Research Training Group
Urban Green Infrastructure
Technische Universität München

RTG Urban Green Infrastructure

Training Next Generation Professionals for Integrated Urban Planning Research

Short Brochure – November 2023

Spokesperson: Prof. Dr. Stephan Pauleit

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Short Summary:

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. 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.

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 (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 systems 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.

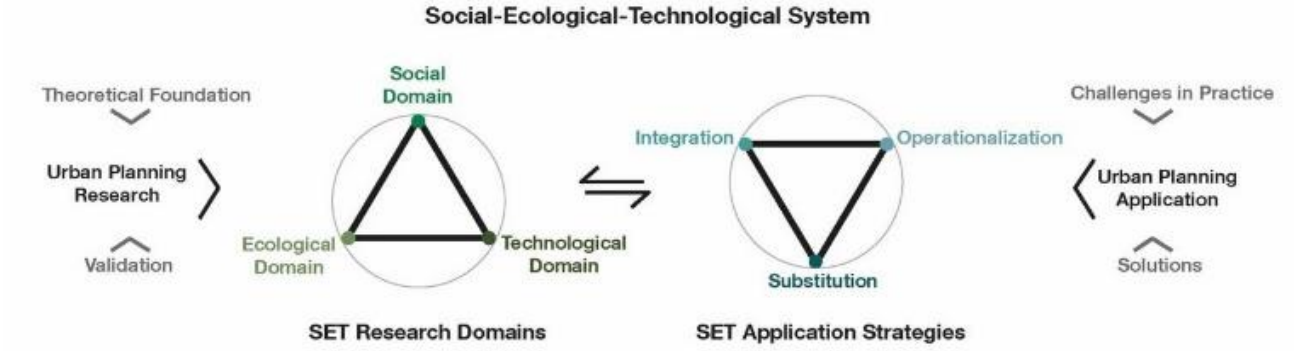


Figure 1: Research and application on social-ecological-technological systems (SETS) within the graduate program

Cluster overviews

Within the SET frame (Figure 1), we analyze the potentials of operationalization, substitution, and integration for developing and implementation of novel UGI in three research clusters (RC), each focusing on an urban development challenge. The RC explores the feasibility of various approaches:

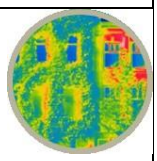
- **RC 1 - Transforming Urban Space with UGI** explores the interactions and potential of UGI as a driver of change in the transformative production processes of urban redevelopment. The focus will be on synergies between biodiversity and the multifunctionality of green corridors in terms of natural habitat connectivity as well as pedestrian and cycling attractiveness. The cluster will identify innovative governance mechanisms for UGI implementation.
- **RC 2 - Improving Urban Indoor and Outdoor Climate** focuses on the interactions between urban plants, climate, energy, and interactions between plants, climate, energy and human health to explore how thermal comfort under climate change can be increased by integrating UGI into the built environment. This would reduce energy use and the associated carbon footprint of buildings and improve human health.
- **RC 3 - Sustainable Urban Stormwater Management** addresses the interactions between urban plants, water and soil to explore the potential for substitution of engineered water management in terms of both water quantity and water quality.

The subprojects (SP) of the RC will be shortly presented with a summary, their status and next steps:
RC 1 aims to significantly enhance the process of transformation of the existing urban fabric and its elements towards a multifunctional UGI as a resource for biodiversity, sustainable urban mobility and reconstruction in SP 1–5.

SP	Title
1	**Urban Green Spaces as Hotspots for Biodiversity**  *Summary* This SP assesses the contribution of various elements of UGI to the promotion of animals within cities. *Current status* Investigating public urban squares in Munich has shown that while the over-all greenness of a square is important for most taxa measured, each taxa responds differently to the features composing green. This underlines that the way humans design the built environment for their own use affects other species that potentially cohabit these spaces. 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. *Next steps* • Continue investigating how different urban features affect bird diversity • Develop a distribution model for city birds to predict diversity changes at different scenarios
2	**Breathable Corridors. Mobility in Multifunctional Urban Spaces**  *Summary* The main goal is to understand the share of UGI in active mobility comfort. This SP wants to discover how differently UGI elements play a role in two modes of trips at different times of the day, week, and year. *Current status* The SP focuses on developing the theoretical framework and methodological approaches. The results encompassed the development and refinement of innovative research methods through dedicated courses 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 objectives of the research group.

	Next step: • Further surveys and travel diaries are employed, including pivotal surveys, a comfort survey and a Public Participation Geographic Information System survey • Qualitative data collection on a user-based understanding of UGI benefits for active modes are implemented
3	**Key Urban Structures for Green Urban Reconstruction Processes**  *Summary* This SP consists of two doctoral candidate projects: 1. The goal is to suggest strategies for urban policies to leverage the potential of frontages in order to increase the continuity of UGI along mobility networks. 2. This research focuses on Munich's spatial process in land transformation and its ecological implications. *Current status* 1. In the first year, the project focus was defined, a literature review conducted, the collection of the necessary Geographic Information System data sets completed, and the first spatial mapping analysis done. 2. The conceptual framework of the project is developed; objectives and research questions are defined, and a literature review is conducted. *Next steps* The work to answer each research question will be continued.
4	**Transformative UGI-Governance**  *Summary* 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, allowing the expansion of UGI systems. *Current status* The SP is coming to the end of the “Status quo” phase. While this phase was done: • A suitable framework was identified and tailored to align with the specific needs of the SP. • Ten case studies were chosen for the analysis. • 17 semi-structured interviews were conducted; the information was transcribed, translated and prepared for further analysis; for ten cases, a detailed case study profile was created. *Next steps* The analysis results serve as basis for the first paper on "*Collaborative governance arrangements for UGI in the context of complex urban land ownership patterns*". Drawing on the insights from these analyses, the second phase "*Learning*" has started, providing insights from various contexts to understand how to overcome the identified barriers hindering collaborative UGI governance in Munich.
5	**Designing UGIs as Dynamic Processes**  *Summary* The overall objective is to develop a workflow to design UGI as open dynamic systems with only partly predictable developmental pathways. *Current status* The conceptual novel approach for designing UGIs from a 3D voxel point of view in cities to maximize leaf area was published in *Journal of Digital Landscape Architecture* entitled *A target-driven tree planting and maintenance approach for next generation urban green infrastructure (UGI)*. A data paper was submitted to the journal *Scientific Data*, and is under review now. *Next steps* • The multidisciplinary and multilayer urban tree dataset model is under development and the result will be submitted to the journal *Sustainable Cities and Society* • A multidisciplinary and multilayer urban tree dataset species recognition model is under development and the result will be submitted to the journal *Remote Sensing of Environment* • Furthermore, multidisciplinary and multilayer urban tree dataset-planter will be developed.

RC 2 aims at the improvement of the urban in- and outdoor climate by assessing the causes and magnitude of the negative effects of the environment of a city (high heat intensity, high degree of sealed surfaces, lack of green areas etc.) on human comfort and health; and developing solutions to overcome these challenges by employing the RTG strategies in the SP's 6-9.

SP	Title
6	**Indoor Comfort and Energy Consumption of Buildings**  *Summary* 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. *Current status* A machine learning model was set up based on artificial neural networks. This model was combined with a 3D model of the trees and buildings in Munich to analyze the influence of urban trees on energy demand of buildings, revealing a reduction of cooling energy demand due to trees. For the synergistic improvement of several aspects by UGI, we finished a study including indoor/outdoor thermal comfort, heating and lighting energy demand. The results show that the magnitude of the interaction between the aspects depends on the specific building conditions, e.g. refurbishment standards. *Next steps* 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.
7	**Microclimate-Green Infrastructure Interactions**  *Summary* The underlying objective is to understand the interaction of different types of surface coverage with or without vegetation, their spatial heterogeneity, as well as their vegetation dynamics (e.g. annual cycles of water use, plant growth, phenology). *Current status* We investigate the influence of surface coverage on outdoor thermal comfort, with emphasis on the cooling effect by multilayered vegetation. A field campaign was conducted in 15 public squares of varying green coverage in Munich during warm, summer days. Results show that squares with high tree and grass coverages have lowest mean radiant temperatures, 7K and 9K lower than fully sealed squares respectively. Shrubs have an effect on the radiant temperature with a decrease of 6.6K compared to sunny sites. The studied shrubs significantly differed in leaf physiology indicating species differences in ecophysiology and the importance of species selection for outdoor thermal comfort. *Next steps* Present results at conferences and continue work on selected squares to understand the interactions between various vegetation layers.
8	**Structure, Functioning and Ecosystem Services of Urban Trees**  *Summary* We investigate the annual mortality rates of urban trees. The growth and drought resistance of promising, future urban trees species is analyzed and an overall model approach tested on how to plan, achieve and control a sustainable stock of urban trees. *Current status* We used tree inventory data of five German cities containing 5–10 years of tree monitoring information. Following the calculation of city-specific annual mortality rates, we examined the association of mortality rate and stem diameter size. The findings show a variability of the annual mortality rates within the cities, yet a consistent trend across all cities from 2015–22. Street trees had a mortality rate of 0.3% higher than the total urban tree population. We found an elevated mortality rate for young, small trees, and reduced mortality for middle, large stem diameter sizes. Our analysis of the survival/mortality curve aims to pinpoint factors influencing high mortality rates, shifting as trees age and mature. *Next steps* Our study explores urban tree population dynamics, including planting, growth, mortality, removal and replacement cycles. The aim is to bridge gaps in understanding mortality rates, discover drought-

	resistant tree species, and develop a model for improved urban planning, enhanced tree management and sustainability.
9	**Spatio-temporal Patterns of Pollen and Fungal Spores and its Impact on Health and Disease**  *Summary* We focus on verifying the risk of pollen and fungal spores of aerobiological origin in space and time for Augsburg and Munich. An aerobiological information tool based on urban ornamental trees and concentrations of airborne pollen grains is proposed. In order to achieve these multiple technologies are used. *Current status* • Remote sensing technics are used to determine the exact position of objects (buildings and trees) to create a high-resolution digital surface model of the environment. • Risk maps for Augsburg and Munich are created by combining pollen data with different instruments (volumetric 7-day Burkhard pollen trap, a pollen monitor, an aerosol particle measuring system and portable pollen traps) • 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 closely as possible and to detect possible correlations between these parameters. *Next steps* 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.

RC 3 investigates the uptake of urban stormwater run-off and pollutants decontamination by enriched sorption materials, soil microbiome and plants. This may result in improved water purification, carbon sequestration, biodiversity, and food and flower production, as well as a more buffered urban climate by increasing evapotranspiration through specifically designed plant mixtures in SP 10–13.

SP	Title
10	**Effects of Sustainable Urban Drainage Systems on Water Quality**  *Summary* We test high-carbon organic soil amendments combined with nutrients to improve urban soil structure and functionality and sorption material enrichment for contaminant remediation. We study the uptake and degradation of pollutants from stormwater runoff at different weather conditions, analyzing the mobility of already retained pollutants by sequential extraction protocols. *Current status* First results show that high-temperature (850 °C) biochar from mixed forest residues has a comparable zinc removal to granular activated carbon. Specifically, this biochar treatment shows a higher copper removal than granular activated carbon, and a comparable removal of diuron and terbutryn. *Next steps* Biochar will be studied combined with compost and skeletal subsoil to test the potential for circular resource use in bioswales. We aim to ensure a sufficient dewatering capacity and supporting conditions for plant survival in collaboration with SP11 and 13. We intend to improve the urban bioswales ES with transferrable and scalable knowledge. Future experiments include column and mesocosm experiments for assessing the effects of the amendments in plant communities.
11	**Carbon Sequestration Improving Soil Functionality**  *Summary* Evaluation of the functionality of mixing high-carbon organic soil amendments with subsoil waste to serve as dewatering systems, pollutant retainers and water filters, fertile habitats for native biodiversity as well as carbon sinks.

	Current status In drying mixing high-carbon organic soil amendments 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 high-carbon organic soil amendments inputs, microbial activity and residual available mineral binding surfaces having minimal to no effect. *Next steps* There is evidence that the type of high-carbon organic soil amendments 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 underway.
12	**Soil Microbiomes as Drivers for Environmental and Human Health**  *Summary* We aim to improve microbial biodiversity and functionality in soils of urban environments. The aim is to reduce the risk of emerging new antibiotic resistant microbial genotypes in soils of urban environments. *Current status* We performed a greenhouse experiment adding different materials with differing sorption capacity for heavy metals to the soil derived from construction waste. We used the heavy metal accumulating plant *Deschampsia cespitosa* ssp*. cespitosa* and investigated microbial community structure and their resistome at the plant soil interface, as well as in the bulk soil and on the roots. The application of heavy metals to soil strongly affected microbial biomass independent from the amendments, 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 heavy metal application strongly influenced microbial communities involved in N turnover. *Next steps* 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.
13	**Novel Plant Systems for Storm Water Management**  *Summary* This SP investigates plant communities using ecological criteria combining water management, urban soil development, pollutant immobilization and biodiversity maintenance, and thus aims to boost synergies of ES in infiltration swales, using ecological criteria. *Current status* To study different native plants for their potential use in urban drainage systems, a greenhouse experiment was conducted. Five grass species 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, including different substrates, heavy metal pollution, and cyclic flooding/drying. 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. *Next steps* To further our knowledge on the significance of plant community design for improved performance of urban infiltration swales, a climate chamber experiment was started. A gradient of contrasting species (mesic to fluctuating soil conditions) is realized, that are exposed to roadside pollution, flooding, drought and heat waves. The results 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.

System Model

Background

One goal of the RTG is to develop a systems model that captures the intense interactions of UGI and its surrounding environment. With this model, the inherent complexity of the urban system shall be investigated. The clusters are in the development of qualitative causal-loop diagrams including the research of each SP within the clusters (see Figure 2 as an example of RC 2). The main aim is to represent main interactions between the SPs of the entire RTG as a foundation for further quantification and analysis of whole system behavior.

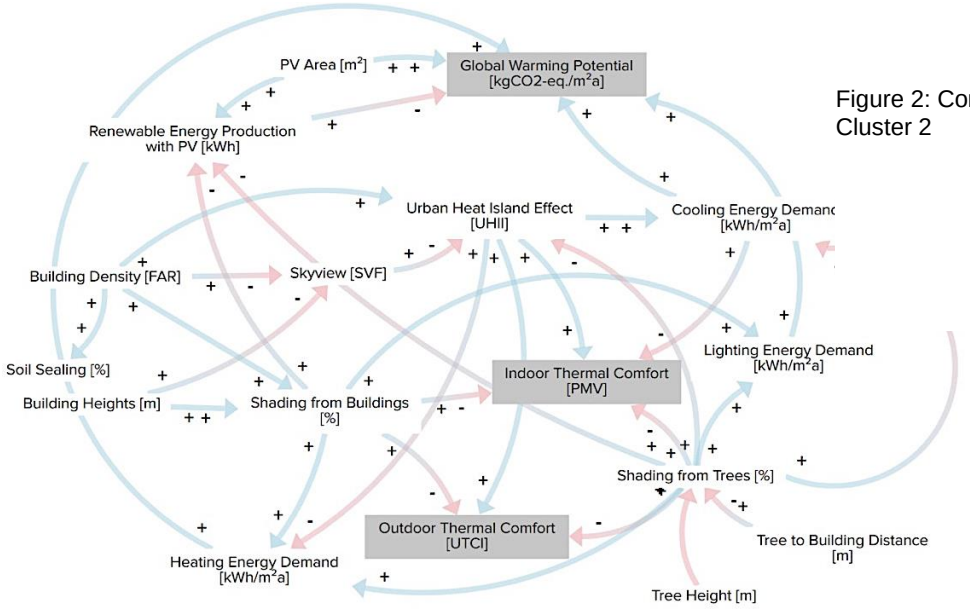


Figure 2: Conceptual Loop Diagram of Cluster 2

Urban Typologies

Background

Urban typologies were developed to characterize the urban fabric of Munich thereby enabling the scholars to assign various study sites to these types, compare results originating from different locations of the city, and scale from site to city level (Figure 3). Having these overarching typologies will also contribute to a common nomenclature and help to connect the subprojects in a comprehensive urban systems model. The typology is based on an already established urban typology used for Munich urban planning and monitoring purposes, thus supporting the transfer of knowledge into practice. The approach is 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).

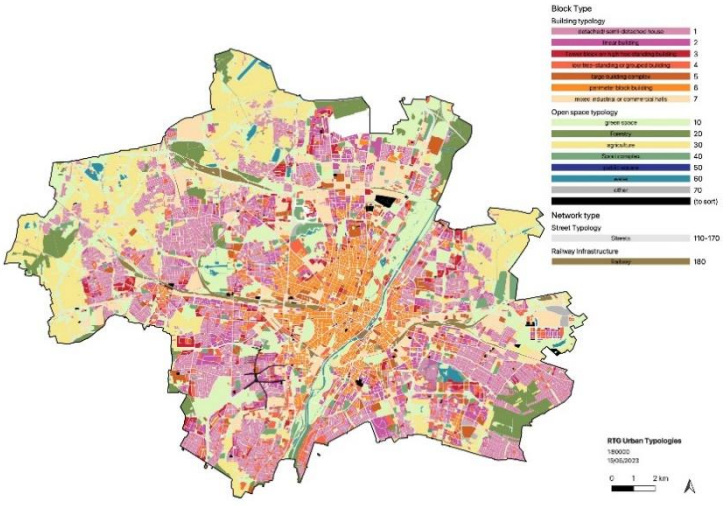


Figure 3: *Spatial representation of "Block type" Typologies without sub-categorization*

Outlook

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 RTG-UGI, the 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 transformation of urban space with UGI, improving indoor and outdoor thermal comfort and sustainable urban storm water management.

The system model will establish the interdependencies between the different researches. Moreover, urban typologies will enhance the incorporation of each subproject findings into the 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 ES is of utmost importance. The ultimate goal of the model is to show to which degree UGI can substitute grey infrastructure solutions 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. The RTG uses Munich (Germany) as a case study, but the system model approach will support transfer and upscaling of findings for UGI planning.

Diversity Circle

Within the RTG-UGI a ‚Diversity Circle' has been established to address the above topics. Its mission is to develop a series of diversity-related activities that respond to actual needs of all RTG members. It will monitor diversity problems and help with developing adequate solutions through surveys, regular meetings, invitation of experts, personal support and a diversity handbook. The Circle consists of a PhD representative from each cluster, the coordinator and two senior scientists. It meets every 1-2 months to discuss current issues and its overall strategy. The Diversity Circle reports to the management of the RTG.

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 - (2) 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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