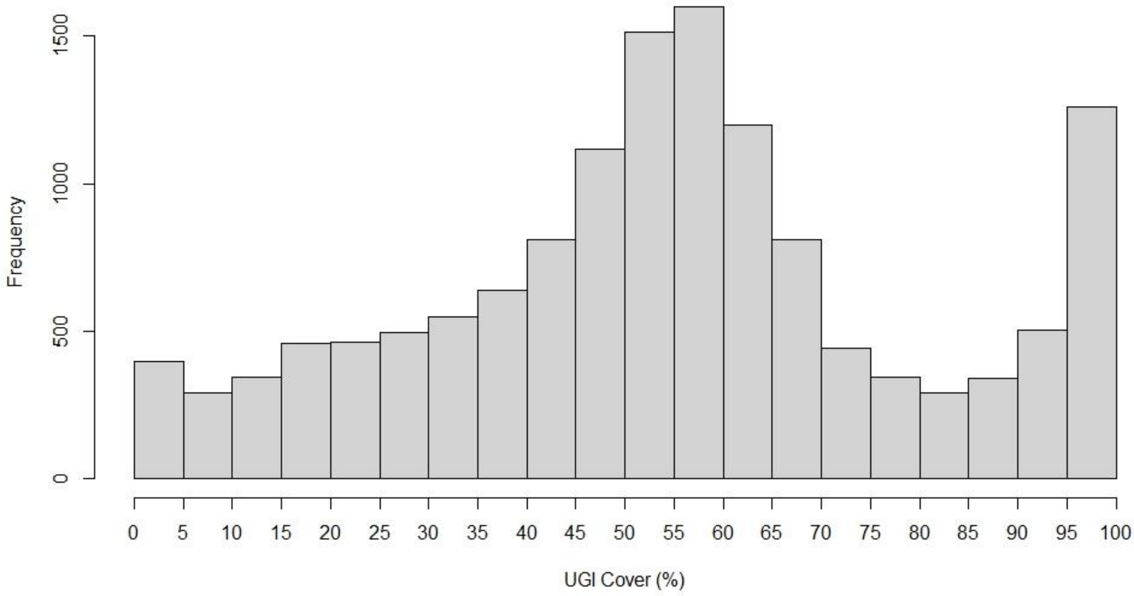

Figure 6: Distribution of UGI cover values within the typologies

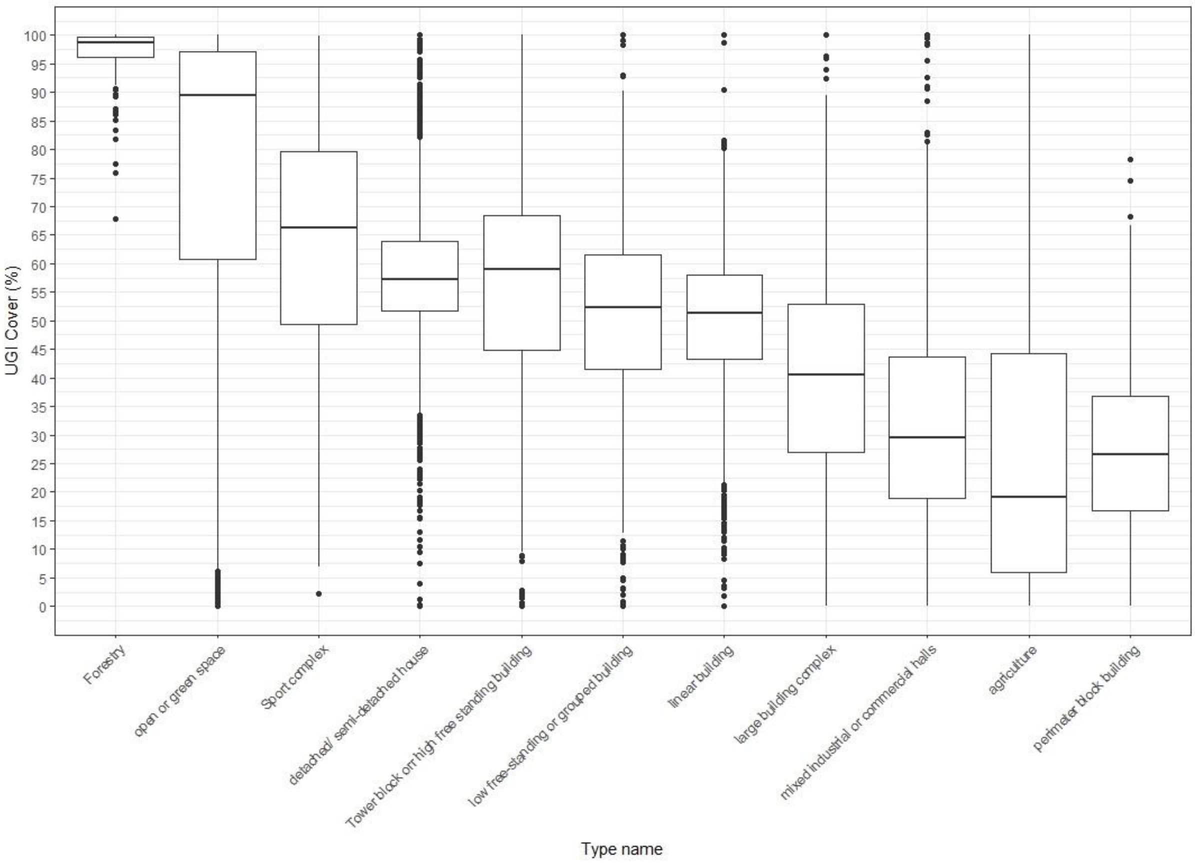

Figure 7: Distribution of UGI cover values within the typologies

SP1: Urban Green Spaces as Hotspots for Biodiversity

M.Sc. Andrew Fairbairn, Prof. Dr. Wolfgang Weisser

Background

Growing urban populations and increasing pressure to house and feed them have led to urbanization being a leading cause of biodiversity. As such, there is a growing agreement on the importance of urban biodiversity, and people are becoming increasingly aware of biodiversity's role in providing ecosystem services and impacts on human health. The aim of this project is to better understand the distribution and drivers of urban biodiversity so that cities can design multifunctional urban green infrastructure that meets not only the needs of people but also wildlife.

Objectives

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

- WP1: Examine the impact of design elements on biodiversity in urban squares.
- WP2: Methods and workflows for monitoring the contribution of UGI to biodiversity (AI-driven and advanced technology-based biodiversity assessment).
- WP3: Quantifying the contribution of UGI to the occurrence of animals.
- WP4: Synthesis with other sub-projects.

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

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

Results

Investigating public urban squares in Munich, WP1 has shown that while the overall greenness (NDVI) of a square is important for most taxa measured, each taxa responds differently to the features composing that green. Our results underline that the way humans design the built environment for their own use affects other species that potentially cohabit these spaces. Consequently, planning strategies for biodiverse cities aiming to increase human-nature interactions must be multifunctional, considering the needs of humans and other taxa to create diverse cities. The preliminary results were presented at the 2022 GFÖ conference in Metz, and a manuscript is in preparation.

To better understand the drivers of urban biodiversity, we are focusing on one taxonomic group and undertaking large-scale monitoring throughout the city. To do this, we are developing methods and workflows for monitoring birds using acoustic recorders. We are investigating machine learning to automatically identify bird species in recordings. We have developed an experimental R-package, "chirpR", to automate some of the analysis of acoustic recordings. The results of WP2 and part of WP3 will be presented at the GfÖ 2023 in Leipzig, and a manuscript analyzing BirdNET is in preparation.

Expanding on the results of WP1, WP3 is investigating how overall greenness drives bird diversity throughout the city. The results will be used as a proof-of-concept case study in a presentation at the GfÖ 2023 in Leipzig.

Outlook

This year and next summer, we will continue investigating how different urban features affect bird diversity. This will culminate in the development of a distribution model for birds in the city which can then be used to predict changes in bird diversity under different scenarios. Two manuscripts, one for WP1 and one for WP2, are expected to be submitted before the end of the year.

SP2: Breathable Corridors. Mobility in Multi-functional Urban Spaces

M.Sc. Mahtab Baghaiepoor, Prof. Dr. Gebhard Wulfhorst

Background

Increasing urbanization and global climate change necessitate the transition towards sustainable modes of transport more than at any time now which is included in Sustainable Development Goals of 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 Urban Green Infrastructure as the users of these modes have a direct exposure to their surrounding environment. So far, active modes have been mostly studied from the perspective of transportation infrastructure. This subproject, aims to dig dipper into the benefits of UGI for a more comfortable walk or bicycle ride.

Objectives

The main goal of this research is to understand the share of UGI in active mobility comfort. In doing so, this research wants to also discover how differently UGI elements play a role in these two modes of trips 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 for different groups of users

O2: To understand user-specific needs and perception of comfort in active modes

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

Results

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

1. *Testing and Refinement of Novel Research Methods in an Applied Classroom Setting and Workshops*

A dedicated course was introduced to use and refine the User Experience methods in Munich, 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 for data collection phase.

2. *Master Thesis Supervision and Understanding Cyclists' Willingness to Reroute for Increased Greenery*

A master’s thesis has been supervised, exploring the potential of green corridors for a connected network of cycling. Using network analysis, survey, scenarios, and user testing, 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 2km 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.

3. *Development of Contextual Street Typologies for Urban Green Infrastructure*

In alignment with other RTG projects, a new street typology was developed based on the existing literature, and existing road regulations in Germany and with a new approach of combining function, greenery and human scale in road classifications. The development of the GIS layer is still ongoing due to a need for more data at the city of Munich; however, this shows the usability of this classification beyond the purpose of SP2 and RTG UGI.

4. *Papers: conference CRB for research framework and methods*

Research collaborations within Cluster 1 include two papers that describe the bigger picture of Cluster 1. The papers evolve around the mobility and its adjacent areas in the city. On the individual level, SP2 research framework and proposed methodology will be presented at the Cycling Research Board annual meeting, October 2023 in Wuppertal.

Outlook

To be able to compare the general and user-based perception of active modes enhanced by UGI, surveys and UX travel dairies will be employed. Spring 2024 will witness pivotal surveys, including a Comfort survey and PPGIS survey, offering rich insights into cyclist 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.

The PPGIS survey will be developed in collaboration with GreenTravel project at the University of Helsinki to join forces between these two research projects that share the same fundamentals and research goals.

A forthcoming internship collaboration with the city of Munich is anticipated to happen in Spring 2023 as well. This collaboration aims to execute surveys, enhance street classification methodology, and gather real-world data

SP3: Key Urban Structures for Green Urban Reconstruction Processes

M.Sc. Julia Micklewright, M.Sc. Ishika Alim, Prof. Mark Michaeli

Background

To develop a coherent continuous network of green infrastructure in our dense cities, it is necessary to activate every available surface and think across ownership barriers. More and more city administrations are eager to encourage green infrastructure elements where possible but often struggle to influence areas outside of their ownership. Nonetheless, private spaces in cities represent a large share of potential green spaces. Whether these spaces are brownfields which will undergo future development or green spaces such as gardens, front yards or courtyards, it is necessary to plan strategically on a city scale to integrate them in urban green infrastructure strategies.

Objectives

Project J. Micklewright:

The goal of this research is to suggest strategies for urban policies to leverage the potential of frontages in order to increase the continuity of urban green infrastructure along mobility networks. Step by step, it will (1) characterize and quantify the typology of frontages in Munich, (2) explain 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.

Project I. Alim:

This project will focus on Munich's spatial process in Land Transformation and its ecological implications. It will (1) look at how the nature protection laws translate on privately acquired land, (2) how this manifest itself into future development projects and if this transformation presents a risk of fragmentation and (3) finally, the project will make strategic planning recommendation based on scenarios.

Results

Project J. Micklewright:

In this first year, the project focus was defined, a first literature review was conducted, the collection of the necessary GIS data sets was completed, and the first spatial mapping analysis was conducted. Julia also contributed to a joint publication with multiple RTG members and coordinated by Z. Grabowski which was published in the journal Biodiversity and Conservation with the title Cosmopolitan conservation: the multiscalar contributions of urban green infrastructure to biodiversity protection.

Project I. Alim:

The conceptual framework of the project has been developed. Project objectives and research questions of the research project were defined. The literature review has been conducted. However, due to health issues the project was then put on hold and will resume soon.

SP4: Transformative UGI-Governance

M.Sc. Elizaveta Weber, Prof. Dr. Stephan Pauleit

Background

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 (e.g. buildings, transportation networks) and on the non-state owned property (Figure 8).

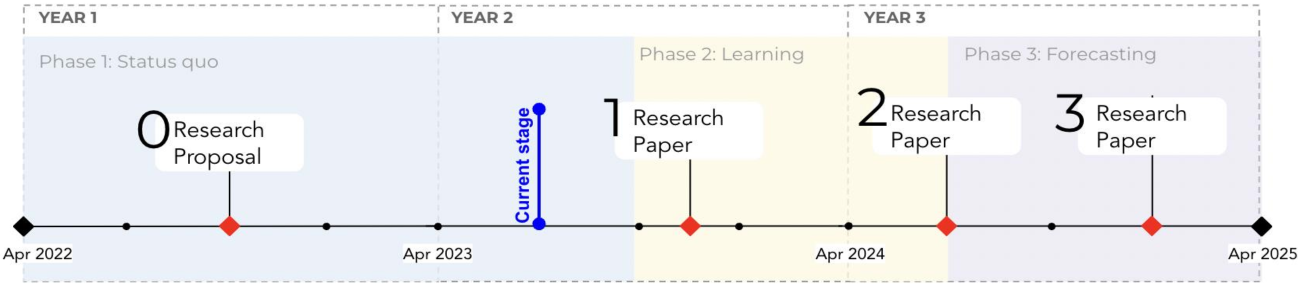

Figure 8: Overview of the Subproject 4 Cohort 1

Objectives

Two interdependent research needs are critical: 1) understanding current governance arrangements driving and limiting UGI system development, and 2) potential transformations to governance, including the potential for improved collaboration, that would allow for the expansion of UGI systems.

Results

Individual:

Currently the research is coming to the end of the “Status quo” phase. During this phase was done:

- A suitable framework for the analyses was identified and tailored to align with the specific needs of this study.
- 10 case studies were chosen for the analysis.
- Based on the selected research framework, a total of 17 semi-structured interviews have been conducted to date. The gathered information was transcribed, translated and prepared for further analysis. For each of the 10 cases, a detailed case study profile was created. This profile encapsulates insights into stakeholder interactions across different stages of project development - idea development, implementation, management.
- An internship was undertaken at the Urban Planning Department in Munich from 9th to 27th January 2023

Taking part in further workshops:

- PhD course: Researching Landscape Governance (May 8 and May 15 – 18, 2023)
- Workshop for social science methods (14 - 15 March, 2023)

Taking part in further publications:

- Grabowski, Z., Fairbairn, A. J., Teixeira, L. H., Micklewright, J., Fakirova, E., Adeleke, E., Meyer, S. T., Traidl-Hoffmann, C., Schloter, M., & Helmreich, B. (2023). Cosmopolitan conservation: the multi-scalar contributions of urban green infrastructure to biodiversity protection. Biodiversity and Conservation. DOI: 10.1007/s10531-023-02614-x
- Linke, S., van Lierop, M., Erlwein, S., Fakirova, E., Pauleit, S. and Lang, W. (2022). Climate Change Adaption between Governance and Government—Collaborative Arrangements in the City of Munich. Land

2022, 11(10), 1818. DOI: 10.3390/land11101818

- van Lierop, M., Fakirova, E. (2022). Strategies and tools for just collaborative planning of nature-based solutions. 58th ISOCARP Congress “From wealthy to healthy cities”. Brussels, Belgium, October 2022

Joint activities with RTG

- RTG Exchange with LHM - 7 February 2023
- Journal club: 18 Apr - 25 July
- PhD Thesis Proposal workshop on September 26th 2022
- Regular meeting within research cluster 1 and PI’s
- Reflection session 22 September 2023

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". The paper is planned to be submitted by the end of the current year. Concurrently, drawing on the insights from these analyses, the second phase "Learning" will be started. This phase is designed to learn insights from various contexts, helping to understand how to overcome the identified barriers hindering collaborative UGI governance in Munich.

Planned papers:

- Collaborative governance arrangements for UGI in the context of complex urban land ownership patterns
- Conference paper on System Model. Probably for the PLEA Conference.

SP5: Designing UGIs as Dynamic Processes

M.Sc. Hadi Yazdi, Prof. Dr. Ferdinand Ludwig

Background

In light of the growing trend of urbanization and the impact of climate change, the concept of urban green infrastructure (UGI) has gained prominence as a mean to enhance human health and well-being 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 decision-makers 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 (Erker et al., 2019; Parmehr et al., 2016; Ucar et al., 2018).

Objectives

O1: A Target-driven Tree Planting and Maintenance (conceptual paper)
This step proposes 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.

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 point clouds and Quantitative structure models.

O5: TreeML-Planter; a tree planting design tool based on the tree growth model in (O3). The model uses the 3D voxel model (O1) as a target leaf area for achieving the goal Ecosystem services.

Results

O1-> The result of this step was published in Journal of Digital Landscape Architecture entitled “A Target-driven Tree Planting and Maintenance Approach for Next Generation Urban Green Infrastructure (UGI)”

O2-> The data paper is submitted in Scientific Data journal by Nature and it is under review now.

Outlook

O3-> The TreeML model is under development and the result will be submitted in Fall 2023 in Sustainable Cities and Society journal by Elsevier.

O4-> an TreeML-Species recognition model is under development and the result will be submitted in winter 2024 in Remote Sensing of Environment journal by Elsevier.

O5-> Furthermore, TreeML-planter will be developed and submitted until end of 2024.

SP6: Indoor Comfort and Energy Consumption of Buildings

M.Eng. Roland Reitberger, M.Sc. Farzan Banihashemi, Prof. Dr.-Ing. Werner Lang

Background

Buildings and UGI act as highly interconnected parts of the complex urban system. Capturing this complexity is a challenging task in research and urban planning.

Objectives

Our goal is to investigate the interactions between built and green elements of urban systems. This includes:

- Quantifying the influence of urban trees on buildings (energy, indoor comfort) on city level to set up typologies
- Investigating the potential of vegetation to improve several aspects synergistically (e.g., indoor / outdoor comfort, energy consumption)

Results

We set up a machine learning (ML) model based on artificial neural networks. Therefore, we conducted 100,000 parametric building simulations to generate training data for the model. We combined this ML model with a 3D model of the trees and buildings in the city of Munich to analyze the influence of urban trees on buildings' energy demand. This bottom-up approach revealed the reduction of cooling energy demand by urban trees (Figure 9).

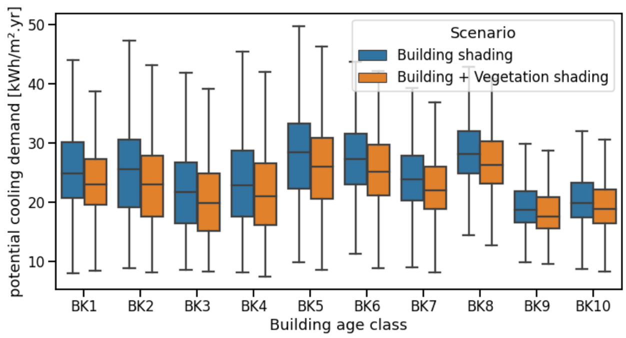

Figure 9: Potential cooling demand per building age class (BK) for two scenarios: With and without vegetation in Munich (for about 132k residential buildings).

Regarding the synergistic improvement of several aspects by UGI, we finished a first study that included indoor / outdoor thermal comfort, heating, and lighting energy demand (Figure 10). The study showed that the magnitude of the interaction between the aspects depends on the specific building conditions, e.g., refurbishment standard. Within this work, we set up an urban simulation model that captures various aspects and can be expanded in future. The results have been published in a conference paper at the SBE Conference 2023 (Reitberger et al., 2023).

Outlook

Our next steps include deriving typologies from the energy model and publishing the approach. Additionally, we are working on quantifying synergies and trade-offs in urban planning.

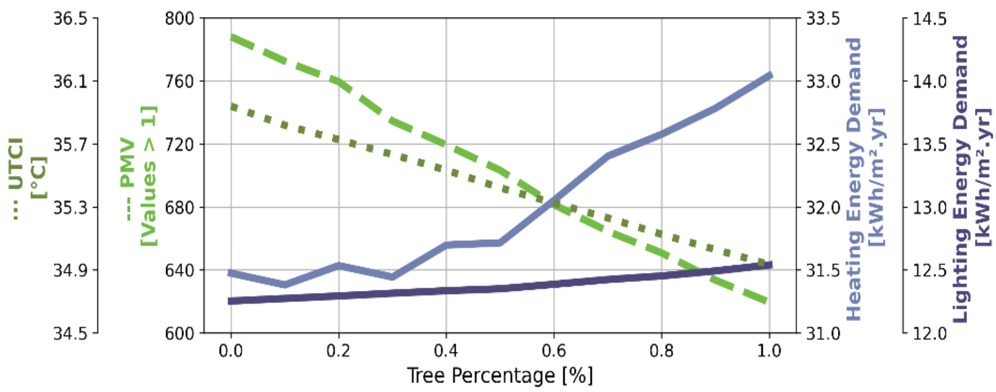

Figure 10: Dependence of mean heating / lighting energy demands and indoor / outdoor thermal comfort on increasing tree per-centage in a generic neighborhood.

SP7: Microclimate-Green Infrastructure Interactions

M.Sc. Nayanesh Pattnaik, Prof. Dr. Stephan Pauleit

Background

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 Urban Heat Island (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 well-being 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, well-being, 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 ecosystem services offered by this multi-layered 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.

Objectives

The aim of the subproject will be towards improving outdoor human thermal comfort through the integration of multi-layered UGI in cities. Specifically, we want to understand the following:

(a) The interactions of different types of surface coverage and the microclimate.
(b) The spatio-temporal variation of energy and water fluxes of different strata of vegetation as well as impervious surface.
(c) Plant characteristics that control the extent and intensity of different ESS provisioning. The results of this subproject can effectively guide the planning and design of greening strategies in urban areas to improve thermal comfort.

Results

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. Results also indicate the effect of shrubs on the Tmrt with a mean decrease of 6.6 K compared to sun exposed measurements. 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.

Outlook

Results from the first year are being presented in two international conferences – First, World Forum of Urban Forestry in Washington DC (October 2023) and the second in the Annual Meeting of Ecological Society of Germany, Austria and Switzerland (GfÖ) in Leipzig (September 2023).

SP8: Structure, Functioning and Ecosystem Services of Urban Trees

M.Sc. Leila Parhizgar, Prof. Dr. Dr. h.c. Hans Pretzsch

Background

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 ecosystem services (ESS), 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 ESS at a city or quarter level (Poschenrieder et al., 2022; Pretzsch et al., 2021). 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 ESS. This background suggested the following three objectives of our study.

Objectives

O-1: Mortality of Urban Trees

Calculate annual mortality rates for urban trees and address questions: a. What are annual mortality rates for conifer and broad-leaved trees? b. How do they change throughout different size classes? c. What are the most important reasons for tree mortality in cities? d. Do reasons and mortality rates change according to the de Martonne index of different cities?

O-2: Growth & Drought Resistance of Promising, Future Urban Tree Species

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

O-3: 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 ESS using the CityTree model (Rötzer et al., 2019).

Results

For the first objective, we used the cadaster data of five cities in Germany, encompassing 5-10 years of tree monitoring. Following the calculation of city-specific annual mortality rates, we examined the association between mortality rate and Diameter at breast height (DBH) size classes using multivariable logistic regression models. Preliminary findings indicate variability in annual mortality rate among cities, yet a consistent trend across all cities from 2015 to 2022.

Notably, street trees exhibited an average mortality rate of 0.3% higher than the total urban tree population in the dataset. Furthermore, 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. Our analysis of the survival/mortality 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.

Outlook

Our study explores urban tree population dynamics, including planting, growth, mortality, removal, and replacement cycles. 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 ESS and sustainability

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

M.Sc. Carolin Trost, Prof. Dr. Claudia Traidl-Hoffmann

Background

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 urban heat island 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 (Cariñanos et al., 2017; D'Amato et al., 2020; Pawankar, 2014). 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).

Objectives

The general idea of this project is to focus on verifying the risk of aerobiological origin in space and time for Augsburg and Munich. For this purpose, an aerobiological information tool based on urban ornamental trees and concentrations of airborne pollen grains is proposed. In order to achieve these 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 is used (Pecero-Casimiro et al., 2019). This index considers both geography and the built environment to deter-mine the allergenicity of an area individually for each city (Pecero-Casimiro et al., 2020). This index is applied to the genus Betula for this study, since Beech trees have highly allergenic pollen and are one of the predominant pollen species in Europe (Caillaud et al., 2015; Smith et al., 2014). Furthermore, the geolocations of Betula for Augsburg are available.

Further factors like meteorological parameters (e.g., temperature, wind, 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.

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.

SP10: Effects of Sustainable Urban Drainage Systems on Water Quality

M.Sc. Natalie Páez-Curtidor, Prof. Dr. Brigitte Helmreich

Background

Urban runoff carries many contaminants that impact waterbodies and affect human health and ecosystems. This is the case with heavy metals and biocides, which are in relatively high concentration in urban stormwater and are highly mobile and bioavailable.

SUDS are increasingly being implemented in cities to address this issue for runoff drainage and treatment. 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. This is the case with bioswales, which have different topsoil mixtures with vegetation where stormwater infiltrates. While conventional bios-wales can effectively remove particles from stormwater runoff and particulate-bound pollutants, they can fail to remove dissolved pollutants over their life cycle.

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. Biochar is attractive for its potential to remove a broad set of pollutants while being readily available and having relatively low production costs.

Objectives

- To investigate the effect of biochar amendments in enhancing the removal efficiency and long-term retention of dis-solved pollutants (heavy metals and biocides) in bioswales.
- 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.

Results

Preliminary results (Figure 11) show that high-temperature (850°C) biochar from mixed forest residues (Biochar 1) has a comparable zinc removal to granular activated carbon (GAC). Biochar 1 shows a higher copper removal than GAC, and the removal of diuron and terbutryn from Biochar 1 is comparable to that of GAC.

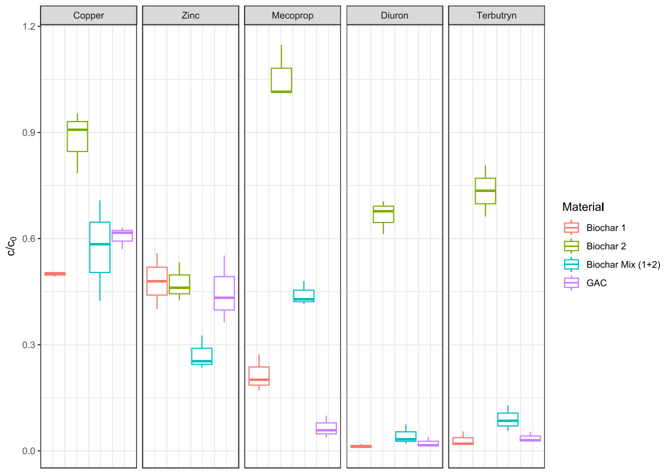

Figure 11. c/c0 after 6 days of batch adsorption experiment in synthetic stormwater (c0 = 100 µg/L, n=3, biochar amount = 0.5 g/L, [Humic acid] = 7 mg/L)

Outlook

Biochar will be studied in combination with compost and skeletal subsoil to explore their potential for circular resource use in bioswales. Simultaneously, the project aims to ensure a sufficient dewatering capacity and supporting conditions for plant survival in collaboration with SP11 and SP13. Overall, the project intends to contribute to improving the urban bioswales ecosystem services with transferrable and scalable knowledge. Future experiments include column experiments and a mesocosm experiment for assessing the effects of the amendments in plant communities.

SP11: Carbon Sequestration Improving Soil Functionality

M.Sc. Lauren Porter, Prof. Dr. Dr. h.c. Ingrid Kögel-Knabner, Prof. Dr. Monika Egerer

Background

The global water cycle is intensifying and with its increased variability is projected to cause more extensive flooding and severe droughts. Through this oncoming crisis, the obsolescence of current city infrastructure is being made clear. The use of constructed soils 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 retention are two functions of urban soils of primary importance in managing a city's stormwater. To enhance the latter, organic matter is often added, with recent studies focusing on 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 novel high carbon organic amendments (HCOAs) on aggregate formation and stability, especially in comparison with other soil binding agents, deserves deeper investigation.

Objectives

Evaluation of the functionality of mixing HCOAs with subsoil waste (Figure 12) to serve as:

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

HCOA	Pyrolysis Temp. (°C)	Feedstock	% Particles < 0.315mm	OC (mg/g)	C/N Rati
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

Figure 12: High Carbon Organic Amendments tested

Results

In drying mixing HCOAs of a practical percentage with a native Munich subsoil, as well as a sandier soil from a neighboring city, both substrates see a shift towards macroaggregation within a 30-day incubation period. The initial structural development in both 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 13).

Outlook

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.

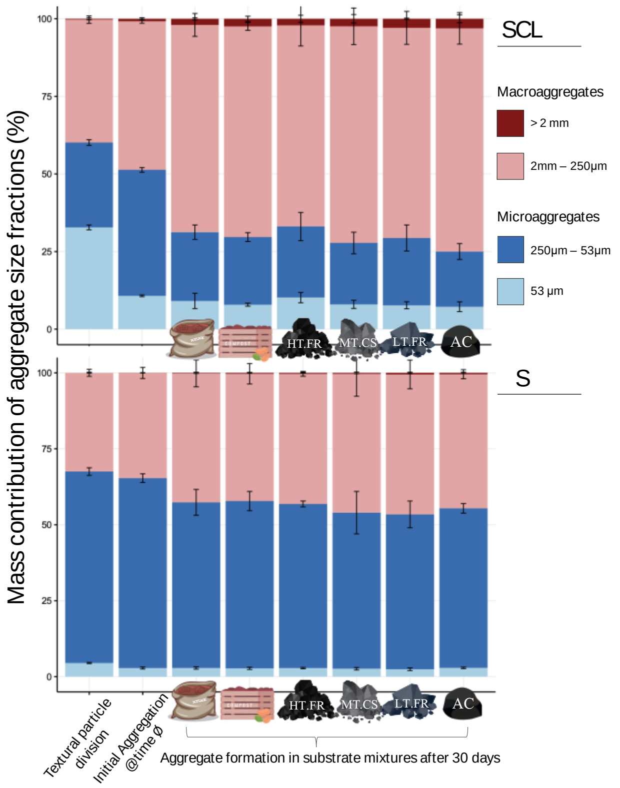

Figure 13: Mass contribution of aggregate size fractions (%)

SP12: Soil Microbiomes as Drivers for Environmental and Human Health

M.Sc. Swanandee Nulkar, Dr. Stefanie Schulz, Prof. Dr. Michael Schloter

Background

Microbiomes have highly important roles for ecosystem functioning and carry out key 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 as 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). So, an increase in the diversity of environmental microbiota could also increase 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, which includes the development of microbial genotypes as a matter of the adaptation of 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 co-selection of genes with codes for heavy metal and antibiotic resistance.

Objectives

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

Results

We selected infiltration swales as here often high loads with heavy metals have been detected as a result of traffic and house building, which on the one hand hinders the development of a high microbial diversity in soil with negative consequences for ecosystem services provided by infiltration swales and on the other hand increases the risk for the increase of antibiotic resistant microbes as a result of co-selection. In the first year we performed a greenhouse experiment where we added different materials with differing sorption capacity for heavy metals to the soil which derive from construction waste (crushed brick material vs sand). We used the heavy metal accumulating plant *Deschampsia cespitosa subsp. cespitosa* as a model and investigated microbial community structure as well as their resistome (collection of all resistance genes in a community) towards at the plant soil interface, as well as in the bulk soil and on the roots. The different soil samples were artificially contaminated with ZnCl2 and CuCl2. The experiment was per-formed together with other SPs.

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 long term consequences of heavy metal addition to soils using samples from sites which have been contaminated for > 10 > 50 years and > 200 years.

SP13: Novel Plant Systems for Storm Water Management

M.Sc. Nadja Berger, Prof. Dr. Johannes Kollmann

Background

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.

Objectives

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

I. Investigate which plants tolerate the ecological stress of infiltration swales and support certain ecosystem functions, i.e. pollutant retention, erosion control and stormwater mitigation, while providing habitat and resources for urban wildlife.

II. Study which above- and belowground plant traits help to achieve these ecosystem functions.

III. Design native plant communities, based on traits but also the species' ecological niches, to be tested in urban environments.

IV. 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.

Results

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 3 months of treatments, that included different substrates, heavy metal pollution, and cyclic flooding/drying. We found that grasses from habitats with either fluctuating or continuously higher soil moisture showed higher biomass production, while the substrate amendment (sand or brick sand) had no effect.

Outlook

To further our knowledge on the significance of plant community design for improved performance of urban infiltration swales, a second experiment started within the climate chambers of 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. The results of the experiments, together with an associated mesocosm study under outside conditions, will be used to identify the effects of plant traits on the performance of novel communities under current and future urban settings.

Summary and Outlook

Dr. Mohammad Rahman, Postdoctoral Researcher

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, 14 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; 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 sub-project 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.

The RTG aims to use Munich city as a living system and describes how a system model can look in the context of a city with a focus on multifunctional UGI. So far, based on the literature review, challenges, scales and variables of the system model were defined and impact matrix analyses have been carried out for each cluster. The indicators were scored according to the relationship strength to understand the influence from or influence to the each other. At present, all SPs consider each cluster as a subsystem to train the quantitative approach keeping the holistic view in mind. As a next step, the doctoral candidates are drawing a sketch system by drafting a preliminary causal loop diagram.

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.

Past Activities of the RTG-UGI

Dr. Astrid Reischl, Coordinator

After the start of the Research Training Group *Urban Green Infrastructure* in April 2022, we have tried to form 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 55 events until September 2023, including cluster meetings, workshops, working group meetings, courses, and exchange talks with visiting scientists.

The most important of these were the:

1. **Kick-off event on 02. and 03. 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 14)!

Figure 14: Consortium of the RTG-UGI in June 2022

2. **PhD Proposal Presentations on 26. 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 selected (Figure 15) and together they discussed what should be the next steps in the RTG.

Figure 15: The selected logo of the RTG- UGI

3. **System Modelling Workshop on 05. and 06. 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 16). 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 16: Consortium of the RTG-UGI in December 2022

4. **Reflection Day 22.09.2023**

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*.

Therefore, on 22nd September 2023, the Graduate College Consortium will meet to reflect on the progress and outcomes of the RTG to date. Next steps for the second half of the first cohort will be discussed.

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

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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