

## A design approach for ecological building envelopes: the ECOLOPES project

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### SUMMARY

Urbanization leads to the loss of green spaces, which results in ecosystem degradation and diminishes the quality of life for residents. Consequently, urban areas are facing significant challenges related to human well-being and ecosystem health. Incorporating ecological principles into the design process at various scales (from buildings to the urban scale) can greatly improve ecological sustainability, reducing environmental degradation, and enhancing comfort and livability conditions for humans. The ECOLOPES project developed an innovative design approach, along with related methods and tools, to incorporate ecological processes and objectives into the design of building envelopes. This contribution presents the interdisciplinary design process and some of the computational components developed, outlining the implications and future perspectives.

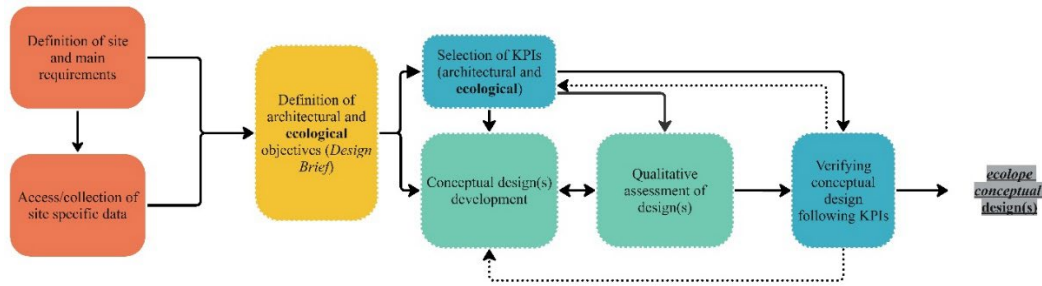
*Keywords: Urban greenery, ecology, optimization, microclimate*

### EXTENDED ABSTRACT

Urbanization is regarded as one of the most transformative processes, significantly altering ecosystems' biotic and abiotic characteristics and substantially impacting biodiversity and ecosystem services. Several studies highlight the crucial role of green spaces within cities in supporting biodiversity and enhancing human well-being, thanks to ecosystem services provision (Sadler et al. 2010). Conversely, evidence indicates that higher population density facilitates the development of compact, low-carbon cities, which help preserve habitats at the edges of expanding urban areas while promoting walkable and more livable environments (McDonald et al., 2023).

**The ECOLOPES design approach** aims at introducing ecological knowledge and related data into the architectural design process (Weisser et al. 2023). To do this, we integrate the ecological requirements and ecological consequences into the architectural design process. This was achieved by modifying the standard architectural design process (Figure 1). Importantly, the general workflow of building design is not changed, but enriched to include the requirements of plants, animals and other living organisms, i.e. non-human inhabitants, as highlighted in Figure 1. One important advance in the ECOLOPES project is that the use of Key Performance Indicators (KPIs) that address the needs of human, and of other species, aligning design development with the dual objectives of designing for humans as well as for other inhabitants such as plants (Selvan et al. 2023). The selection and assessment of appropriate KPIs have proven effective in aligning design development with the dual objectives, which depend largely on the ecological knowledge and data

that designers acquire at the outset.



**Figure 1.** ECOLOPES simplified design workflow (based on Weisser et al., 2023).

The design workflow was tested by master students at the Technical University of Munich, in order to identify the potential and the limitations of the ECOLOPES approach. We will now briefly describe some of the components developed within the ECOLOPES project to support the design process. A case study in the city of Munich (Neuperlach district, in the South-East area of the city) is finally presented to show how a design proposal can be developed following the envisioned design process.

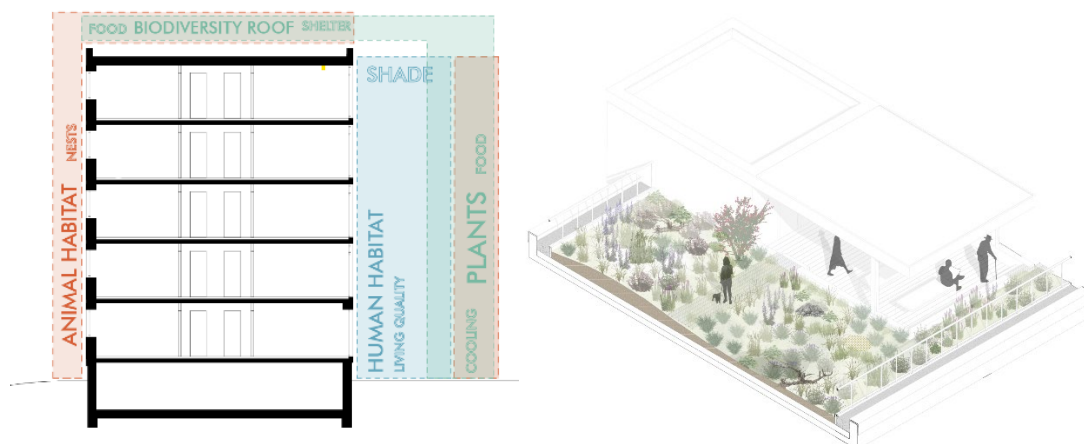
To address the needs of the plants and animals, it became clear that it would be necessary to integrate into the design workflow the interactions between the building, humans, and the other inhabitants (Grobman et al. 2023). This is because the way a building is designed will affect where plants and animals can live. Conversely, plants and animals will modify the building (environmental) conditions, through processes such as colonization, extinction and succession. In this context, interactions and the further development of the site are highly relevant. For this reason, ECOLOPES has started to develop a **plant-animal-soil model** that can simulate the development of the plant and animal community based on soil conditions, and the mutual feedback between the building, plants and animals. In order to deal with the enormous variety of organisms, the project chose to summarize plant and animal species in plant and animal functional groups (Weisser et al. 2023). The model will evolve in complexity over time. At present, buildings affect plants mainly by the shading they exert on plants, and by the depth of soil on various surfaces. The geometry of the building affects the locomotion of animals and the number of resources, for example, the amount of plant biomass, affects what animals can occur on or next to the building, and what their home range is.

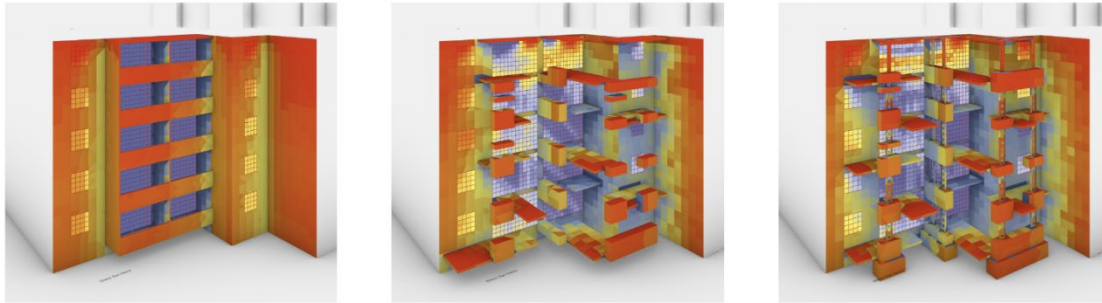
Another component is the **optimization** and evaluation of *ecolopes* design alternatives, based on a hybrid multi-criteria decision-making (MCDM) (Selvan et al. 2023). In particular, a model was developed to facilitate the refinement of multispecies distribution on an *ecolope* based on inhabitants' objective priorities. The model sequentially employs multi-objective (MODM) and multi-attribute decision-making (MADM) to streamline the computation of key performance indicators, such as Soil volume, Solar Radiation, Local PFGs richness, Structural Connectivity, informed by ecological knowledge for architectural design decision-making. The resulting ranked alternatives can be represented geometrically, through a catalogue format, and numerically, through dataframes describing the overall performances of the alternative pool and the abiotic and biotic metadata of each cell per alternative.

The assessment of ecological building envelopes' **impact on microclimate** can then be implemented through the integration of Plant Functional Groups (PFGs) features into a computational-fluid-dynamics (CFD) simulation approach, allowing a stronger connection between ecological and environmental performances. Based on geometrical features of PFGs, such as crown diameter and plant height, the group of plants can be modelled in the 3D CAD

environment and their capacity to provide shading calculated. The integration of this component into the design process serves as a starting point for including the quantification of the environmental performance of the envelope, in addition to ecological performance, with the aim of supporting the ecosystem while also enhancing livability in urban areas (Mosca et al., 2025). Eventually, the interactions between the building and the inhabitants will be encapsulated in an ontology. The **Ontologies** provide knowledge representation for reasoning and can be queried by the designer and aid rule-based processes (Pruski & Hensel, 2022). The initial design consists of (1) the *translational* process and (2) the *generative* process. In the former the designer analyses, correlates, and spatially locates architectural and ecological requirements contained in a design brief, taking into consideration relevant constraints. This process involves a knowledge graph that is queried by the designer to support decision making concerning spatially locating architectural and ecological elements in the CAD environment. The spatially located elements in the CAD environment and datasets in the ECOLOPES Voxel Model, are input for the *generative* design process in which rule-based generative processes are aided by ontologies, resulting in variations of spatial organization and surface geometry in urban and building scales. Design outputs of the initial design stage are 3D geometry in Rhinoceros 3D, datasets in the ECOLOPES Voxel Model, and ontological output.

**Case study:** The proposed approach has been applied by an interdisciplinary team of architects and landscape architects, supported by ecological experts, to renovate building façades in Munich as a case study. The project focused on the 3D transitional space beyond the building envelope proposing refurbishment strategies to address two key challenges: wildlife damage to the building envelope and excessive heat on the south-facing balconies. Computational tools optimized soil distribution in the gabion walls and balcony sizes, while plant selection for the southern façade was based on sun exposure analysis. Vegetation will completely envelop the structure, improving air quality, reducing the urban heat island effect, and serving as a model for sustainable urban architecture. Figure 2 shows the application of the design workflow on the real case study described and the proposed design outcomes.





**Figure 2.** ECOLOPES case study concept and visualization. Top: concept and floor plan; bottom: façade surface temperatures from current state to design project, high (red) to low (blue) (credit: Lukas Meisner, Nairi Koulakezian, Nicklas Neubauer, Lewin Schmid).

**Summary and future perspectives:** The ECOLOPES approach can lead to integrating the interactions between the building, humans, and the other inhabitants in the design process. This establishes foundational frameworks for future advancements at multiple scales, such as environmental integration within urban infrastructure and architectural elements for the building envelope, multispecies components for animals and plants. Furthermore, considerations arise regarding the maintenance needs of multispecies habitats and their integration into existing building maintenance protocols. Additionally, the interplay between humans, animals, and plants—particularly human responses to the introduction of animals into urban environments—requires careful consideration and understanding of its broader implications.

#### ACKNOWLEDGEMENTS

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