ECOLOPES

A multi-species design approach to building envelope design for regenerative urban ecosystems

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ABSTRACT

Urban areas are facing significant challenges regarding degradation of environments and ecosystems, species loss, and increased vulnerability to climate hazards, all of which impact negatively upon human health and well-being.

Focusing on building envelopes can offer an effective approach to the regeneration of urban ecosystems, by providing new spatial opportunities in dense urban environments.

The H2020 FET Open project ECOLOPES - ECOlogical building enveLOPES aims to develop a game-changing design approach for regenerative urban ecosystems. An Ecolope is a building envelope designed as a multi-species living space for four types of inhabitants: plants, animals, microbiota, and humans. ECOLOPES adopts a holistic multi-species approach, going beyond the provision of ecosystem services (i.e., benefits provided by nature to society and the economy). The goal is to develop the technology to plan and design urbanization with an integrated approach that addresses the requirements of the urban ecosystem. The paper presents an overview of the first steps towards this approach with focuses on data selection and integration, algorithmic modelling, and on developing an urban classification system that will be used for the project development.

1. INTRODUCTION

Urban ecosystems are complex, fragmented, heterogeneous habitats that are densely populated (European Commission. Directorate General for Environment., 2021; Groffman, 2017) that can provide a wider range of regulating, provisioning, and cultural ecosystem services (Millenium Ecosystem Assessment, 2005) to benefit humans. Urban growth is strongly related to a significant reduction and fragmentation of vegetation and green networks that do not only impact upon urban and natural balance but also on human health (Mitchell et al., 2016).

Currently, more than half of the world's population lives in urban areas and this condition is projected to increase to 70%worlwide by 2050 (United Nations, 2018). This trend and the destruction of natural ecosystems due to urbanization (Bernardo et al., 2021) causes local species' extinction and significant reduction of ecosystem services. To limit urbanisation effects, one of the most promising solutions is to foster climate change adaptation measures by adding vegetation and green spaces to improve microclimate, human health as well as increase biodiversity (Lee and Maheswaran, 2011).

These actions can help reducing green fragmentation and improving local biodiversity and foster multispecies design approaches on a building scale. The potential role that architecture can play in this context has been stated (Hensel, 2013). For example, the great amount of building in need of refurbishment could be used to experiment with new envelope designs, that consider the needs of urban ecosystems. This will require the setting of standards for individual and collective behaviour (policies, codes, rules, and regulations). So far, few examples of wildlife-inclusive urban design were able to incorporate provisions for multiple species into architecture (Apfelbeck et al., 2020) and a systematic approach is still missing.

This paper introduces and discusses the “ECOLOPES - ECOlogical building enveLOPES: a game-changing design approach for regenerative urban ecosystems” (https://www.ecolopes.org), as well as first steps toward its implementation.

2. ECOLOPES VISION

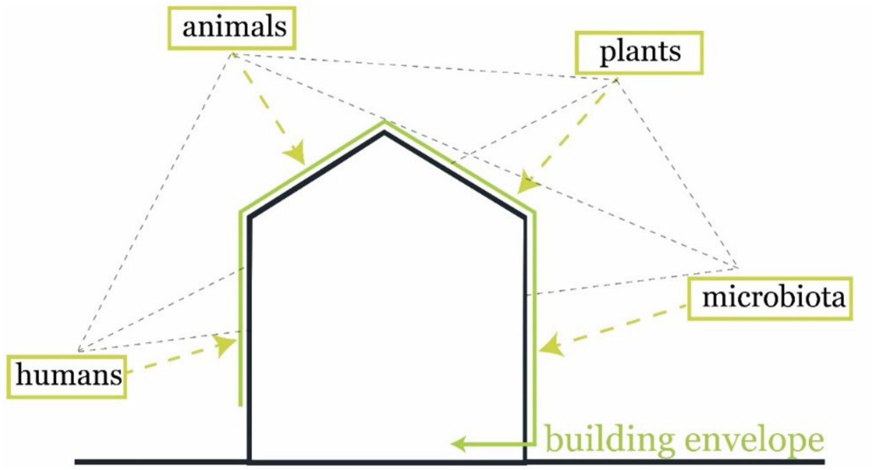
2.1 MAIN OBJECTIVES AND COMPONENTS

The project ECOLOPES adopts a radically new integrated ecosystem approach to architecture. This is done with the aim to enable nature to co-evolve with the city to support biodiversity and human well-being. Building envelopes, that is the enclosure of new and existing buildings, are proposed to be designed as ecolopes, multi-species living space for four types of inhabitants: humans, plants, animals, and microbiota (i.e., microbes living in or on the inhabitants). Indeed, an ecolope is new key concept for building envelope that include architecture, soil and different inhabitants. To make this possible it is necessary to develop a suitable design approach with a computational framework and workflow that includes a range of expert data-bases, an information model and a range of algorithmic processes and tools, and most critically, a data-driven design recommendation system. More specifically this includes the ECOLOPES Information Model (EIM Ontology) that defines the relationships between the inhabitants, architecture and the abiotic environment. A tailor-made computational framework will make the knowledge embedded in the information model available for design. This includes front-end tools for design, modelling and visualisation, and a computational simulation environment that enables iterative design development integrated with multi-criteria decision-making strategies. The ECOLOPES design approach will be validated through design cases, located in different urban environments.

Figure 1:
ECOLOPES Multispecies approach.

2.2 MULTISPECIES APPROACH

Since soil, microbiota, plants, animals, and humans play significant roles in natural dynamics, a wildlife-inclusive design is required within cities (Garrard et al., 2018; Snep and Opdam, 2010). Within an ecolope, a multitude of species can be hosted. Plant and animal dynamics and their interspecific multitrophic interactions and relations with soil and abiotic environment, microbiota and humans can thus become key elements of building envelopes. Subsequently, the ecological data obtained from multiple species in the ecolope will feed into an information model that enables design decision support.



2.3 MULTI-CRITERIA DECISION-MAKING APPROACH

The integration of multi-species cohabitation into building envelopes requires a holistic data-driven design process informed by ecological factors. The inhabitants of the ecolope require specific environmental conditions to function. Therefore, it is important to consider how an ecolope can contribute to maintaining and regulating these conditions. Key performance indicators (KPIs) derived from expert knowledge, will be assigned to each of the inhabitants to evaluate the ecolopes' impact on the KPIs and vice versa. Multi-criteria decision making (MCDM) strategies will be employed to understand the trade-offs and hierarchies of the KPIs in relation to the design of the ecolope.

MCDM processes can be understood in two distinct ways depending on the problem definition (Penadés-Plà et al., 2016; Yazdani et al., 2019). The first approach entails Multiple Attribute Decision Making (MADM), where weights are assigned to discrete criteria and the strategy results in a ranked list of solutions. The second approach entails Multiple Objective Decision-Making (MODM), which allows for the generation of a continuous set of solutions using two or more criteria.

In architectural design Multiple Objective Optimization (MOO) algorithms can be implemented to identify optimal solutions and the co-benefits or trade-offs between conflicting criteria that need to be simultaneously adjusted (Gunantara, 2018; Hamdy et al., 2016).

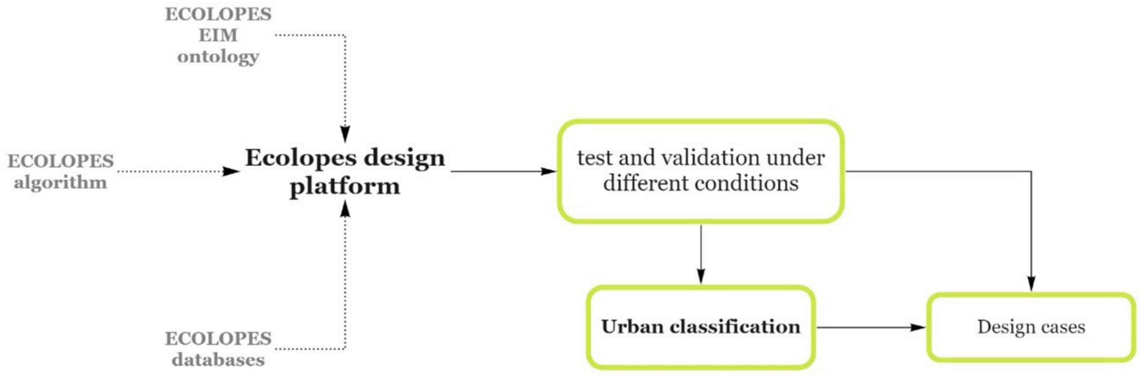
In ECOLOPES weights will be assigned to the KPIs to establish a hierarchy that informs the design outputs of the MOO strategy. The KPIs will then be optimized through an iterative design process. In this way the process enables analysis of the design of a building envelope in relation to plants, animals and humans (KPIs for these three stakeholders with high and equal weight) compared with one that is developed for humans and plants (high weight to human and plant KPIs, low weight to animals), or one just designed for humans. MADM strategies will also be implemented to rank design iterations based on weights assigned to the KPIs, as well as their optimized performance values resulting from the MOO. This serves to assess and formulate KPIs under different sets of conditions.

2.4 ECOLOPES FRONT-END TOOLS

ECOLOPES' front-end tools are part of the ECOLOPES design platform and make the ECOLOPES Information Model (EIM Ontology) available to architects and planners. Built as plugin in a standard CAD environment (Rhino and Grasshopper), they enable the design of ecolopes, provision of support in the decision-making process and systemic coordination of planning actions of multi-species environments. Furthermore, ECOLOPES front-end tools visualise the output of the EIM ontology (spatio-temporal data from multi-species dynamics) as a 3D model, which is be useful for ecologists and architects. In order to foster the collaboration between several disciplines in the design process, ECOLOPES web tools will be accessible through a standard web browser, without prior knowledge using CAD software.

The tools are made from different sets of algorithms compiled as Grasshopper (https://www.grasshopper3d.com/) components allowing the user to analyse, evaluate, and optimise their 3D models based on the developed ECOLOPES approach.

Figure 2:
Role of urban classification in the ECOLOPE development.



3. FIRST STEPS TOWARD IMPLEMENTATION

3.1 ECOLOPES INFORMATION MODEL (EIM) ONTOLOGY – FIRST STEPS TOWARD DATA INTEGRATION IN A 3D MODEL

The ECOLOPES Information Model (EIM) Ontology defines the relationships between architecture, the abiotic environment and all the inhabitants (soil, plants, animals, microbiota, and humans).

The EIM Ontology is a central component of the decision support system. It is tailored to guide design generation and to bring ecological and engineering knowledge into the early phase. The ontology links with the expert database that structures volumetric spatio-temporal data for query and is represented as voxel model, and will be reasoned to capture instructions that are selectively executed in a recursive, iterative and generative algorithmic process. This process will generate a voxelized 3D model at various levels of resolution. Selected data will be translated into a CAD model for the design generation. The voxel model provides an interface between interdisciplinary datasets incorporating expert information and parametric design methods. Voxel models are collections of values assigned to a three-dimensional grid with precisely defined resolution. Different tools in open-source GIS packages serve to analyse geophysical traits, such as geomorphons, slope analysis, water run-off, etc. Expert knowledge from the field of soil science contributed by the soil scientists will be integrated into the analytical framework. Currently we are reviewing existing tools for terrain modelling integrated into the Grasshopper environment including Bison, GHopperGIS, Lands Design, Docofossor, Ibex and ShrimpGIS. GDAL library integrated in GHopperGIS or .asc file format originally developed by ESRI are currently integrated as input format for Ibex and Docofossor plugins. Still, mMost of the currently existing tools are not integrated to the necessary extent, nor designed to exchange information. Hence, while there exists potential for integrating geospatial analysis tools and parametric design processes, there is a need to create interfaces which allow for systematic data exchange that preserves the information content represented by the data. In a second step data and models pertaining to plant and animal ecology will be integrated.

3.2 URBAN CLASSIFICATION

The ECOLOPE design platform will be tested and validated by means of selected design cases. A method for urban classification is being developed to select design cases in a systematic way, and to facilitate the comparison of the performances achieved by an ecolope under different sets of environmental and architectural conditions.

The urban classification will serve to identify urban areas characterised by similar conditions, i.e., similar in term of constraints for, and drivers of biodiversity (i.e., our four inhabitants) and architecture. Biodiversity and architecture are indeed directly and indirectly influenced by a large diversity of biotic and abiotic factors that will be integrated into the urban classification. The urban factors driving biodiversity can be grouped into three categories (Li et al., 2019): the biophysical conditions (e.g., climate and topography), the social–economic environment (e.g., the socio-economic level of the population and the social-economic orientation of the block), and the built and natural environment of the city (e.g., land-use and building height) (Mimet et al., 2020; Pellissier et al., 2012) (Figure 2). For the sake of simplification, the variables used to describe the built and natural environment are usually thematically quite coarse (e.g., based on coarse land-use information). In ECOLOPES, we go further than existing urban classifications (Cadenasso et al., 2007; Li et al., 2019), by considering two different scales and thematic resolutions, for the role of the landscape (variables computed at 100m resolution) and detailed local architectural features (variables computed at 10 m resolution), which are known to be very important for biodiversity (Weisser and Hauck, 2020) and play an important role in driving the architectural design.

Figure 3:
ECOLOPES Urban classification categories.

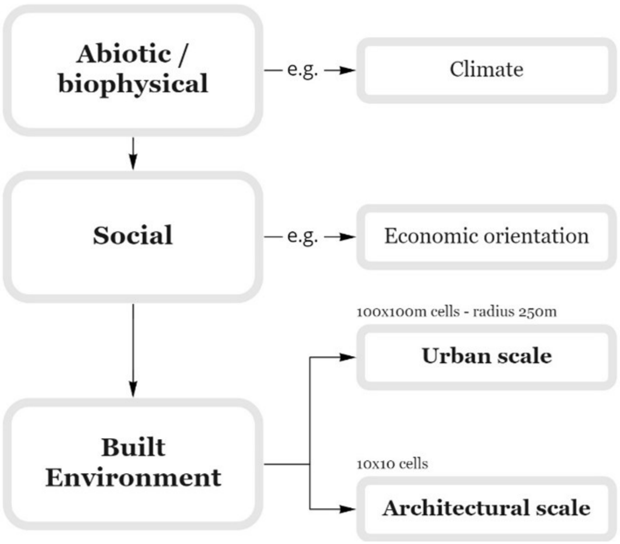
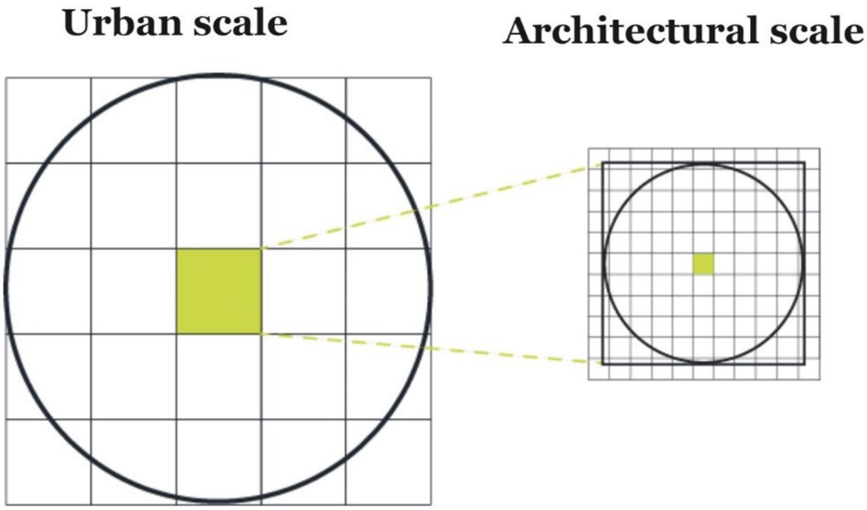


Figure 4:
Scale of the urban classification: 1. for urban scale the grid is made by 100x100m cells, 2. For architectural scale the grid is made by 10x10 m cells. Their radiuses are, respectively, 250m and 50m.



The classification will be implemented to identify and further describe the features of a given cell in a 100m x 100m resolution, for urban scale, and 10m x 10m resolution for architectural scale as well as their radius of, respectively, 250m and 50m.

4. RESULTS

In this section we provide an overview of the initial results and of some expected results that are related to the data integrated design approach and on the urban classification for design cases selection

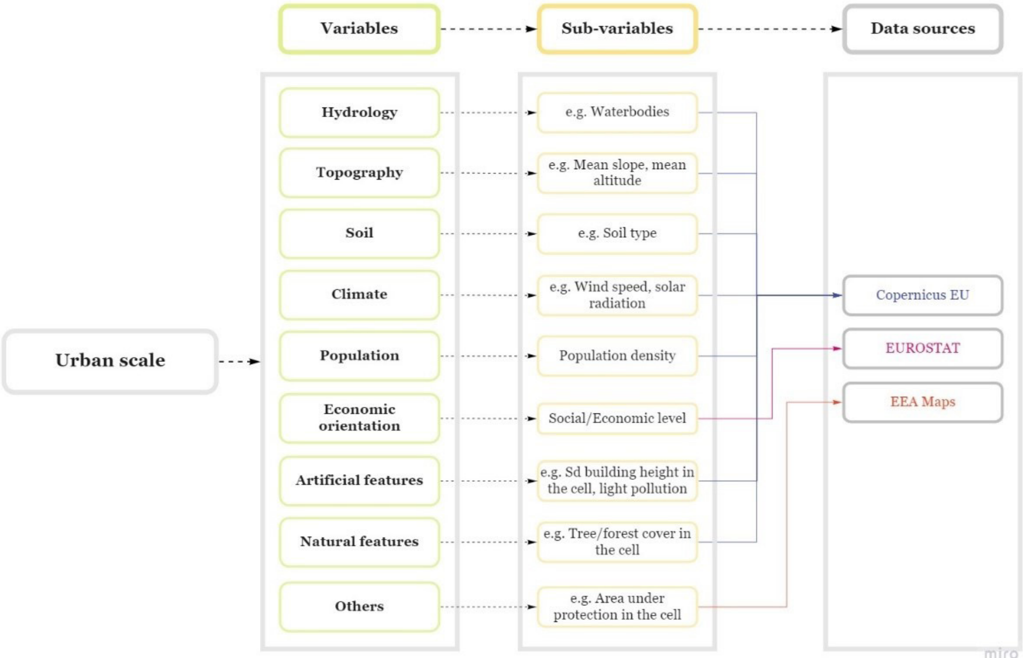
4.1 DATA INTEGRATED DESIGN APPROACH – CURRENT AND ANTICIPATED RESULTS

Ontologies have long been used in the domains of architecture, engineering, landscape and ecology. However, the pursuit of using ontologies for turning agent-based modelling into an intelligent system for simulating the dynamics and form of an ecolope constitutes a new approach. Regarding voxel models we focus on applications related to volumetric particle simulations (e.g., OpenVDB) and to the application of Computed Tomography (DICOM and NIfTI). At the current stage a more general implementation is considered to simplify the creation of interfaces with the required range of disciplinary tools and methods. Regarding the algorithmic tools, an overall service-oriented software architecture (SOA) is anticipated that structures coherent algorithms into independent services and enables a flexible and scalable implementation of various datasets. The functionalities of the algorithmic tools are specified by the definition of different use cases combined with user requirements. We are currently developing algorithmic tools and methods that address the correlation between ground and building structures, with both components forming a terrain with specific soil-related parameters as an underlying resource for the multi-species approach. Initially we focus on tools which are related to terrain and slope modification and evaluation of terrain related parameters such as slope, aspect, surface water flow and soil stability. The intended combination of terrain related modelling and evaluation tools enables feedback on the environmental impact of different designs on the projected terrain from the early design phase onward with the aim to ensure adequate conditions for plants, animals, and microbiota.

4.2 URBAN CLASSIFICATION: PRELIMINARY RESULTS

Within the context of the ECOLOPES, it is important to consider the building characteristics, as well as variables in the surrounding environment that can inform design and planning decisions. Using open-source databases such as, at urban scale, Copernicus, EUROSTAT, EEA, and at architectural scale OpenStreetMaps as well as Google Maps and Google Earth, enables a comprehensive data pool of 2D and 3D information for characterization on a 10m scale. Figures 4 and 5 show the variables and main sub-variables at the urban and architectural scales.

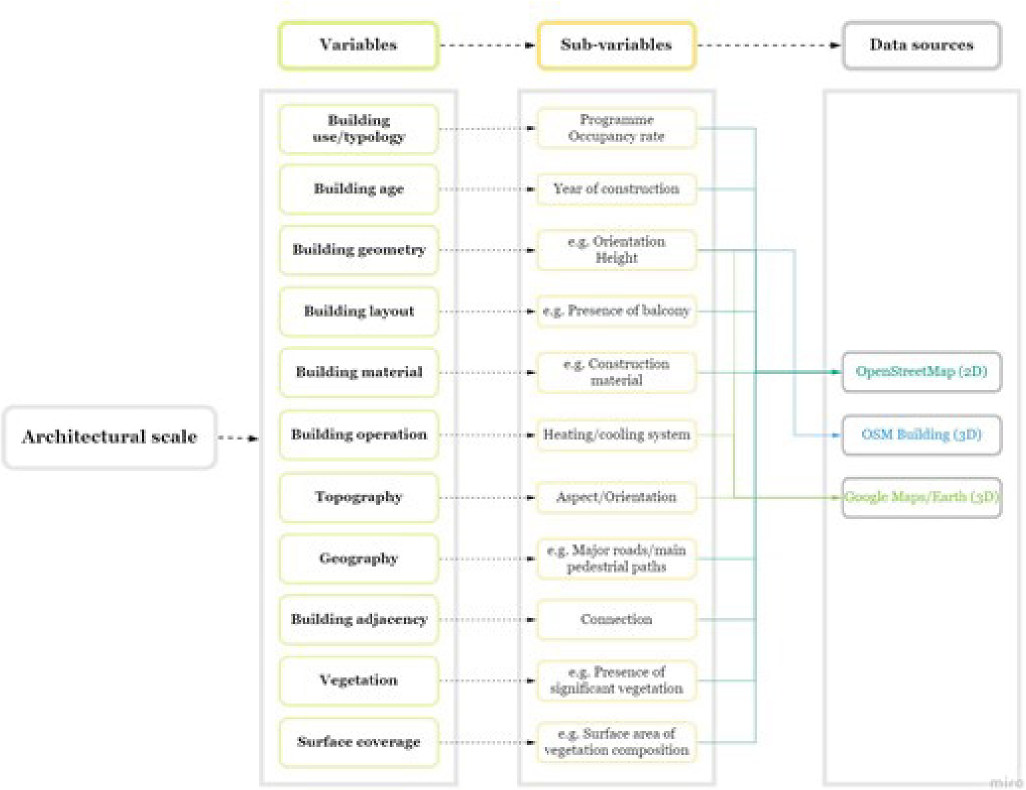
Figure 5:
Urban scale variables, sub-variables and data sources.



The urban classification system will be based on the identified variables and sub-variables that allow the selection of suitable design cases in different cities in different countries. Clusters will be generated and organised in such way as to allow description of selected areas for design and the surrounding features and conditions.

Machine learning strategies such as Hierarchical Clustering Analysis (HCA) provides a systematic overview of variations within clusters (Araldi et al., 2021) and facilitates an integrated classification workflow from the urban scale to the architectural scale.

Figure 6:
Architectural scale variables, sub-variables and data sources.



5. CONCLUSIONS

The paper describes the ECOLOPES radically new integrated ecosystem approach to architecture and provided an overview on the holistic data-driven design process informed by ecological factors.

The activities of ECOLOPES implemented so far led to promising results regarding depth studies on multi-specie interactions through the EIM Ontology. This also includes methods that explore how the expert database that structures volumetric spatio-temporal data for query can be represented as a voxel model.

Concerning the urban classification, the workflow will be further developed, to be applicable for strategic site selection in an urban planning perspective. This will enable the identification of prospective areas for design and implantation of an ecolope, for example, for improving habitat connectivity. Furthermore, the urban classification provides knowledge of urban conditions that will make it possible to extend the results of different ecolopes to analog urban areas in different contexts.

The next steps within the ECOLOPES project include the further development of the ECOLOPES Information Model, to define the relationships between the inhabitants, architecture, and the abiotic environment, and of the computational tools for modelling and visualizing the ecolope, the set-up of the computational simulation environment and the validation of the ECOLOPES' overall design process through specific design cases, selected thanks to urban classification methodology presented in the paper.

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