



ECOLOPES

ECOLOGical building enveLOPES: a game-changing design approach for regenerative urban ecosystems

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Abstract

ECOLOPES proposes a radical change for city development: instead of minimizing the negative impact of urbanisation on nature, we aim at urbanization to be planned and designed such that nature - including humans - can co-evolve within the city. In the project, we envisage a radically new integrated ecosystem approach to architecture that focuses equally on humans, plants, animals, and associated organisms such as microbiota. To do so, ECOLOPES focusses on the envelope, the building enclosure. We will transform the envelope into an *ecolope*, a multi-species living space for four types of inhabitants, humans, plants, animals, and microbiota. To achieve this, ECOLOPES will make biological knowledge available for the architectural design process, to find architectural solutions that enable synergies and limit conflicts between the inhabitants.

This report describes the progress of the project in the second year, in the period 1st April 2022- 31st March 2023. Major achievements of the second year are the further development of the computational workflow, including the development of a number of modelling tools, advances in the ecological modelling, a first implementation of a nested hierarchy of key performance indicators (KPIs), and a roadmap for a knowledge graph as a first part of the ontology. A number of experiments that obtain data for the modelling process have been conducted. The ECOLOPES project also extended its communication and exploitation activities, including the set-up of a new webpage. Overall, the project has made significant progress in year 2.

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EXECUTIVE SUMMARY

In ECOLOPES we propose a radical change for city development: instead of minimizing the negative impact of urbanisation on nature, we aim at urbanization to be planned and designed such that nature - including humans - can co-evolve within the city. We envisage a radically new integrated ecosystem approach to architecture that focuses equally on humans, plants, animals, and associated organisms such as microbiota. ECOLOPES focusses on the envelope, the building enclosure. We will transform the envelope into an *ecolope*, a multi-species living space for four types of inhabitants, humans, plants, animals, and microbiota. ECOLOPES will make biological knowledge available for the architectural design process, to find architectural solutions that enable synergies and limit conflicts between the inhabitants.

In the second year of the project, we have further developed the core technologies that will allow the design of *ecolopes* in a systematic way. In close collaboration between disciplines, we have developed and updated the user workflow for the design of an *ecolope*, and have finalized the first ECOLOPES platform architecture, including the computational workflow. A core element of bridging between ecological dynamics and architecture is the ECOLOPES Knowledge Generation Framework (KGF) that connects ecological dynamics with building geometry. The KGF can now be run in the cloud. In the second year, the local ecological model that simulates the dynamics of plants and animals' communities at the spatial level of a home-range has been further developed and integrated in the ECOLOPES plugin in the 3D CAD system Rhino/Grasshopper used in the project. A first version of the ECOLOPES plugin (front-end tool) for Grasshopper is available for internal testing. Furthermore, the structuring of ECOLOPES objectives and key performance indicators (KPIs) has been framed into a nested hierarchy, an essential step in the design-decision support workflow. A roadmap for a knowledge graph as a first part of the ontology has been developed.

With respect to dissemination and exploitation, the webpage of the project has been fully redesigned, to make it more agile and attractive. The consortium has communicated regularly, using several platforms and social media. A regular online "ECOLOPES TALKS" series has been set up where prominent speakers present talks on topical issues related to the transformation of cities, with respect to the connection between architecture and ecology. In the consortium, several studios and other teaching activities have been carried out at universities, as a testbed for ECOLOPES ideas.

The consortium has published several scientific papers, outlining the overall ECOLOPES approach, conceptual work on the relationship between architecture and ecology, and on technical details, such as the derivation of a hierarchy of key performance indicators and multi-criteria optimization.

The ECOLOPES consortium meets regularly as a whole in general monthly virtual meetings as well as targeted topic in meetings and the interactions are lively and fruitful. This regular exchange has proven to be key for progress. To summarise, the ECOLOPES project has made considerable progress in the second year, and we are optimistic that our development of a design procedure will be successful.



ABBREVIATIONS AND ACRONYMS

AI: Artificial Intelligence

CAD: Compute-Aided Design

***ecolope*:** An ecological building envelope

ECOLOPES: the FET-Open Ecological building envelopes project

EIM: ECOLOPES Information Model

KGF: Knowledge Generation Framework

KPI: Key Performance Indicator

ML: Machine Learning

PFG: Plant functional group

AFG: Animal functional group

WP: Work Package



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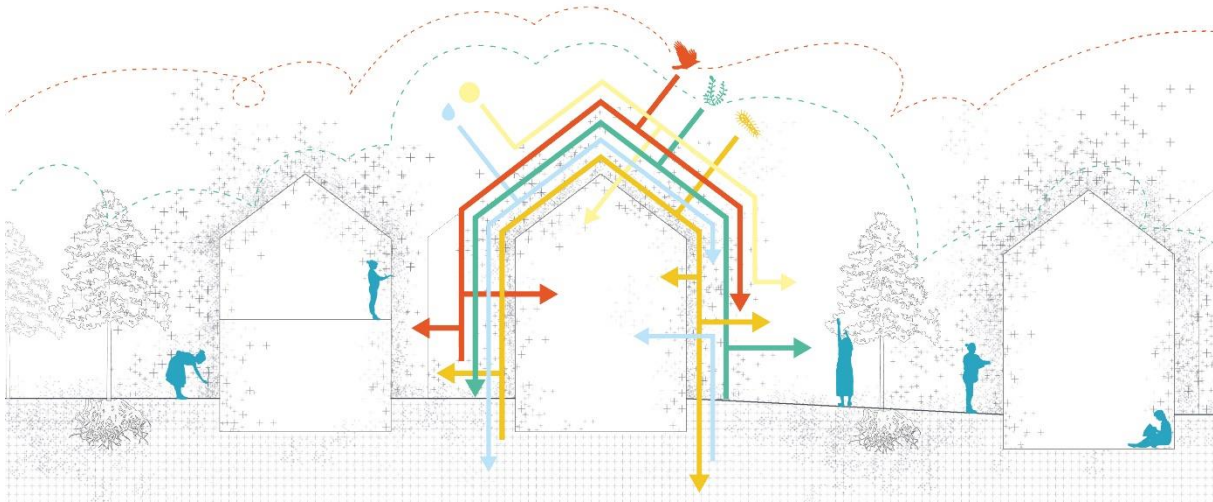


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1 INTRODUCTION



Urbanization constitutes a major environmental issue of the 21st century. Within cities, densification, the decrease of green open spaces, and a continued reliance on grey infrastructure approaches result in increasing separation of people from nature and decreased access to ecosystem services. This decreases the liveability of cities and reduces human well-being. Current approaches fall short in providing breakthrough solutions, because they perpetuate the human-nature dichotomy due to anthropocentric design.

In our ECOLOPES EU FET-OPEN project, we focus on the envelope, the building enclosure, as it is the buffer zone between the inside and outside that has been tried so far as a single function entity - a barrier between the inside and outside. We will transform the envelope into an *ecolope*, a multi-species living space for four types of inhabitants, humans, plants, animals, and microbiota. ECOLOPES will develop the core technologies for designing *ecolopes* in a systematic way, considering the needs of both humans, as well as of plants, animals and beneficial microbes. To do so, ECOLOPES will make biological knowledge available for the architectural design process, to find architectural solutions that enable synergies and limit conflicts between the inhabitants. The *ecolopes* designed by this multi-species approach will restore the beneficial human - nature relationships in cities.

In ECOLOPES, we develop a design approach that is supported by a computational framework and workflow that includes a range of expert databases, an information model and algorithmic processes and tools, to result in a data-driven design recommendation system. A tailor-made computational framework will make the knowledge 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.

2 SCIENTIFIC APPROACH AND ACHIEVEMENTS OF SECOND YEAR

2.1 Background

In the urban environment, a reliance on 'grey' infrastructure, i.e., technological solutions whose harmful effects on organisms, ecosystems, and the natural environment are poorly



considered, has led to a severe loss of ecosystem services (Brondizio et al. 2019). These services deliver indirect benefits for humans, such as the regulation of climatic conditions and mitigation of extreme events such as heavy rainfall or heat waves but they also provide direct positive effects on our health and well-being, including stress reduction and providing a sense of place (Peccia and Kwan 2016, De Palma et al. 2018, Marselle et al. 2019). Cities have thus been considered as an important showcase for the One Health or Global Health concept and indicate that a healthy environment is a strong driver for human health and well-being (Bruen et al. 2014).

Making cities sustainable, resilient, and liveable is thus one of the greatest challenges for humans (CBD 2012). To tackle this challenge, various plans and environmental policies have been implemented worldwide, such as the Green Deal of the European Union (European Commission 2019). In this effort, such policies place special emphasis on the development of green infrastructure, a strategically planned network of natural and semi-natural areas (Benedict and McMahon 2012, European Commission 2013). This also entails increasing the use of innovative nature-based solutions, i.e., the sustainable use of resources and natural processes for solving societal challenges and delivering a wide range of ecosystem services (Eggermont et al. 2015). In the next decades, with the advent of new robotics and autonomous systems, cities will undergo a technological revolution that can have both positive or negative impacts on urban biodiversity and human-nature relationships (Goddard et al. 2021). Making cities more biophilic thus requires new planning methods that mobilizes all disciplines involved in urban development (Kellert et al. 2008, Thomson and Newman 2018, Elmqvist et al. 2019, Söderlund 2019, Thomson and Newman 2020).

ECOLOPES starts from the premise that to create a healthy environment for humans in cities, architecture needs to be activated for the support for urban biodiversity. This is because buildings and constructions are the essence of cities, and designing these buildings is the domain of architecture. ECOLOPES proposes that a first step in creating such a multi-species habitat is the design of an *ecolope*, an ecologically designed building envelope that provides a habitat for many organisms. Because such an *ecolope* does not exist yet, ECOLOPES develops a design strategy that draws on knowledge from ecology, as well as architecture, sustainable building design, and design computation. This design strategy will make ecological knowledge available to the architectural design process, enabling practitioners to find architectural solutions that facilitate synergies from a multi-species perspective. Thus, ECOLOPES will provide technology and design methods that will help to achieve the vision of an integrated ecosystem approach to architecture.

2.2 ECOLOPES overall design approach and work packages

A systematic approach is needed to be able to consider the interactions between the abiotic environment including architecture and the different biota of the *ecolope*, and between the different inhabitants themselves. A systematic approach is also needed to bring local context-specific information into the design process. ECOLOPES tackles the challenge by simulating the *ecolope* ecosystem and its various sub-systems, in space and time. To enable a systematic approach, ECOLOPES will develop **Key Performance Indicators** (KPI's), measuring the consequences of a particular design for human well-being, and for abundance of the non-



human inhabitants. ECOLOPES considers the *ecolope* as a dynamic system that can be adapted to changing needs. Thus, modelling also includes the projection of *ecolope* development after initial building completion. This includes ecological succession, e.g., how soil will develop and generate positive feedback for plant development and colonization of animals. In the future it will also include modelling the effects of human management, such as trimming of vegetation. Taken together, our approach captures the relevant processes for *ecolope* design. This includes the development of a **data-driven design recommendation system**, which will radically advance our understanding of the feedbacks between building design, the ecology of species in cities, and consequences for human well-being. The data-driven design recommendation system will assist architects and planners in the design of *ecolopes*, aiding decision making and facilitating systemic coordinated action in the planning of multi-species environments for regenerative cities. The overall goal of ECOLOPES is thus to provide technology that enables this iterative design process based on the simulation of the dynamic development of the *ecolope*, and of its various subsystems and their interactions.

The work of ECOLOPES is carried out in eight work packages (Table 2.2-1). Because work packages (WP) are closely interconnected, we will report our major advances separately, and not WP by WP (see below, structure of this report).

*Table 2.2-1: Work package structure*

WP	Title	Leader	Email Address
WP1	Project management and coordination	TUM Wolfgang W. Weisser	wolfgang.weisser@tum.de
WP2	Dissemination and exploitation	TUM Ferdinand Ludwig	ferdinand.ludwig@tum.de
WP3	ECOLOPES Platform Architecture	MCNEEL Verena Vogler	verena@mcneel.com
WP4	Data acquisition and information modelling	TUM Wolfgang W. Weisser	wolfgang.weisser@tum.de
WP5	ECOLOPES Voxel & Computational model	VIE Michael Hensel	michael.hensel@tuwien.ac.at
WP6	Computational Simulation and Analysis	TEC Shany Barath	barathshany@technion.ac.il
WP7	Overall Validation	UNIGE Katia Perini	katia.perini@unige.it
WP8	Ethic	TUM Anne Mimet	anne.mimet@tum.de



3 ACHIEVEMENTS OF THE SECOND YEAR

The work of the ECOLOPES project in the second year is described in this report and in the following deliverable

- D3.2 Draft ECOLOPES platform architecture (Month M 19)

Please also note that this report builds upon the deliverables that were already submitted within the first year of the project, in particular:

- D1.1 Data Management Plan (M6)
- D1.2 Preliminary Risk and Quality Management plan (M9)
- D1.3 Report of first year (M12)
- D2.1 Website and project logo (M9)
- D2.2 First report on dissemination and communication activities (M12)
- D2.3 First dissemination and exploitation plan (M12)
- D3.1 Prototype technical requirement report (M12)
- D3.2 Draft ECOLOPES platform architecture (M19)
- D4.1 Preliminary EIM Ontology (M12)
- D5.1 Development process for ECOLOPES algorithmic tools (M12)

Here, we give an overview over major achievements of the second year and point to the sections, where these are described in more detail:

- Based on the **First dissemination and exploitation plan** (D2.2, M12), the consortium has increased its efforts in communication and dissemination. These advances are described in the report of WP2. For example, the **webpage** of the project (www.ecolopes.eu) has been completely redesigned. A regular online “**ECOLOPES TALKS**” series has been set up where prominent speakers present talks on topical issues related to the transformation of cities, with respect to the connection between architecture and ecology. The project has also increased its activities on social media platforms. In the consortium, several **studios** and other teaching activities have been carried out at universities, as hotspots for co-creation of knowledge and as a testbed for ECOLOPES ideas.
- With respect to making the work of ECOLOPES visible in the scientific community, the consortium has published several scientific **papers**, in particular a paper on the ECOLOPES approach (Weisser et al. 2023, *Creating ecologically sound buildings by integrating ecology, architecture and computational design*, *People and Nature*, 5:4-20), that also includes some general considerations on the relationship between architecture and ecology (see below, list of papers).
- In terms of developing the new design strategy, the general **design workflow** of ECOLOPES has been further developed (Section 4.1). This workflow describes the steps in the design of an *ecolope* from the user perspective, e.g., a team of architects and ecologists. This workflow helps the consortium in asking the important conceptual questions, and it guides the development of the individual computational components needed.



- Several advances have been made in developing the computational tools of ECOLOPES. The **ECOLOPES platform architecture** and the **computational workflow** was completed in 2022 and was presented in detail in D3.2 (M19). In the year 2022 we completed the first version of the **ECOLOPES plugin** (front-end tool) that has been developed for Rhino/ Grasshopper. The ecological modelling was successfully integrated into a 3D CAD system. Thus, ecological modeling becomes an intrinsic part of the form-finding process for parametric building envelopes. These advances are described in section 4.2.
- The **ecological model** that models the ECOLOPES ecosystem has also significantly advanced and now includes a more detailed description of animal communities and plant-animal interactions. Significant progress has been made in the development of generalized plant functional groups (section 4.3).
- The **Knowledge Generation Framework**, the first toolset developed in ECOLOPES to systematically explore the relationship between architecture and ecology, that is based on the ecological model and a vital part of the computational workflow is now fully functioning and runs in a cloud (section 4.4).
- To guide the optimisation process, a first implementation of a nested hierarchy of **key performance indicators** (KPIs) has been achieved (sections 4.5 and 4.6). The conceptual advancement of developing KPIs for both architecture and ecology has been summarized in a manuscript that has been published.
- A Roadmap for a knowledge graph as a first part of the **Ontology** has been developed that is described in detail in section 4.7 and WP4.
- A number of **experiments** that obtain data for ECOLOPES have been conducted. These concern data on validating plant functional groups, on the role of how soil conditions and plant communities for the development of microbial communities, and on human perception of nature. These achievements are described in section 4.8.
- The **management structure** of ECOLOPES that was developed in the first year has proven to be successful and has been followed closely in the second year. The structure of the ECOLOPES project including the meeting held are described in the report of WP1.

3.1 Publications

In the past year, the first papers have been published that originated from work in the ECOLOPES project:

- 1 Weisser, W. W., M. Hensel, S. Barath, V. Culshaw, Y. J. Grobman, T. E. Hauck, J. Joschinski, F. Ludwig, A. Mimet, K. Perini, E. Roccotiello, M. Schloter, A. Schwartz, D. S. Hensel, and Vogler, V. (2023) Creating ecologically sound buildings by integrating ecology, architecture and computational design. *People and Nature* 5(1), 4-20. <https://doi.org/10.1002/pan3.10411>



- 2 Selvan, S.U. *et al.* (2023) ‘Toward multi-species building envelopes: A critical literature review of multi-criteria decision-making for design support’, *Building and Environment*, 231, p. 110006. <https://doi.org/10.1016/j.buildenv.2023.110006>.
- 3 Canepa, M., Mosca, F., Barath, S., Changenet, A., Hauck, T. E., Ludwig, F., Roccotiello, E., Pianta, M., Selvan, S. U., Vogler, V. and Perini, K. (2022) “Ecolopes, beyond greening. A multi-species approach for urban design”, *AGATHÓN | International Journal of Architecture, Art and Design*, 11(online), pp. 238–245. <https://doi.org/10.19229/2464-9309/11212022>.
- 4 Selvan, S.U. *et al.* (2023) ‘Multi-species building envelopes: Developing a multi-criteria decision-making methodology for cohabitation’, in *Proceedings of the 28th International Conference of the Association for Computer-aided Architectural Design Research in Asia. CAADRIA 2023, India*.
- 5 Tyc, J., Selami, T., Sunguroglu Hensel, D., and Hensel, M. (2023) A Scoping Review of Voxel-Model Applications to Enable Multi-Domain Data Integration in Architectural Design and Urban Planning. *Architecture*, 3(2), 137-174. <https://doi.org/10.3390/architecture3020010>

3.2 Conferences

Members of the ECOLOPES consortium were very active in attending conferences and presenting the work of the ECOLOPES project (Table 3.2-1).

Table 3.2-1: List of conferences where ECOLOPES research has been presented in 2022 and 2023

Conference/Event	Title	ECOLOPES Presenter	Type	Leading Institution	Link
2022					
Digital Landscape Architecture (DLA) Conference 2022, Harvard Graduate School of Design, Cambridge, Massachusetts	Artificial coral reef design & ecosystem-aware design	V. Vogler	Talk	McNeel	https://2022.dla-conference.com/home/
Rhino User Meeting Copenhagen 2022, Denmark	Rhino developments and Research projects	L. Fraguada	Talk	McNeel	https://www.eventbrite.com/e/rhino-user-meeting-copenhagen-2022-tickets-347818543627
Human-Animal Studies in Israel	Multi-species Building Envelopes: From human-centered to ecological inclusiveness	S. U. Selvan	Talk	TEC	https://www.hasiconference.sites.tau.ac.il/
Conference "STADT LEBENS RAUM – Perspektiven und Initiativen"	ANIMAL-AIDED DESIGN Einbeziehung von Tierbedürfnissen in die Planung und Gestaltung städtischer Freiräume	W. W. Weisser, T. E. Hauck	Talk	TUM, SAAD	https://umweltermine.bayern/pdf/dfx/181/62986a62ebd18_6122_A_NL_Symposium_STADT_LEBENS_RAUM.pdf



VIII International Plant Science Conference (IPSC) - 117th Congress of the Italian Botanical Society	Plant functional groups and vegetation dynamics within urban ecosystems: the ECOLOPES' project approach	M. Pianta	Talk	UNIGE	https://www.societabotanicaitaliana.it/117/eng/detail.asp?idn=5004
Naturschutztag NABU Brandenburg "Siedlungsnaturschutz"	ANIMAL-AIDED DESIGN Einbeziehung von Tierbedürfnissen in die Planung und Gestaltung städtischer Freiräume	T. E. Hauck	Talk	SAAD	https://brandenburg.nabu.de/wir-ueberuns/infothek/veranstaltungen/naturschutztage/31913.html
Conference „Architektur + Biologische Vielfalt“	ANIMAL-AIDED DESIGN Einbeziehung von Tierbedürfnissen in die Planung und Gestaltung städtischer Freiräume	T. E. Hauck, W. W. Weisser	Talk	SAAD, TUM	https://www.ufu.de/architektur-biologische-vielfalt/
Lecture Series "Zero Waste – Kunst und Wissen"	"Die Stadt als Ko-Habitation für Mensch und Tier"	T. E. Hauck	Talk	SAAD	https://www.urania.de/zero-waste-kunst-und-wissen-0
American Society of Landscape Architecture (ASLA) conference 2022: Designing a better future, San Francisco, USA	Assessment of Environmental Aspects of Landscape Projects Using Parametric Design	V. Vogler	Educational accredited session	McNeel	https://www.aslaconference.com/
RSD 11 – Systemic Design Association	Cultural Environments with More-than-Human Perspectives	S. Barath	Panel	TEC	Cultural Environments with More-than-Human Perspectives (rdsymposium.org)
National scientific meeting - Italian Botanical Society (SBI) - Ligurian Section	Plant communities around the city of Genoa: response to anthropic pressures	M. Pianta	Talk	UNIGE	
SFE2 - GFÖ - EEB annual meeting	The ECOLOPES plant-animal-soil community model	J. Joschinski	Talk	TUM	https://gfoe.org/en/node/2296
SFE2 - GFÖ - EEB annual meeting	Plant functional groups to model vegetation dynamics in urban ecosystems: the ECOLOPES' project approach	M. Pianta	Talk	UNIGE	https://sfe2gfoemeeting.sciencesconf.org/
SFE2 - GFÖ - EEB annual meeting	The ECOLOPES Animal model	V. Culshaw	Poster	TUM	https://gfoe.org/en/node/2296
URBIO International Conference	The ECOLOPES plant-animal-soil community model.	V. Culshaw	Talk	TUM	https://www.urbionetwork.com/
URBIO International Conference	Integrating ecological modelling in a 3D CAD system for urban planning and for regenerative urban ecosystems	V. Vogler	Talk	McNeel	https://www.urbionetwork.com/
URBIO International Conference	Experiences with the practical application of the Animal-Aided Design method in urban development - a first evaluation of problems and potentials in the implementation of actions	T. E. Hauck	Talk	SAAD	https://www.urbionetwork.com/



D1.5. V.03

EmTech master's program	The scientific revolution in architecture	Y. Grobman	Talk	TEC	https://youtu.be/wYMZ3NzJQwA?list=PLS2zUtsjeelSXJY6eMyyZy9HRmL_PbmwS
2023					
Final Conference of the research project "Animal-Aided Design im Wohnungsbau – Das Beispiel Brantstraße in München"	Animal-Aided Design im Wohnungsbau	W. W. Weisser, T. E. Hauck	Talk	TUM, VIE	https://wiki.tum.de/pages/viewpage.action?pageId=1336901770
CYBO: Conference for Young Botanists	Spontaneous plant communities within a Mediterranean green roof	M. Pianta	Talk	UNIGE	https://www.actaplantarum.org/zz_for_adm/cybo/index_eng.php
Conference for Young Botanists	The ECOLOPES plant functional groups	M. Calbi	Talk	UNIGE	https://www.actaplantarum.org/cybo/index_ita.php
Spring Panel at Carnegie Mellon School of Architecture – Non-Extractive Practices and Non-Human Species	Animal-Aided Design	T. E. Hauck, W. W. Weisser	Talk	SAAD, TUM	https://soa.cmu.edu/public-programs
EmTech lecture series, Architectural Association London, EmTech Master Class	Horizon 2020 Research Projects/ Developments	V. Vogler	Lecture	McNeel	https://www.facebook.com/EmtechStudio/
Rhino User Meeting Basel @Herzog & de Meuron Architects Basel, Switzerland	Horizon 2020 Research Projects @ McNeel Europe	V. Vogler	Talk	McNeel	https://events.mcneel.eu/rhino-user-meeting-basel/
28th International Conference of the Association for CAADRIA	Multi-species Building Envelopes: Developing a multi-criteria design decision-making methodology for cohabitation	S. U. Selvan	Paper Presentation	TEC	https://caadria2023.org/



4 DESCRIPTION OF MAJOR PROGRESS IN THE SECOND YEAR

In this section, we first describe major advances in the project. In the following sections, we summarize the progress work package by work package.

4.1 ECOLOPES workflow

The design workflow (Fig. 4.1-1) has proven to be a suitable framework for the discussion of the different steps in the design and for developing design and simulation tools in the work packages. It is reflected in the computational workflow (section 4.2).

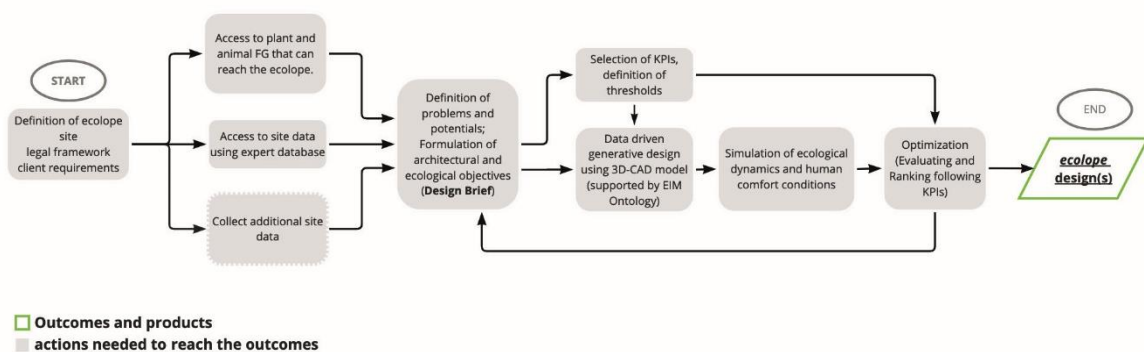


Figure 4.1-1: The ECOLOPES design workflow.

The first step of the workflow is to select a site where the project takes place. This is typically done by the client who would like to develop a project. This client will have certain objectives with the project. In addition, there are legal requirements and higher-level urban planning objectives. It is thus important to consider that the framework conditions for an *ecolope* are not just defined by objective factors, such as the local climatic conditions or the urban structure, but by normative settings, in particular external constraints set by e.g. government rules (laws and regulations) and administrative proceedings and plans, and by internal constraints set by the values and commitments of the client, which are expressed in the client requirements, and by the values of the interdisciplinary planning team.

In the second step, the environmental conditions of the site will be analysed. These site data include data on the 3D-geometry of the site, urban form, climate, topography, but also information specific for *ecolope* design such as terrain and the occurrence of plant, animals and microbes on the site and in the surroundings. For the user, the raw data will already be processed to e.g., reduce the list of species to those that can reach the building site. Wherever necessary, additional data will be collected. In a later state of the ECOLOPES project, an initial analysis (zero variant) would be to analyse the ecological potential of the site based on available data to help the user defining reasonable ecological objectives, before the design process starts.

The third step of workflow corresponds to formulating the design brief. This design brief brings together the existing data, the client's requirements, the legal framework, higher-level planning strategies, and also the design goals of the interdisciplinary design team with respect



to aesthetic quality, ecology and other functional requirements. The design brief defines both the design objectives (e.g., ecological and architectural objectives) and the boundary conditions of the design (ECOLOPES design space). Thus, it is the human user that will evaluate all information and set design targets yet based on a large array of data.

The design brief is the starting point for the selection of key performance indicators (KPIs) defined for each stakeholder (humans, plant, animals, and microbiota) that will guide the design of the *ecolope*. We envisage a generative design process whereby architectural forms are generated in a data-driven way. The settings for the design process concern, for example, architectural geometry, soil (compaction, depths) and water drainage. Following the requirements, a number (n) of variants are developed in the interplay of terrain and building structure. Generation of the variants is supported by the ontology, that encapsulates relationships between architectural form and function and draws on the knowledge base where these relationships are stored (see computational workflow, Deliverable 3.1). The consequences of the design variants are then evaluated for each stakeholder, i.e., the human user (e.g., with respect to human comfort), plants, animals and microbes, with the help of the ecological model (and the representative of the non-human stakeholders in the design team e.g., ecologist) that also considers the interactions between the different stakeholders. The KPIs will be used to numerically grade and assess the performance of the different variants for the different stakeholders, resulting in a report of the performance of the variants for the different criteria, and ranking of the design solutions.

In a final step, the user (design team) will assess the results of this computational evaluation process, i.e., the ranking of the variants and their performance, to decide which initial design solution should be chosen. Thus, the user workflow mixes computer-aided design recommendation with human evaluation of the outcome.

Importantly, the design process will be iterative. Based on the user assessment of the design outcome, the user can decide to modify the design objectives, the settings for the generative design, and the KPIs, to start a next design cycle. We envisage that, similar to traditional architectural design process, the cycle (design loop) from formulating design objectives, specifying settings for the generative design, and formulating KPIs to assessment of the optimisation outcomes is repeated several times.

Importantly, the design solutions obtained in this iterative design process will become more and more efficient and precise, until the user is satisfied with the design. The aim of the first design loops will likely explore the widest possible range of suitable and performing variants.

4.2 ECOLOPES updated computational workflow

In year two the computational framework was put into practice. As described in detail in the deliverable D3.2, the computational framework has been embedded in a conceptual framework, which reviewed existing work and tools and mapped out the expected relationship between architectural and ecological variables. During development it also has become clear that a full-fledged operable **Knowledge base (KB)** is required as soon as possible. The workflow has been updated accordingly in such a way that the **Knowledge Generation Framework (KGF)** is directly used to inform design generation and optimization. The ontology and ontology-driven generative design are developed in parallel and will complement and enhance the current KB draft at a later point. This incremental and strongly



compartmentalized software development approach helped us achieve an operating computational framework quickly. In particular, D3.2 reported on the successful integration of the following modules into the 3D CAD environment Rhino/Grasshopper:

1. Open and expert databases
2. Working **environmental models** that use the database as input, and whose output is used by the ecological model:
 - a. A **shading model** based on Ladybug Tools
 - b. A **soil depth model**
3. An **ecological model** that uses the environmental models as input, and simulates plant, animal and soil communities
4. The **Knowledge base** which stores the inputs and outputs of simulations testing the response of the *ecolope* ecosystem to the building geometry (geometries, environmental and ecological model outputs; requiring manual extraction)
5. A **design evaluation and optimization environment** based on MCDM and MOO

The deliverable further reported on the first successful use of the integrated computational workflow within the KGF to derive a first set of correlations.

However, D3.2 also summarized the main challenges that were encountered in the process, for instance, limited data accessibility and portability, conversion between 2D raster data and 3D geometry data, further development of integrated, yet compartmentalized components, and lastly, the processing time.

Since the submission of D3.2 in M19, the computational framework has been further developed and enhancements were made: First, all technical partners optimized the existing algorithms and computational processes to increase their efficiency and fix bugs that were encountered during the first use case. The bug fixing and optimization resulted in considerable performance increases, for example the plant model runs approx. 20 times faster than before, and additionally now supports parallelization and efficient use of computing power. Second, tools for the automatic (rather than manual) conversion and transfer of inputs/outputs were developed. This included standardization of input/output formats of all environmental and ecological models into JSON files. Third, the computational framework is fully operational on a Windows Cloud server, which runs as a server on a local machine. A CI/CD system was set up on GitLab to support cross-compilation and help tracking down portability issues. The CI/CD system is currently deployed on GitLab's virtual machines, and executables are manually retrieved, but direct deployment through Rhino.Compute will follow shortly. Lastly, the computational system is accessible to users by the ECOLOPES Grasshopper plugin, which operates as a UI between cloud services, computed results and the 3D modelling environment in Rhino. A first version of the plugin is developed.

In the following sections, the integrated components and processes are further described (4.1.1), together with the challenges for the integration of the ecological model in a 3D CAD system (2.2), and lastly, the ECOLOPES Grasshopper plugin is briefly introduced (2.3).



4.2.1 Integrated components

The computational workflow connects individual modules developed by each partner. For instance, while the local and regional ecological models (green) are developed by the team of ecologists, the form generation and optimization environment is developed by architects (pink). Figure 4.2.1-1 shows the updated version of the computational workflow and all the components that are integrated (black frame).

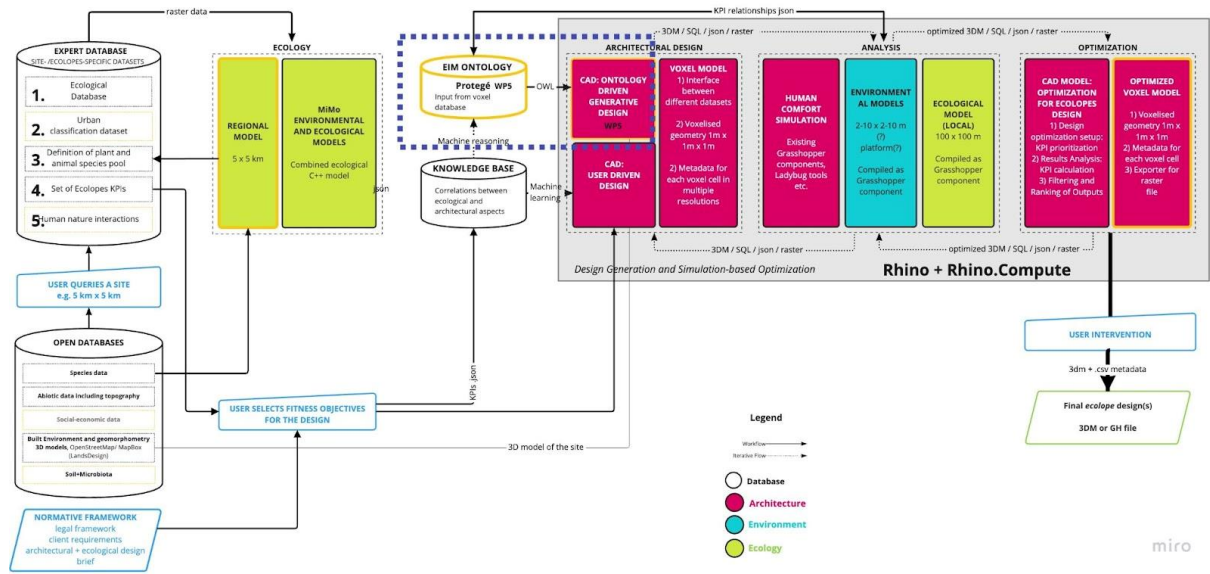


Figure 4.2.1-1: ECOLOPES Computational workflow.

For the integration, McNeel elaborated on the use of *Rhino* as an open development platform for the ECOLOPES plugin, allowing to write a library of custom algorithms in Grasshopper and C++, as well as for the development of a frontend tool. D3.2 further reports on the use of *Rhino.Compute* as backend service to bring process-intensive algorithms into the cloud, and of *Hops* to wrap up algorithms for communicating with Rhino.Compute.

The software development approach adopted in ECOLOPES takes into account the multiple types of applications, their maturity, intended usage, and lifecycle. As the ECOLOPES project progresses, we continue to manage software development based on an incremental approach rather than an agile or waterfall system. This approach allows us to design and develop several sections in parallel, a process supported by the early definition of the system architecture, common data models, and interfacing mechanisms. To ensure consistency with respect to development and integration McNeel coordinates weekly WP3 workshops and a monthly meeting that reports on the latest developments. Furthermore, action points and their state are tracked within a shared Excel table.

So far, there are five major modules of the computational workflow that are already integrated within the ECOLOPES computational platform and further described below: open and expert databases, environmental models, the ecological model, the Knowledge base (KB), and the design optimization environment (see D3.2, Section 3.3).

- **Open and expert databases (WP3-WP7):** Site-specific environmental data such as open climate data (e.g., .epw, .stat, .txt, .ddy) can be accessed through open street



maps in Grasshopper/ Ladybug Tools and used for solar radiation analysis to evaluate adequate areas for plant growth.

- **Environmental models (WP3):** Environmental models calculate shading (Ladybug Tools in Grasshopper), soil depth, and in the future water runoffs and shelter for a specific building geometry/ site to input this information as spatio-temporal dynamics of functional groups in a resolution of 1 sqm
- **Ecological model (WP4):** The ecological models written in the C++ programming language are interconnected sub-models that model the community dynamics of functional groups based on regional and local models. As an input, it requires environmental and geometry information. It is now fully integrated into *Grasshopper*, a visual algorithm editor for Rhino, a standard 3D CAD software in AEC. The ecological model provides variables to define architectural and ecological performance indicators (KPIs) that facilitate multi-objective optimization processes.
- **Knowledge base (KB) (WP3):** The ECOLOPES Knowledge base (KB) provides information and resources generated through the Knowledge Generation Framework (KGF, D3.1 and D3.2). The computational system in ECOLOPES uses the KB as its repository for the knowledge needed to support decision-making and as Elm connection.
- **Optimisation environment (WP6):** The optimisation environment inputs the optimized values of key performance indicators and identifies weights for each key performance indicator. A developed MADM Grasshopper component then sorts the range of optimized design solutions according to given architectural or ecological objectives.

Ecological and environmental analysis are computationally heavy processes, e.g., the ecological model requires 15-20 min for analysis of a site of the size 100 m x 100 m, and the environmental models take about 2-5 min to compute. For this reason, we developed and put into practice a cloud-based system where all processes are computed on a cloud server using Rhino.Compute. The user interface (UI) between the cloud server and the user is the ECOLOPES plugin. The ECOLOPES plugin enables design generation based on ecological analysis results, knowledge from the KGF, and the KPIs. Furthermore, existing designs can be evaluated for suitability as an *ecolope*. The processes for the integration of the ecological model and the ECOLOPES plugin are described in the following sections.

4.2.2 Integration of ecological modelling in a 3D CAD system

The core of the computational workflow is the ecological model and the work needed to make ecological analysis available for design decision-making and design optimization. In the second year of the ECOLOPES project, we technically achieved the goal of integrating ecological modelling in a 3D CAD system which can then be used to inform urban planners to make more efficient design decisions that also consider the requirements of the urban ecosystem. In the first step, the ecological model was developed by TUM, UNIGE, and SAAD (see 4.3). The model was then integrated into the Rhino/Grasshopper environment by McNeel. In the last step, the developed system is made available for evaluation using case studies.

This section describes in more detail the updates of the developed computational system, which reflects the uniqueness, and interdisciplinary nature of the ECOLOPES research project



and the way in which it interacts with emerging technologies and techniques/methods. Besides more general challenges for the computational system such as big data, high performance, databases, information systems, integrated and embedded hardware/software components, and networks, the main obstacle was to bridge the gap between the 2D Raster file format of the ecological model and the 3D file format used for architectural design and analysis. For instance, if we look at an urban section, precise georeferenced and geometry information for the vertical parts of the urban landscape is missing in the raster file format. But especially these areas have a great potential to become multi-species habitats for non-human species. To tackle this challenge, we developed a system that can generate this missing data for the ecological model input by using voxel cells. The workflow requires input generation for the ecological model. Thus, a random building design was used to generate geometry, shading and soil depth inputs with respect to this specific building shape for the ecological model (Figure xx). In the next step, 3D data was converted into 2D raster data (JSON files) by a voxel model (Figure xx). In the final step, the ecological model uses geometry and architectural analysis results such as shading, soil depth, in the future, water runoffs, and shelter as input to calculate spatio-temporal dynamics of functional groups in a resolution of 1 sqm. Only with the generated inputs, community dynamics between soil, plants, and animals can be modelled for this specific shape (Figure 4.2.2-1).

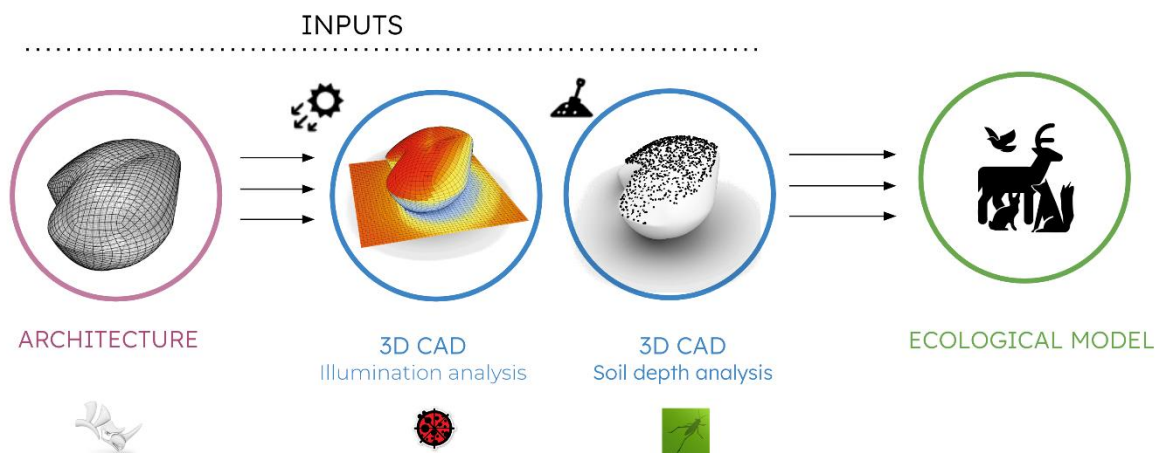
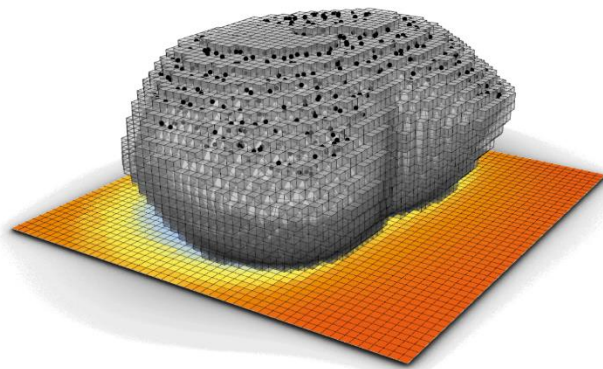
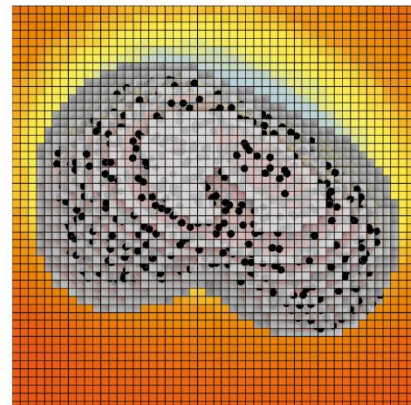


Figure 4.2.2-1: Parametric 3D models and environmental analysis results are used as input for the ecological model.

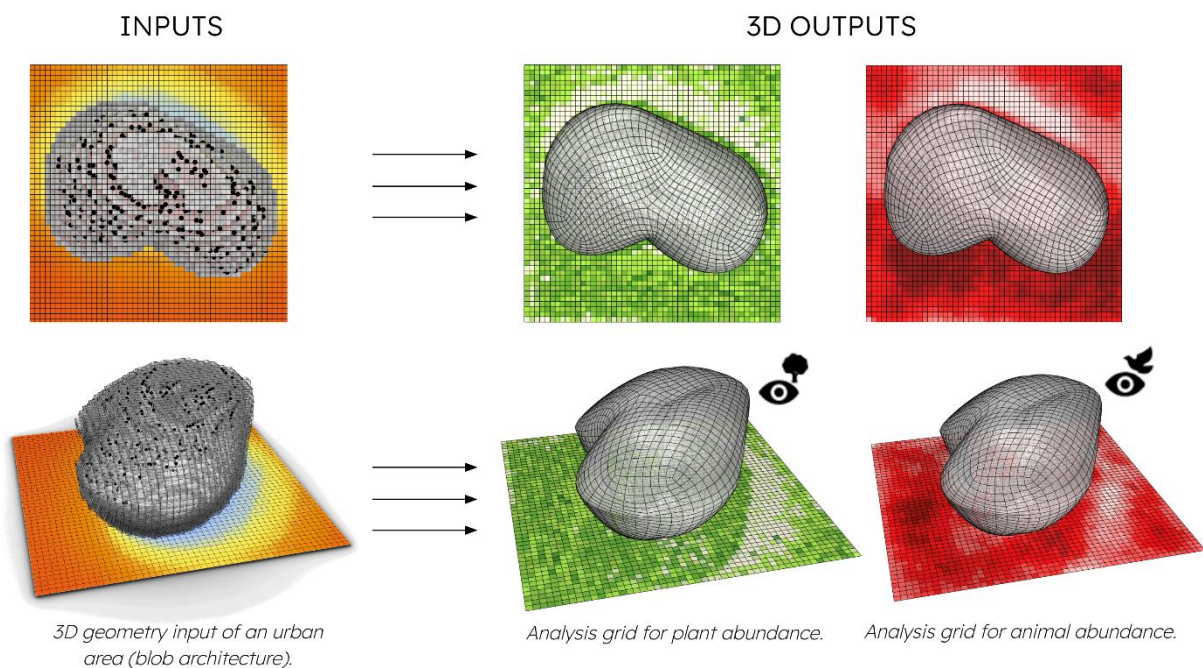


Voxelised 3D model (1m x 1m x 1m) of a random shaped building envelope (geometry, shading, and soil).



Conversion into raster data -> XML/ JSON.

Figure 4.2.2-2: Conversion of data through a voxel from 3D to 2D raster data.



3D geometry input of an urban area (blob architecture).

Analysis grid for plant abundance.

Analysis grid for animal abundance.

Figure 4.2.2-3: Relationship between shading and the abundance of plant and animal communities.

In summary, the computational framework aligns computational modelling processes in the project and helps to define the requirements for each analysis component. For the development process, it is crucial to understand in detail how community dynamics are modelled and which inputs, data structure and file formats are required. Our results show that, through the integration of the ecological model in a 3D CAD system, ecological modelling becomes an **intrinsic part** of the form finding process of building envelopes in our cities. Furthermore, as a parametric system, the approach works with multiple geometry inputs and



surrounding buildings. Lastly, the implemented cloud architecture with Rhino.Compute was essential to enable and guarantee an intuitive computational process for users of our system.

In year 3, we will work on how to precisely project information from ecological analysis to the building envelope for design decision-making (Figure 4.2.2-4). Architects will need more precise information about each part of the building as well as a validated ecological model to apply the developed approach in design.

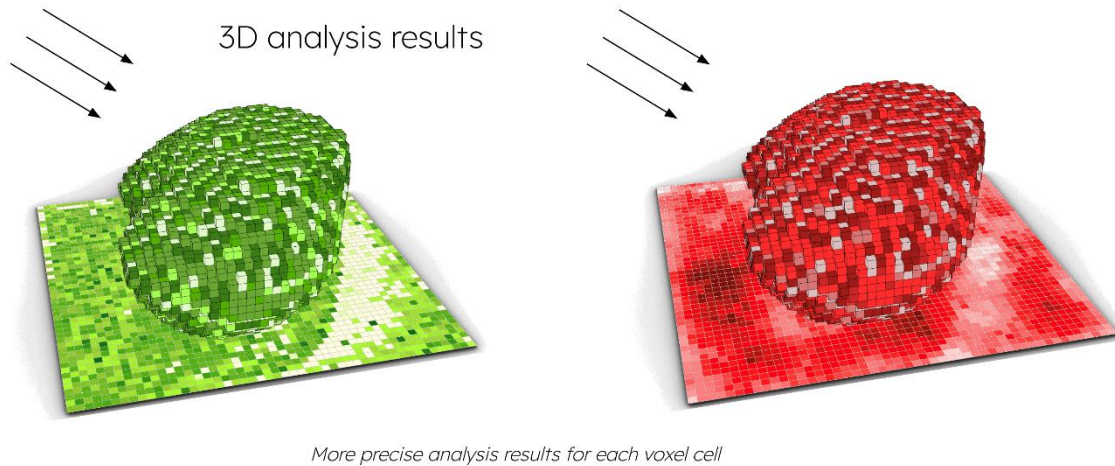


Figure 4.2.2-4: Future analysis results for design-decision support.

4.2.3 ECOLOPES plugin for Rhino/ Grasshopper

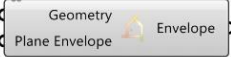
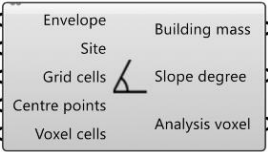
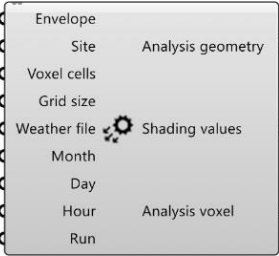
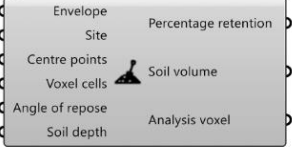
After the submission of D3.2, we were able to develop the first version of the ECOLOPES Grasshopper plugin. Grasshopper components were built by utilizing McNeel's .NET APIs as well as web applications leveraging Rhino.Compute and JavaScript APIs.

There are components for data exchange between 2D raster and 3D voxel data, components for data conversion from metadata to JSON files, components for ecological and environmental analysis, and preview components to display community dynamics between soil, plants and animals in Rhino, a 3D CAD environment.

The first version of the ECOLOPES plugin is fully operational and required as the tool/technology to enable the KGF and to provide information about the relationships between ecological and architectural parameters in the KB (Table 4.2.3-1).



Table 4.2.3-1: Components of the ECOLOPES Grasshopper plugin.

Grasshopper component	Short description
	<p>Envelope converter: Converts any geometry object into a “Envelope” geometry for analysis.</p>
	<p>Arch Solver: Computes building mass, surface roughness and slope angle for each voxel cell.</p>
	<p>Shading Solver: Computes shading values for each voxel cell, and outputs analysis mesh and metadata.</p>
	<p>Soil Solver: Computes soil depth for each voxel cell.</p>



	<p>Raster Solver: Data structure for raster cells in CAD and insertion point for Envelope geometry.</p>
	<p>Voxel Solver: <u>Voxelizes</u> envelope and site geometry input and outputs voxel cells, center points, number of cells and number of cells in z direction.</p>
	<p>JSON Compiler: Reads datasets and combines them into 1 JSON file.</p>
	<p>Run ECO Model: Runs ecological c++ program on Windows cloud server and pushes analysis results to the cloud.</p>
	<p>Preview component for plant abundance: Outputs values and color gradient for species abundance.</p>
	<p>Preview component for animal abundance: Outputs values and color gradient for species abundance.</p>

4.3 Ecological model

The ecological model has been described in the Report of first year (D1.3), and, in more detail, in Deliverable D4.1. The ECOLOPES ecological model simulates the development of the *ecolope* ecosystem over time. Here, we describe the further developments of the model in year two.

4.3.1 Description of the model

The ecological model computes the effect of architecture (as well as local site conditions and the wider environment) on community assembly on the *ecolope*. The model includes a soil component that affects plants, it models plant community dynamics, and it models animal communities. Currently, microbes are included in the model as part of soil structure. By modelling entire communities and abiotic conditions, the model aims at being an ecosystem model. The development of this *ecolope* ecosystem is affected by building design (i.e., geometry), local abiotic conditions (such as radiation or precipitation, that also depend on building design), soil characteristics, human management, and by the species that either colonize the *ecolope* from the outside (i.e., native and non-native species found in the region) or that are introduced by humans on the *ecolope* (e.g., ornamental plants), as well as the interactions between the components. The biotic interactions included in the model concern trophic interactions (including herbivory and predation) and competition. These interactions



have the potential to weaken the abundance of some species and can even lead to local species extinction. The ecological model uses spatial data to produce spatial outputs (maps), showing e.g., the distribution of soil, plants, and animals on the *ecolope*, at each time step (year) of the simulation. Currently, the model inputs directly affect plants and soil, while animals are affected indirectly via a change in plant abundance and composition.

Building such a model using species as the biological unit would be extremely complex, computationally intensive, and possibly not generalizable to a wide range of environmental conditions, as there are many species in a particular region, i.e., several thousand. To overcome these limitations, the ECOLOPES ecological model uses plant (PFG) and animal (AFG) functional groups as biological units. This approach allows to cluster species together that are similar in their characteristics. Conceptually, species occur within a multidimensional niche space. Each dimension of the niche space is built using functional traits. In this approach, a functional group is a group of species that share similarities in every aspect (or every dimension) of their multidimensional niche space, and hence have a similar functional niche owing to a convergent ecological strategy and similar impacts on the ecosystem. The functional traits used to characterize the dimensions that define the niche space are chosen based on the ecological processes that we considered important for the modelling approach. Deriving these functional groups will be major step forward for ecological modelling, beyond the approach of modelling organisms in cities.

The model is based on a two-scale approach (Fig 4.3.1-1). The **regional model** determines which FGs are available within the regional species pool and have a reasonable chance to colonize the *ecolope* according to its location in the city. The **local model** applies a second filter on these species based on the abiotic and biotic conditions delivered by the *ecolope*. The local model thus consists of several sub-models that simulate soil-microbiota development, PFG abundances, and AFG home ranges in cells on 1 m². This resolution has been defined by the consortium as a compromise between (i) the relevant spatial scales of the different organisms: soil microbiota, plants, and animals (from insects to mammals), and (ii) typical scale of building envelope elements. The spatial extent of the local model is at least as large as the ECOLOPES site, but needs to be further extended if animals with larger home ranges (“territory”) are to be modelled.

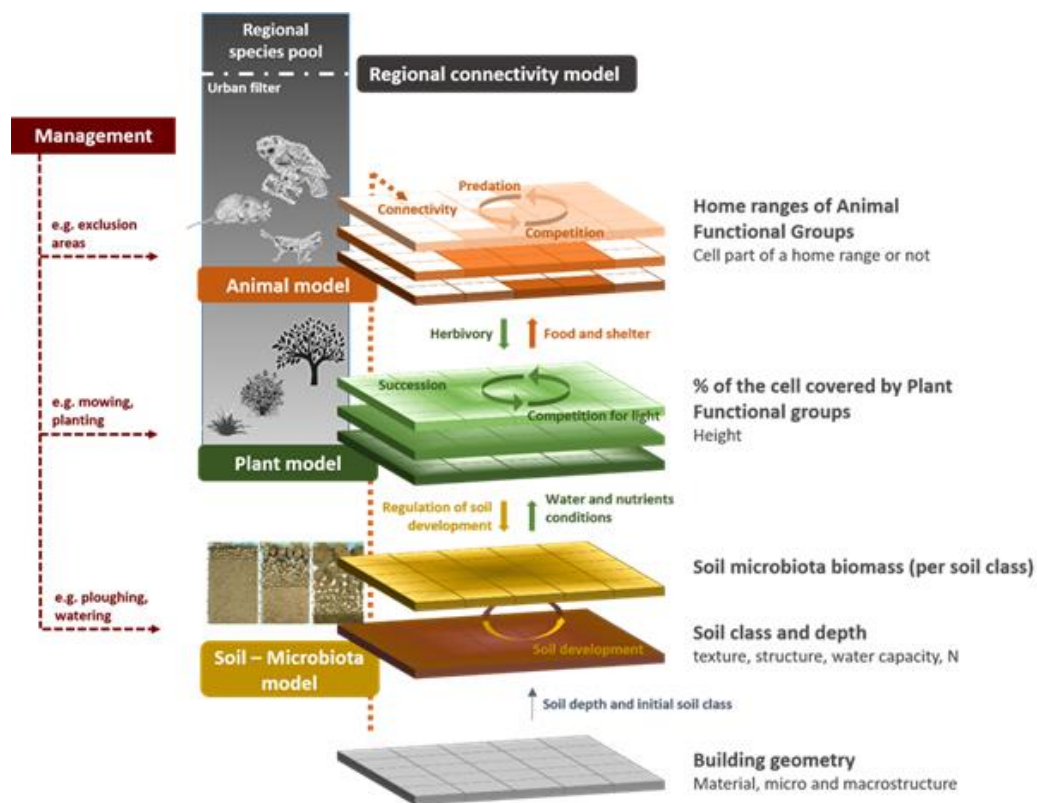


Figure 4.3.1-1: Graphical representation of the ecological model, listing major components and factors that are taken into account.

4.3.2 Progress in the ecological model development

D4.1. reported on the conceptual overview of the ecological model, anticipating a first version of the model running by mid-2022. The report introduced the functional group approach, the regional and the local scale of the model, and the three local sub-models: animals, plants, soil/microbes.

In the past year, we have successfully built a first full version of the local model, including all the processes that were planned for the first step. For the plants, this includes habitat suitability based on soil classes, dispersal, succession and competition for light, as well as disturbance by animals. For the animal model, we implemented home range formation, animal trophic networks and mortality. We further implemented a generic soil development model, a step that was originally planned for a more advanced version of the model. The ecological model now accepts a transition matrix of “soil classes” as an input, which defines the names of soils as well as the annual probability of transitioning from one soil class into another. We envision that once the model is parametrized, differences in the annual transition probabilities will implicitly account for gradual soil development due to a changing microbial community. The soil model and soil development are tightly linked to the plant habitat suitability model, so that soil classes and their change define the spatial distribution of



potential habitat for different Plant Functional Groups. The model does not yet account for feedback effects of a plant or animal community on the soil.

For the plant model, a major achievement of the past year was to reprogram the FATE-HD model (Boulangéat et al., 2014), so that it can be run in the grasshopper environment. Another major achievement was the derivation of the plant functional groups, which is described below.

For the animal model, the original model by Buchmann et al. (2011-2013) model was developed with herbivorous mammals and birds in mind. These types of animals were modelled to form home ranges on a biomass production landscape with cells of 10m x 10m size, without considering mortality or other time dependent processes. Major achievements of the second year were to a) extend the model to include omnivorous, carnivorous and other dietary mammals and birds for more realistic food webs, and b) to derive allometric equations (e.g., locomotive cost, and daily energy requirement) for these types of animals, hence giving a correctly scaled animal community, c) to implement realistic time steps into the model.

To do so, we conducted a thorough literature search for time dependent allometric equations such as life expectancy and background mortality, hence giving the model time steps. These equations have all been implemented within the model. Lastly, the biomass fraction allometric equation, i.e., the amount of biomass an individual can extract per m² from the landscape, was created by considering its relationship between locomotive cost, maximum home range size and feeding rate. We have adjusted the animal model to accept landscape cell sizes that are not 10m x 10m, and to no longer run on a plant productivity biomass landscape, but instead on a plant standing biomass landscape. Currently, the animal model has been scaled so to run upon a grassland, where it returns results that correspond to expected values one would expect from maximum home range and population density allometric equations for a generic grassland landscape; however, a workflow has been created so that extending the animal model to be able to run on other plant landscapes, e.g., woodlands or shrublands, is possible. In addition to developing the coding of the animal model, there has been extensive cleaning, debugging and restructuring of the model so that it runs faster and is more user friendly.

4.3.3 Model integration

Overall, the greatest achievement of the preceding year was the integration of the ecological sub-models into the (joint) ecological model, and the integration of the ecological model into the CAD workflow. These integration steps were a prerequisite of including the ecological model into the computational workflow, and the knowledge generation framework KGF. By implementing shading by buildings and adding soil depth to the plant habitat suitability module, the ecological model now responds to microenvironmental changes caused by architectural design, causing changes throughout the trophic network. We successfully



harmonized all data throughout and enabled an automated connection to the other grasshopper components. After a consolidation period with extensive debugging and changes to the architectures of the pre-existing models, we managed to increase speed and performance of the models to a tolerable threshold. We further implemented switches that allow us to toggle off parts of the models, allowing us to target the model run towards specific questions. These advances in the automated workflow, together with deployment of the model via a cloud service allows running the knowledge generation framework in an automated manner and start populating the knowledge base.

We are currently working towards a stable release of the models and their integration into the CAD-workflow. This includes further debugging, repairing model connections that were cut during integration (e.g., disturbance of plants by animals), and more efficient handling of errors.

4.3.4 Plant and animal functional groups and soil classification

Deliverable 4.1. reported on the need for data to parametrize the ecological model and introduced a framework to create generic functional groups.

For the development of **plant functional groups PFG**, our approach focusses on an analysis of the TRY plant trait database (Kattge et al., 2020), which ensures an unprecedented coverage of morphological, anatomical, physiological, biochemical, and phenological characteristics of plant species worldwide. From TRY we retrieved the most measured traits and applied an emergent group approach (Hérault, 2007), to let groups of species with similar values of traits emerge from the available data. These groups have to be as generic as possible, representing the majority of plant species and being potentially applicable anywhere in the world.

One axis in the PFG definitions considers the soil requirements of each functional group. To this end, the deliverable outlined a general approach in which we combine a number of data sources, such as the SoilGrids database of soil information (Hengl et al., 2017) and the Global Biodiversity Information facility (GBIF, <https://www.gbif.org/>), PREDICTS (Hudson et al., 2016), and BIEN (Maitner et al., 2018) databases of plant occurrences, to establish a soil-plant co-occurrence database and assess the soil requirements of each PFG.

In the past year, the main emphasis of our classification effort to derive functional groups was on the development of the plant functional groups (Figure 4.3.4-1). After a first, time consuming, data cleaning and categorization step, missing trait data was imputed taking into account evolutionary relationships between species. Then, plant traits were sorted into ecologically relevant dimensions and clustered for each dimension to highlight similarities and exacerbate differences between species. Successively, dimension clusters were combined to form generic Plant Functional Groups (PFGs). The set of considered traits comprised: plant life form, age of maturity, longevity, tolerance to shade and frost, specific leaf area, height, seed dry mass, dispersal and pollination syndrome, leaf nitrogen content, rooting depth, woodiness, resprouting capacity, seedbank longevity, leaf phenology type, and flower color. Functional groups were then parametrized according to specific trait values to be included into the model. Moreover, a validation step is envisaged to test the effectiveness of Functional groups to represent species communities' heterogeneity. A first version of the full PFG (including the soil dimension) will be finished by the end of April 2023. This will not only allow running the ecological model at a much larger scale (defining ca. 200 PFGs instead of 2-5



groups for testing), but it will also allow deriving correlations in the KGF that are based on actual data.

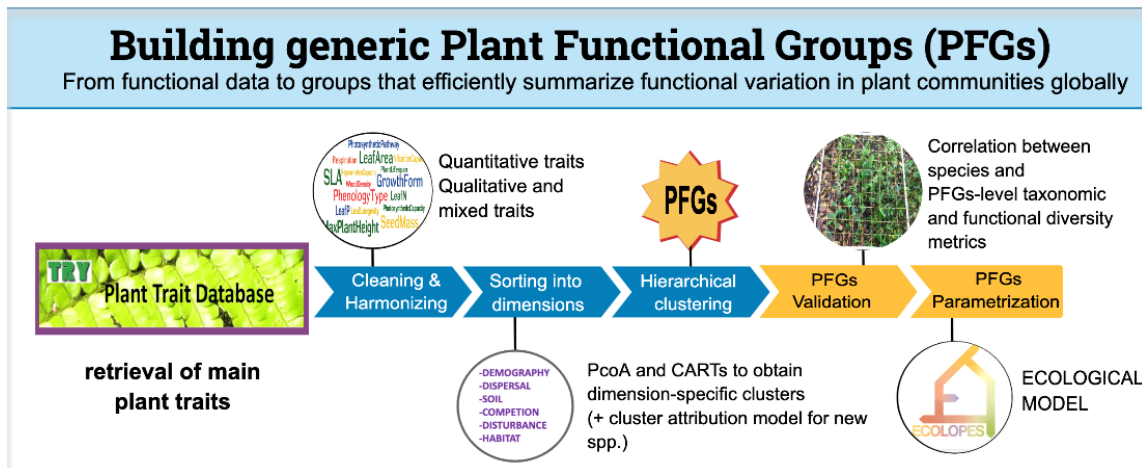


Figure 4.3.4-1: Methodology for building the generic plant functional groups.

To finish the definition of PFGs we required a definition of soil requirements and plant-soil interactions. We strived to define soils and associated microbial functional groups that are generalizable and interpretable, yet contain enough information to be biologically relevant; at the same time, the classification needed to be based on variables that can be easily quantified and are in general known or can be deduced by an architect. We chose to base the classification on soils rather than on the microbial community living inside them, assuming that soils and their microbe communities are intricately related. To this end, we based a microbial community classification on the soil variables texture, pH and “biological activity”, which is loosely associated with organic carbon content, micro- and macrostructure. These variables are easily quantified and show good correlation with microbial community composition (Cébron et al., 2021).

The SoilGrids database imputes basic soil properties at 250 m resolution, based on over 230,000 soil profile observations (Hengl et al., 2017). Using a sample of 100,000 random draws of the database, we explored the parameters space of the soil dimensions texture, pH, organic carbon content and bulk density. After cleaning, processing and analysis, we decided to define 14 soil classes based on 8 texture classes and a subdivision of textures by two pH levels where necessary. The 14 classes were further divided into 3 classes of biological activity and soil functioning, using organic carbon content and bulk density as proxies (42 classes in total).

The **soil classification** is applied in ECOLOPES in two ways: first, we implemented soil development into the soil model (see section 4.3.2), so that soil can gradually develop along the three biological activity classes within each texture/pH class. While the general soil development process can now be modelled with the ECOLOPES tools, we will require external data sources to parametrize this soil transition matrix. Secondly, the classification is used in the plant model to define habitat suitability for plants. To assess which soil classes are suitable for which PFGs, we created a soil-plant-co-occurrence database: We harmonized plant occurrence records in the GBIF, BIEN and PREDICTS databases, cleaned and filtered records, and then joined the plant database with the soil classes derived from SoilGrids. This way, we



retrieved 21,042,048 soil class- species occurrence pairs for 18,524 species. The data is being used as soil tolerance dimension in the PFG development approach mentioned above.

The development of the **animal functional groups AFGs** has also advanced over the course of this year. An extensive search for data was carried out, where we have collected from a variety of published papers (e.g., De Cuyper et al. 2019) and open-source databases (e.g., encyclopedia of life (EOL), <https://eol.org/>) with information for the traits that are important in the regional and animal models: taxonomic classification, body mass range, diet, and habitat/shelter preference. In total over 40 datasets have been collected, where each dataset has up to 50,000 entries. In our search, we did not include parasites, or animals who can only live in a water habitat (e.g., fish, but we did include amphibians). An initial cleaning of these datasets has taken place; however, these datasets still need to be joined together, perhaps by the method proposed by Kissling et al. (2018), before analyses can be taken place to create AFGs. While awaiting the final AFGs that have been built from the sourced datasets, initial mammal AFGs have been created so to be able to run the animal model. We created 11 categories of body mass to represent the main mammalian herbivore groups, with the final body mass range being between 0.001-100 kgs, as seen in Doherty et al. (2019) and Cruz & Pires (2022). Two meso- and two apex predators have also been created, with body mass ranging between 0.12-25kg. We used the predator-prey ratio, adjusted to predator gut capacity, from De Cuyper et al. (2019) to assign realistic-sized prey to each predator diet trait.

4.4 Knowledge Generation Framework

In the literature, there is little systematic information on how the architectural form affects Ecological Communities (Weisser et al. 2023). The existing knowledge linking architecture to ecology only exists in fragmented and specific ways. For instance, we might know from the literature review the needs in terms of food and shelter resources of a given bird species. Such knowledge can be used by architects to create artificial nests of the right shape and height, to attract particular bird species. However, an artificial nest may only enable an individual of this species to live on the building if a number of other conditions are met, i.e., if the environment provides the other factors necessary for the species to complete its life cycle, such as access to sufficient food resources or mates. This species-specific knowledge is not necessarily straightforward to translate at the FG level. Understanding whether an *ecolope* provides sufficient resources for particular FGs is a requirement for design. Similarly, we also need to understand how the architectural form influences biodiversity variables at a higher organizational level of the *ecolope* ecosystem, i.e., at the community level (e.g., diversity of FGs, presence of predators). Ideally, such information is provided intrinsically in the design process by means of an ontology that encapsulates the relevant relationships. However, as very little is known about the relationship between architecture and ecology, such knowledge needs to be generated. The **Knowledge Generation Framework (KGF)** was designed to address the knowledge gap. By simulating how architecture (e.g., form, building mass) drives the environmental conditions on the *ecolope* (e.g., shading, soil depth, in the future water runoff), and hereby the ecology (e.g., identity and abundance of FGs), novel correlations between different parameters can be generated. Besides asking questions such as how architectural form promotes biodiversity, biomass, and ecological performance in our cities, a



variety of questions concerning the effect of architecture on ecology are and will be addressed by the KGF, for instance:

- What are the FGs suitable for the chosen building and what is the suggested initial distribution of the FGs on the building surfaces?
- How strong is the influence of shade vs. soil type and depth on the distribution of plants on the building?
- How does heterogeneity in soil type or soil depth affect plant community development?

In the second year, we addressed a number of obstacles to obtain a KGF that is now running in the cloud. The ECOLOPES Grasshopper plugin puts the KGF into practice to generate information to be stored in the Knowledge base (KB) (see section 4.2.3). This implies that main challenges such as interoperability between 2D raster and 3D geometry data were overcome, algorithms for environmental analysis were developed, and the ecological model was integrated as a key component within a 3D CAD system (Figure 4.4-1). Furthermore, debugging and code cleaning drastically enhanced the technical performance of the KGF. Consequently, experiments for knowledge generation using changing geometry inputs can be initiated from the beginning of the 3rd year.

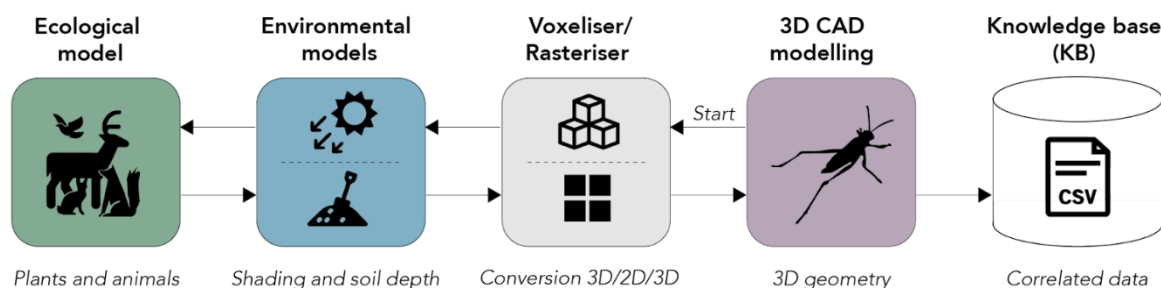


Figure 4.4-1: The Knowledge generation framework (TUM, SAAD, McNeel, TECHNION).

In our test runs, we generated datasets and statistically analysed the information to extract relevant relationships between architecture and ecology for the design process. An example of those relationships is how the form of a building or building mass increases biodiversity (= total number of FGs), or how the inclination of a building envelope fosters biomass. These simple examples show that the KGF runs and produces outputs coherent with general ecological knowledge. In our findings, eco-architectural correlations could answer more precisely how the inclination of a building envelope and abundance of plants are related or how building mass influences the abundance of FGs on the ECOLOPES plot (Figure 4.4-2).

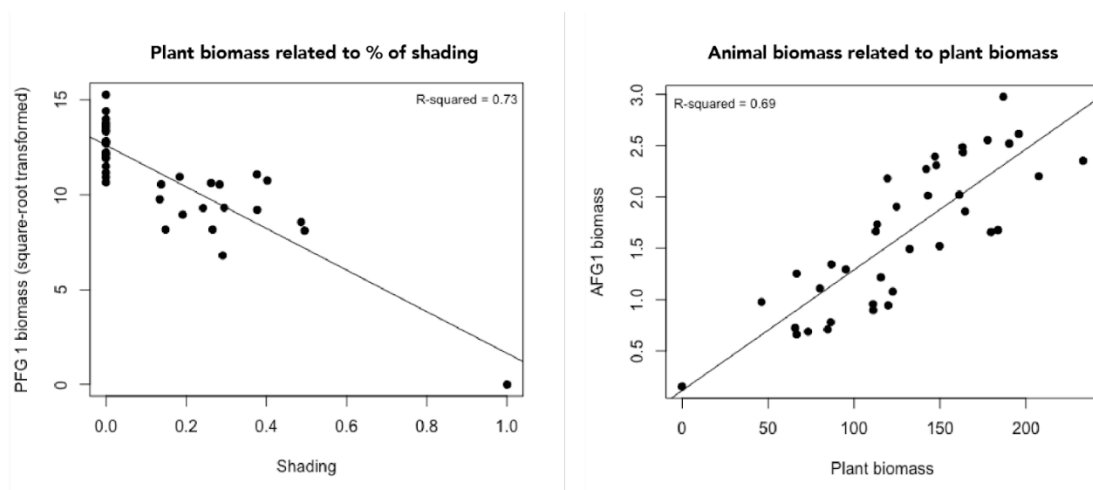


Figure 4.4-2: First KGF results from test simulations. The left panel correlates shading values of each pixel cell (percent of the pixel area that is shaded) with plant biomass values as outputted by the ecological model (summed over all plant functional groups living on a pixel cell). The right panel shows the results of the animal model (also summed over all animal functional groups) that based the resources for animals on the existing PFG distribution. Plant biomass is in this draft version of the model an unparametrized and dimensionless value that was scaled to achieve reasonable resource landscapes for the animal model.

Our example demonstrates that the KGF can be used to generate knowledge that is essential for designing building envelopes, also for design decision support. It also serves as an open-ended accumulative knowledge generator for the ECOLOPES project.

In the future, the KGF can help to answer important scientific questions, such as

- How does the geometry of the building enhance/reduce the number of shaded areas for the building envelope, i.e. what is the surface temperature on the envelope and where are shaded areas located and for how long are they shaded?
- How much soil can be maintained by a specific building form? Will the geometry of the building impact soil erosion to accumulate in other places? Once eroded, can soil be replaced by other biotic or abiotic materials?
- Does the geometry of the building allow for walking animals to access its envelope?
- Does the geometry of the building support water to be stored/retained in the soil in some areas? How much water is required for an envelope to become an *ecolope*? What is the minimum amount of humidity in each area of the *ecolope*?
- Will soil placed on the building stay at its place, or will the soil erode and accumulate in other places?

Our interim KB is a non-deterministic database, as the constantly generated data is stored each time a new geometry input is analysed (Table 4.4-1). Thus, the KB is the result of the KGF but also a key element for further knowledge extraction during future design generation and optimization processes.



Table 4.4-1: The interim KB and the data stored for the first computed typology (cylinder, see highlighted field). Columns 1-6 indicate architectural data, columns 7-9 environmental, and columns 10-21 ecological data.

TAG	GEOMASS	X	Y	Z	SRFRUGH	SRFINCL	SRFAREA	SHADING	SOILDEPTH	p1_t5	p2_t5	p1_t15	p2_t15	p1_t50	p2_t50	a1_t5	a2_t5	a1_t15	a2_t15	a1_t50	a2_t50
site	0	0	0	0	0	90	1	0.000611999999999946		0	0	0	0	0	0	0	0	0	0	0	0
site	0	0	1	0	0	90	1	0.000611999999999946		0	0	0	0	0	0	0	0	0	0	0	0
site	0	21	19	0	0	90	1	0.035532		0	0	0	0	0	0	0	0	0	0	0	0
site	0	21	20	0	0	90	1	0.035532		0	0	0	0	0	0	0	0	0	0	0	0
site	0	21	21	0	0	90	1	0.049495		0	0	0	0	0	0	0	0	0	0	0	0
site	0	21	22	0	0	90	1	0.0687990000000001		0	0	0	0	0	0	0.00611218	0	0	0	0	0
site	0	21	23	0	0	90	1	0.091843		0	0	0	0	0	0	0.0134433	4.34874	0	0	0.0201272	0
site	0	21	24	0	0	90	1	0.146716		0	0	0	0	0	0	0.0514568	13.1566	0	0	0.0366927	0
site	0	21	25	0	0	90	1	0.220042		0	0	0	0	0	0	0.0827715	17.6882	0	4.36218	0.0876002	4.29764
site	0	21	26	0	0	90	1	0.243374		0	0	0	0	0	0	0.190147	22.0155	0.0252896	8.68021	0.154654	4.29764
site	0	21	27	0	0	90	1	0.31724		0	0	0	0	0	0	0.0885395	17.512	0.013458	8.75154	0.0929221	4.29764
site	0	21	28	0	0	90	1	0.301589		0	0	0	0	0	0	0.0693698	17.512	0.013458	0	0.0645769	0
site	0	21	29	0	0	90	1	0.296883		0	0	0	0	0	0	0.0311078	8.88038	0	0	0.0439285	0
site	0	21	30	0	0	90	1	0.29069		0	0	0	0	0	0	0.013585	0	0	0	0	0
site	0	21	31	0	0	90	1	0.226425		0	0	0	0	0	0	0.013585	0	0	0	0	0
site	0	21	32	0	0	90	1	0.166146		0	0	0	0	0	0	0.013585	0	0	0	0	0
site	0	21	33	0	0	90	1	0.166146		0	0	0	0	0	0	0	0	0	0	0	0
site	0	22	21	0	0	90	1	0.066728		0	0	0	0	0	0	0.00733108	0	0	0	0	0
site	0	22	22	0	0	90	1	0.074926		0	0	0	0	0	0	0.018821	0	0	0	0.0201272	0
site	0	22	23	0	0	90	1	0.129792		0	0	0	0	0	0	0.0613798	13.1566	0	4.36218	0.0447997	0
cylim	224.137142	23	23	8	0	0	0	1		0	0	0	0	0	0	0.176597	26.356	0.0053306	13.0696	0.184093	8.65973
cylim	224.137142	24	23	8	0	59.878638	0.2301	0.18348	6.324191	71.85	0.9	119.8	4.5	119.8	4.5	0.744806	30.7617	0.549936	26.0658	0.944131	8.65973
cylim	224.137142	25	23	8	0	44.955972	0.227714	0.13373	6.814985	57.1	0.9	95.2	4.5	95.2	4.5	0.921947	30.6577	0.877887	26.0658	1.29363	12.9622
cylim	224.137142	26	23	8	0	59.878638	0.2301	0.191194	6.324191	48.05	0.9	80.1	4.5	80.1	4.5	0.71672	30.6746	0.713314	26.0658	1.10917	8.65973
cylim	224.137142	27	23	8	0	0	0	1		0	0	0	0	0	0	0.16326	17.512	0.0190449	17.3763	0.172431	8.65973
site	0	22	29	0	0	90	1	0.423792		0	0	0	0	0	0	0.0751883	13.2076	0	8.75154	0.0645769	0
site	0	22	30	0	0	90	1	0.322082		0	0	0	0	0	0	0.0311078	8.88038	0	4.38936	0.0492768	0
site	0	22	31	0	0	90	1	0.306873		0	0	0	0	0	0	0.013585	0	0	0	0	0
site	0	22	32	0	0	90	1	0.199522		0	0	0	0	0	0	0.013585	0	0	0	0	0
site	0	22	33	0	0	90	1	0.193355		0	0	0	0	0	0	0.00747286	0	0	0	0	0

In summary, the KGF is unique and a major achievement, because it represents the first systematic modelling approach to analyse the relationship between architecture and ecology. It has now been developed to the point that it can be run in the cloud, and we expect major insights into how architecture affects ecological communities. The KGF will also allow us to derive general relationships that can be used in a systematic design process. This will be valuable well beyond the ECOLOPES project. However, the developed system and its results need to be validated through real-world data and experiments.

4.5 Ecological and architectural objectives and key performance indicators

4.5.1 Background

This section sets out the *methodology* for developing the ecological and architectural objectives and key performance indicators (KPI). One of the main aims of the ECOLOPES project is to make biological knowledge available for the architectural design process, and to find architectural solutions that enable synergies, and limit conflicts, between the different building stakeholders: **humans, plants, animals, and microbiota**. This process essentially involves the development of a design approach based on a wide range of expert knowledge on *architectural and ecological principles / objectives*. However, contrary to the **architectural objectives**, i.e., *enhancing thermal comfort (indoors / outdoors), advancing energy efficiency,*



improving air quality, advancing material properties, promoting green infrastructure, and more, the setting of **ecological objectives**, alongside the architectural ones, is not a common practice. Conventional architecture is mainly anthropocentric, and there is no connection between ecological knowledge and the applicability of green infrastructure on buildings, and their surroundings.

The introduction of ecological knowledge into architectural design process poses several challenges. During the second year we started developing the ECOLOPES **framework** that defines ecological and architectural objectives, and the key performance indicators (KPIs) that derive from them. Answering the following questions helps promote the exchange of expert knowledge between the different disciplines, as well as the collection of data that will be used for defining thresholds:

- What are the **architectural and ecological Key Performance Indicators (KPI)** that will be employed by the KGF in the initial form generation process and later in the optimization process? Under which **objectives** do these operate?
- What are the **methods and tools** required to evaluate the Key Performance Indicators?

The definition of objectives and KPIs will be employed in the KGF (Knowledge Generation Framework) to build knowledge on the response of the KPIs to the initial architectural form, that will later contribute to the generation of an initial envelope form that integrates the recommendation of the KGF with the architectural demands. It will also be used in the optimization process to establish quantitative objectives and evaluate design performance (described in the next section).

4.5.2 Definition of Objectives and KPIs

The objectives are chosen at the stage of the design brief. Objectives are defined for each stakeholder (humans, plants, animals, and microbiota), and aim to reflect the interest of the stakeholder and fix targets for this stakeholder on the *ecolope*. For instance, human objectives can relate to human comfort, while animal objectives could be expressed as the presence of given animal functional groups on the ECOLOPES. Objectives can have a purely architectural character, i.e., *achieve minimal heating-cooling loads*, while also may support both architectural and ecological characteristics, such as, *'maximise area for plant colonization'*. Objectives are described by the KPIs and represented using Goals. KPIs are defined as directional attributes that help improve a decision-making problem, while Goals are target levels expressed in a specific state in space and time. To bridge different objectives, we have developed a method for nested sets of KPIs and objectives - see (Figure 4.5.2-1) (Selvan et al., 2023b). Nested sets provide systematic linking subsets in a hierarchical structure like Matryoshka dolls. Nested sets are often employed to handle large amounts of datasets that require hierarchical relationships (Gyorodi et al., 2016). This allows for higher-level objectives to be deconstructed into lower-level objectives which can be quantified by KPIs.



The framework is flexible enough to replace lower-level objectives and their correlated KPIs with higher-level objectives when more knowledge becomes available.

The evaluation of the interconnections and trade-offs of the selected choices of the KPIs denotes the quality of the **site-specific multi-species envelope prototypes**. Inherent challenges towards the multi-species envelope include the questions of how to evaluate and integrate data from the different disciplines in a meaningful way, and how can the proposed data-driven design process and simulation results can encapsulate the various sub-systems and their interactions in the best possible way.

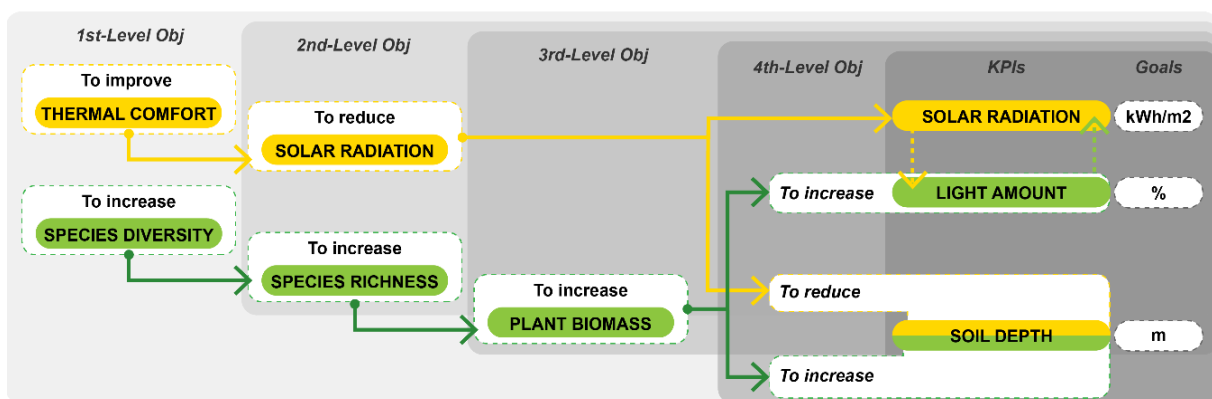


Figure 4.5.2-1: Nested hierarchy scheme using an architectural and ecological objective (Obj), optimization direction, light and soil Key Performance Indicators (KPIs), and Goals.

4.5.3 Defining ecological and architectural KPIs

During the past year we have started developing the method for selecting and evaluating ecological and architectural objectives and KPIs. This challenge comprises a phase of developing an individual set of objectives and KPIs for each discipline (architecture and ecology) and a phase of examining the interconnections and trade-offs between the objective and KPIs of both disciplines.

There are four main steps where objectives and KPIs are used in the ECOLOPES design and computational workflows. In the design workflow, the first step is when the design brief is translated into practical objectives, and in KPIs for the ECOLOPES design alternatives. The second step is when the design team evaluates the performance of the different ECOLOPES designs using KPIs. The third step is within the computational workflow, when the KGF creates knowledge about the relationships between architectural form and ecology, the KPIs being one of the outputs. The fourth is when the objective and KPIs are used to optimize the generated *ecolope design alternatives*.

In year two we have defined the architectural KPI's and the existing methods and tools for its evaluation. This work will be finished in April and presented in the coming consortium meeting for discussion and approval.



The group of ecologists has initiated a process for defining the ecological objectives and KPIs. The results of this process are expected during the first half of the coming year. The group has identified a number of statements that draw a first structure of the ecological part of the objectives and KPIs framework. These statements shall be seen as objectives that need to be achieved. The ecological part of the objectives and KPIs framework should respect the following statements:

- **It should be based on an existing normative description** of the biodiversity already in use in city management or other ecological/management contexts (e.g., biodiversity monitoring, policies, restoration, conservation). We aim the ECOLOPES description of the biodiversity to be based on one or several existing and validated biodiversity management/monitoring frameworks to ensure method robustness and possible comparison and easy integration to urban biodiversity planning and management programs.
- **It should be designed from (a list of) fixed ecological objectives and KPIs:** the framework might propose a list of potential objectives from which the user can choose the one(s) they wish to apply to their ECOLOPES project.
- **It should only use ecological objectives and KPIs that can be easily assessed from the environmental and ecological models' outputs.** The direction and/or goal of the chosen KPIs should be easy to define based on the identified objectives
- **Each stakeholder (microbiota, plants, and animals) should have its own objectives and KPIs.** Some KPIs might, however, contribute to the objectives of different stakeholders.
- **It should be based on a low number of objectives per stakeholder and a low number of KPIs per objective:** the multi-criteria optimization process has limited capabilities, and the ecological KPIs are not the only ones that need to be optimized; the number of KPIs should therefore be as small as possible.
- **It should be based on simple 1st order objectives,** easily understandable to the (non-expert) ECOLOPES user: the user will ultimately be the one defining the ecological objectives for their project; therefore, it is important that they can easily grasp the ins and outs of the objectives they define.
- **It should make use of the environmental conditions** simulated by the environmental models as 2nd order KPIs that can help to target the range of conditions to be explored by the ecological models (1st order KPIs) and hereby lower the computation time.

4.6 Optimization and Decision-making processes

4.6.1 Introduction

This section describes the proposed hybrid multi-criteria decision-making (MCDM) methodology to employ multi-objective optimization (MOO) and multi-attribute decision-making (MADM) for the ECOLOPES design approach. The proposed methodology that was developed in year 2 is a component of the design generation and simulation-based



optimization container within the ECOLOPES computational workflow as described in Section 3.3 of D3.2 (Fig. 4.6.1-1). The primary objective of this process is to generate optimized design alternatives informed by ECOLOPES key performance indicators and ranking the alternatives based on varied performance priorities.

First, an overview of MOO and MADM is presented and the proposed sequence of the two strategies is discussed. Then, the schematic flowchart of the proposed methodology is detailed and discussed. The developed method is comprised of six steps that encompass the ECOLOPES design approach for design and knowledge generation, design optimization and simulation, design ranking, and validation.

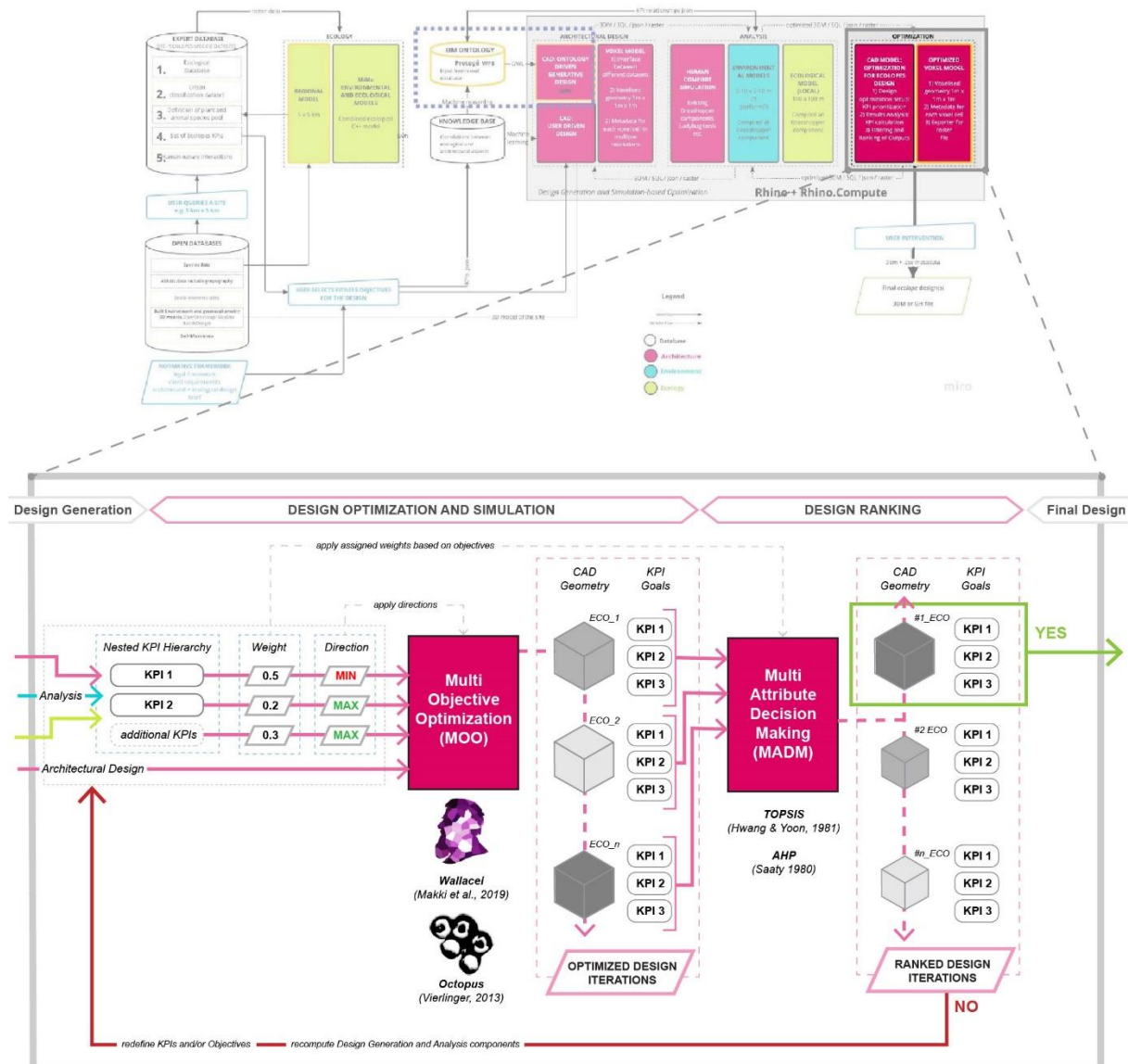


Figure 4.6.1-1: Schematic flowchart of the proposed hybrid multi-criteria decision-making (MCDM) methodology integrated with the nested hierarchical KPI strategy.



4.6.2 Proposed Hybrid Multi-criteria Decision-making Methodology

In the second year, efforts were focused on operationalizing the proposed hybrid multi-criteria decision-making (MCDM) methodology described in section 8.2.1 of the Year 1 deliverable (D1.3). The systematic literature review that provided the conceptual and theoretical framework for the methodology was completed and published (Selvan et al., 2023a). The publication enabled us to highlight existing gaps and identify opportunities in current decision-making applications within the architectural and ecological domains. The publications also allowed us to identify two MCDM strategies: multi-objective decision-making (MODM) and multi-attribute decision-making (MADM). These strategies were also detailed in the Year 1 deliverable (D1.3) in Section 8.2.1. Generally, MODM is employed when alternatives are required to be generated while MADM is employed to evaluate existing alternatives based on selected criteria. In the ECOLOPES design approach, MODM facilitates the generation of optimized building envelope alternatives based on key performances while MADM aids in the evaluation of these alternatives based on varied performance priorities. In Year 2, developments were also made to establish potential links between the KB and the hybrid MCDM methodology. Initial tests were also conducted to test the interoperability of the proposed methodology which can be described in the following steps: -

Step 1: Definition of the Design Brief and Generating an Early-stage Design Iteration

Based on the ECOLOPES design workflow described in Section 4.1, the design brief will be defined based on normative constraints such as legal frameworks and client requirements. Additionally, the architectural and ecological objectives are also defined to evaluate the performance of the resulting *ecolope*. In this step, an early-stage design of an *ecolope*, characterized by the objectives, will be generated. This initial form will provide a “blank canvas” for the optimization and decision-making process to occur.

Step 2: Correlating Architectural and Ecological Data

Once the initial form is generated, architectural form and ecological analyses are correlated in the KGF (see 4.4, D3.2). The KGF will eventually generate a generalized database of statistical correlations between geometrical parameters (e.g., surface inclination, building mass) and ecological analyses (e.g., abundance of FGs) and stores that information in the KB.

Step 3: Querying Correlated Knowledge for Optimization

The data available in the KB facilitates the ranking process by reducing the design search space from the optimization process. More importantly, the correlations that occur in the KGF are informed by the nested set strategy discussed in Section 4.5.2 which deconstructs objectives into explicit key performance indicators (KPIs). These selected KPIs will be used as input for the optimization process and therefore, they must be computed or queried in Rhino/Grasshopper. With reference to the ECOLOPES computational workflow, currently, the



computation of some of these KPI values (e.g., shading and soil depth) is conducted with the ECOLOPES plugin. However, the most important step is to define KPI values, dimensions and KPI ranges for a meaningful design-decision support strategy for example, through the KB, architectural or ecological thresholds could be defined to limit the design search space during the optimization process. This would filter out alternatives that are not relevant to the decision-making problem defined in the design brief. Additionally, the correlations available in the KB, potentially represented in box plots, will provide a better understanding of the degree of influence architectural parameters have on the selected KPIs. This will enhance the optimization process by selecting fitness objectives and genes that are specific to the design brief.

Step 4: Generating Optimized Design Iterations

Once the correlated KPIs of the initial form have been computed, the optimization process can be conducted. Based on the systematic literature review conducted in Year 1 (Selvan et al., 2023a), multi-objective optimization (MOO) was identified as the appropriate MODM strategy for the ECOLOPES design approach. Two MOO algorithms were selected based on applicability which was NSGA-II and SPEA-II. These algorithms exist as validated evolutionary solver plugins in the Grasshopper platform which are Wallacei and Octopus, respectively. Commonly, to employ MOO algorithms, two main inputs are required: fitness objectives and genes. Fitness objectives are the performances to be optimized for a given design while genes are the geometrical attributes that influence the performances.

In the ECOLOPES design approach, the fitness objectives are represented by the KPIs from the nested sets strategy as seen in Fig. 4.6.1-1. The optimization direction (e.g., to maximize or to minimize) for each KPI will be based on the pre-established architectural and ecological objectives. The genes are selected geometrical parameters, computed in the KGF, that have a significant influence on the performance of the KPI values (i.e., Goals). The output of MOO is a range of equally well-performing *ecolope* alternatives that are characterized by optimized KPI Goals.

An initial experiment using a generic building envelope design was conducted with the Grasshopper plugin Wallacei for MOO (Makki et al., 2019). In the experiment, two objectives were optimized based on a common KPI with conflicting optimization directions. Wallacei produced a set of 113 Pareto solutions in which the KPIs cannot be further optimized without compromising another. Additionally, the plugin provides optimization analytics which aids in the identification of synergies and trade-offs between objectives and their correlated KPIs (Fig. 4.6.1-2). Future developments will include testing the optimization using resulting analyses from the KGF and employing thresholds derived from the Knowledge Database.

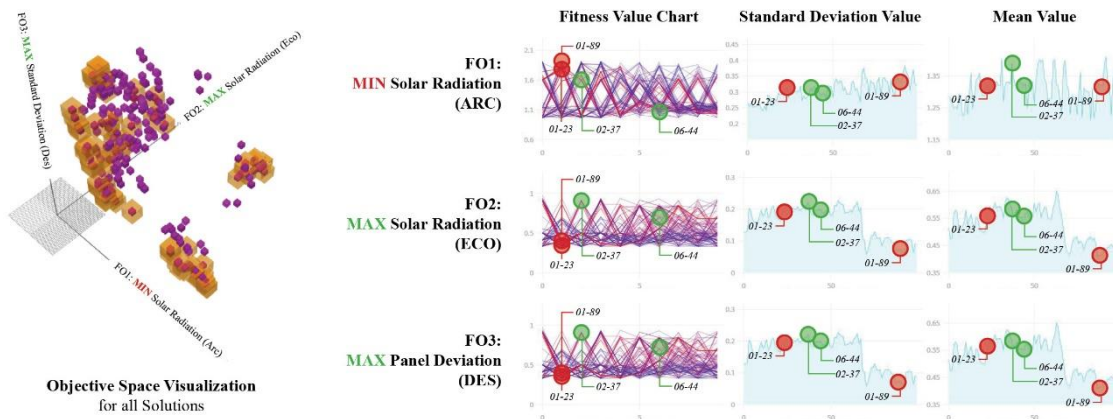


Figure 4.6.2-2: Wallacei Analytics visualization of the objective space and optimization performances for varied KPIs (i.e., Solar Radiation and Panel Deviation) (Selvan et al., 2023b)

Step 5: Ranking Optimized Design Iterations

The design ranking process utilizes the optimized design alternatives generated from the MOO process. As in Step 4, through the systematic literature review conducted in Year 1 (Selvan et al., 2023a), two MADM algorithms were selected based on their frequency of application: TOPSIS and AHP. Unlike the MOO algorithms, these do not exist as plugins in the Grasshopper platform. Therefore, they were constructed using native Grasshopper components based on their respective mathematical formulae (Jagoda et al., 2020; Matthew, 2018). Results of the Grasshopper-based MADM algorithms were cross-checked with the results from their original sources to validate the components. To employ MADM, there are also two main inputs: attribute values and weights. Attribute values are the quantified performances of an alternative while weights establish attribute priorities.

In the ECOLOPES design approach, the attribute values are represented by the optimized KPI Goals while the weights can be derived from priorities established in the nested sets strategy described in Section 4.5.2. The output of MADM is a ranked list of *ecolope* alternatives that is computed based on the objective priority defined in the design brief as illustrated in Fig. 4.6.1-1.

An initial experiment was also conducted that employed TOPSIS to conduct MADM (Selvan et al., 2023b). The experiment used the Pareto front solutions generated from the Wallacei plugin as alternatives characterized by an architectural, ecological, and design objective. Two scenarios were defined to prioritize the architectural and ecological objective, respectively. Through TOPSIS, performance scores for the Pareto front solutions were computed to produce a ranked list of alternatives. Through this list, the highest and lowest-performing alternatives were identified based on the two priority scenarios (Fig. 4.6.1-3). Future developments for the MADM process include validating the results of the selected algorithms using external decision-making platforms with similar algorithms.

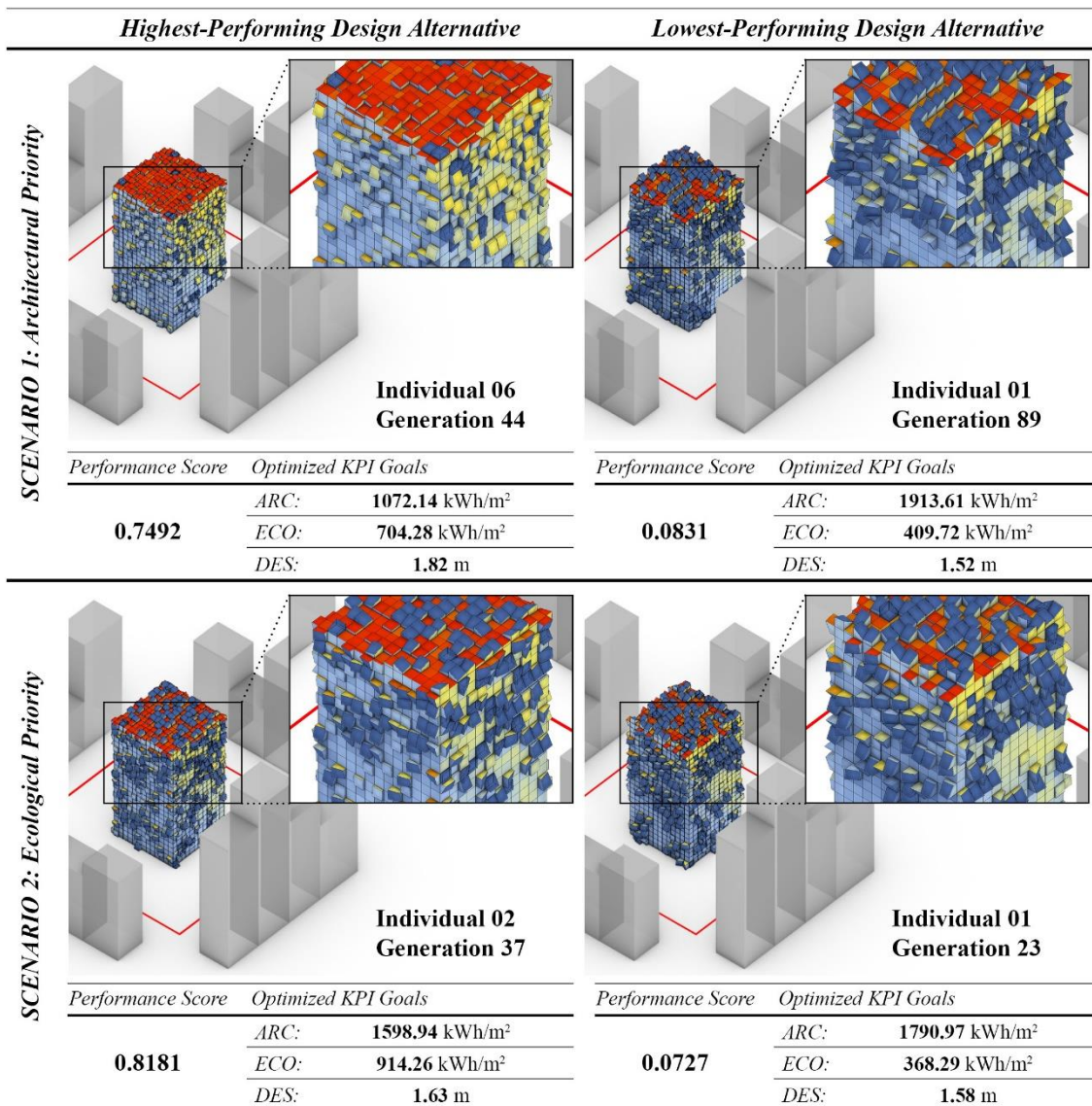


Figure 4.6.2-3: Comparison between the TOPSIS results for the optimized design alternatives based on varied architectural and ecological priority (Selvan et al., 2023b)

Step 6: Validating the Simulation and Design Results

While this step is still in development, the highest and lowest-performing alternatives from each design iteration can potentially be used to validate the computational workflow and the effectiveness of the design alternatives in varied design cases (Work Package 7).



4.7 Ontology-aided Generative Computational Design Process

4.7.1 Introduction

The ontology-aided generative computational design process serves the purpose of generating an informed variety of design outputs, from which one or several can be selected for optimization in the following stage of developing an *ecolope* design. The main inputs for the ontology-aided generative computational design process are the EIM Ontology, expert databases, and ecological models, knowledge generation framework, 3D models of the existing built environment and topography from open databases, normative framework, and design brief.

To ensure practice relevance the ontology-aided generative computational design process is developed to support two distinct standard design cases that include (1) generation of master-plans for given sites (design case 1), and (2) generation of individual building designs (design case 2). The design process for both cases is divided into two distinct stages: (1) the translational process in preparation of (2) the generative process that produces different designs. The ontology-aided generative computational design framework consists of three key components: (1) the EIM ontology that has a key role in informing the two processes, (2) a voxel model that integrates relevant datasets for design, and (3) the CAD environment in which the generative process is executed (see Report D5.1). The CAD part takes place within the Rhino and Rhino.Compute framework implemented by McNeel.

We commenced by addressing *what* is being modeled and *why*, thereby clarifying the subject matter of the design process for ecological building envelopes. In this context we redefined urban form as *urban landform* (see Report D5.1). This entails continuous terrain characterized by geodiversity that can support biodiversity (Tukiainen et al. 2023) and the provision of ecosystem services (Alahuhta et al. 2018). In this context we understand buildings as instances of *landform* (similar to *landform buildings* as proposed by Allen and McQuade 2011) that are in our definition characterized by variegated landform and scalable landform instances on site, building and part of building scales. Based on this approach, cities can change incrementally, building by building, such that over time larger scale ecological goals that extend beyond the scale of an individual site can be achieved and goals can be adapted and reflected in individual designs in response to changing conditions such as climate change, changing urban ecosystems etc.

Subsequently the different computational components of the ontology-aided generative computational design process were defined and analyzed in terms of the different implied relations and interactions and in terms of required interfaces for the designer that will be implemented in the Rhino Grasshopper environment.

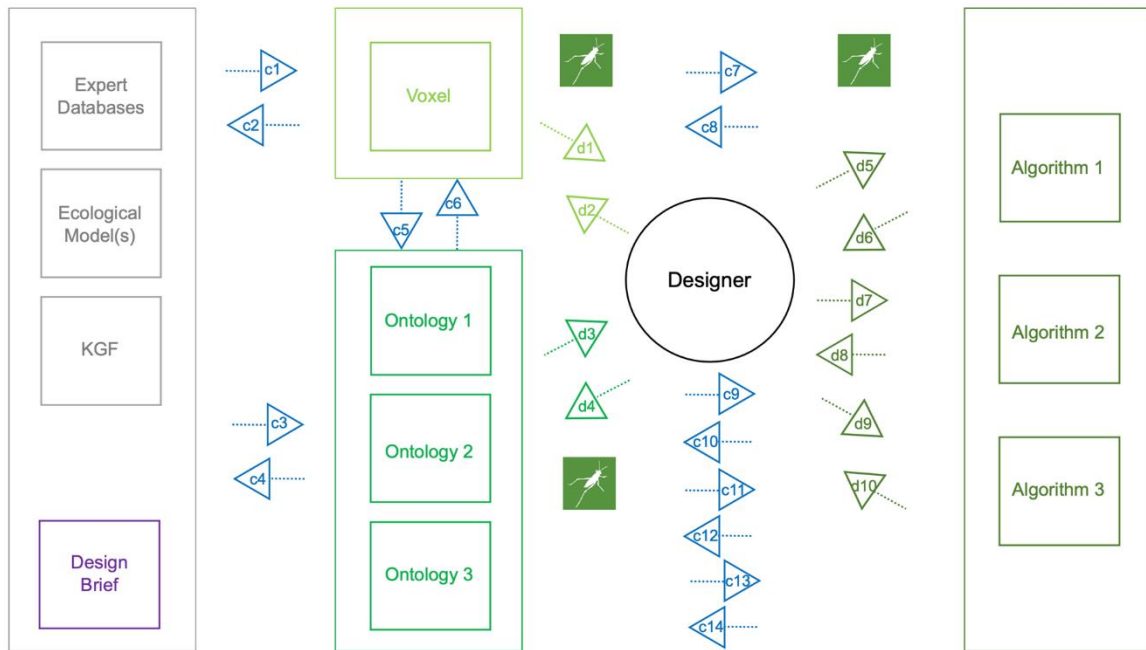


Fig. 4.7.1-1: Diagram showing data sources (left), voxel (center top), ontologies (center bottom), and algorithms for design generation (right), and their direct interactions (arrows marked by the letter c and a number), as well as designer interaction with the components (arrows marked by the letter d and a number).

Voxel	from	to	Designer interface	Ontologies	from	to	Designer interface	Algorithms	from	to	Designer interface
c1	Datasources	Voxel	n/a	c3	Datasources	Ontologies	n/a	c7	Voxel	Algorithms	n/a
c2	Voxel	Datasources	n/a	c4	Ontologies	Datasources	n/a	c8	Algorithms	Voxel	n/a
c5	Voxel	Ontologies	n/a	c5	Voxel	Ontologies	n/a	c9	Ontology 1	Algorithms	n/a
c6	Ontologies	Voxel	n/a	c6	Ontologies	Voxel	n/a	c10	Algorithms	Ontology 1	n/a
c7	Voxel	Algorithms	n/a	c9	Ontology 1	Algorithms	n/a	c11	Ontology 2	Algorithms	n/a
c8	Algorithms	Voxel	n/a	c10	Algorithms	Ontology 1	n/a	c12	Algorithms	Ontology 2	n/a
d1	Voxel	Designer	🐛	c11	Ontology 2	Algorithms	n/a	c13	Ontology 3	Algorithms	n/a
d2	Designer	Voxel	🐛	c12	Algorithms	Ontology 2	n/a	c14	Algorithms	Ontology 3	n/a
				c13	Ontology 3	Algorithms	n/a	d5	Designer	Algorithm 1	🐛
				c14	Algorithms	Ontology 3	n/a	d6	Algorithm 1	Designer	🐛
				d3	Ontology	Designer	🐛	d7	Designer	Algorithm 2	tbc
				d4	Designer	Ontology	🐛	d8	Algorithm 2	Designer	tbc
								d9	Designer	Algorithm 3	tbc
								d10	Algorithm 3	Designer	tbc

Table 4.7.1-2: Table listing all relevant interactions between voxel, ontologies, algorithms and designer, indicating which interactions require interfaces for the designer.

4.7.2 The Design Cases

Our approach addresses two distinct design cases that frequently occur in architectural practice with the aim to enable a practice-oriented approach in developing an ontology-aided generative computational design process (see Report D5.1). Case 1 entails the design of master-plans for the development of given sites. This concerns (1) spatial organization via the



distribution of *primary volumes* (architectural, green, soil), and (2) articulation of urban landform by linking landscape geometry with volumes (*primary landform*). In this way *landform* can be coherently designed across entire sites, with all volumes adhering to the landform scheme such as to promote connectivity of green spaces and extend territories and home ranges for animal species. Case 2 concerns the design of an individual building for which all constraints (footprint, floor area ratio, maximum volume and height, etc.) are given by an already existing masterplan. This entails that *primary volumes* are given that require further spatial organization to articulate and facilitate both the building and its ecological building envelope. Primary volumes are partitioned into *secondary* and *tertiary volumes* (architectural, green, soil). In order to enable different species to inhabit the envelope it is necessary to further derive the specific building geometry that can be articulated as *secondary* and *tertiary landform* to provide accessibility for different species to selected parts of the building envelope.

4.7.3 Two Stage Ontology-aided Computational Generative Design Process

The ontology-aided generative computational design process consists of two parts. Part one is the *translational* process in which requirements of the design brief for a given project and additional requirements are analyzed, correlated, spatialized and prepared for design generation. The *translational* process utilizes the datasets *maps* and *networks* that are described below (see Report D5.1). Part two is the *generative* process in which different versions of volume distribution and landform articulation are generated, analyzed and ranked. This process leads to design outputs that can be optimized in subsequent steps. The *generative* process utilizes the datasets *volumes* and *landform* (see Report D5.1) that are further described below.

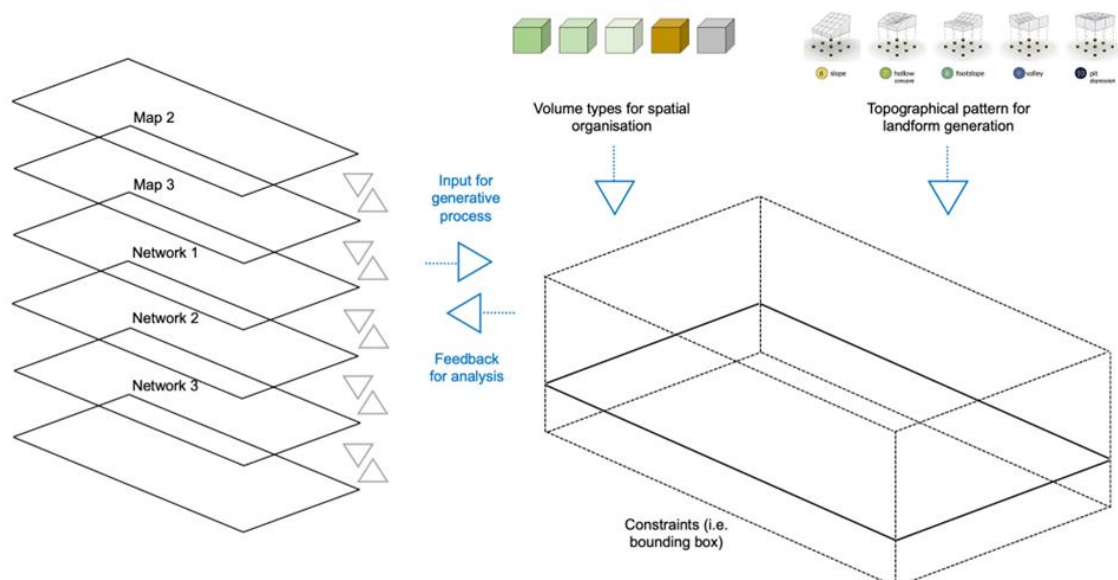


Fig. 4.7.3-1: Schematic representation the datasets *maps* and *networks* of the *translational* process (left) and the datasets *volumes* and *landform* of the *generative* process (right), indicating also the constraints for the generative process.



4.7.4 The Role of the EIM Ontology in the Generative Computational Design Process

An ontology is a formal representation of a set of concepts within or across domains as well as the relationships between these concepts (Staab & Studer, 2009). It provides a common vocabulary and a structured way of representing knowledge. Ontologies play a key role in organizing and categorizing information, enabling knowledge sharing and reuse, and facilitating automated reasoning and inference. By defining the concepts, relationships, and rules in a domain, ontologies serve as a foundation for the development of knowledge-based systems and enable interoperability between different systems and domains. Additionally, ontologies support semantic search, machine learning, and data integration by providing a common understanding of the meaning of the data.

In our work the ECOLOPES Information Model (EIM) ontology will aid the computational generative design process. It can be queried at different stages by the designer and facilitate representing and reasoning over knowledge graphs. The ontology can receive data from five main sources: (1) ecological models, (2) output from the knowledge generation framework, (3) GIS data, (4) CAD data, and (5) specifications from the design brief. The software Protégé is used to build the ontology. It is intended that the ontology will be to some degree open source to enable its development past the project time. The EIM Ontology will consist of three (OWL) ontologies, each of which is being built according to their specific role in the computational generative design process. EIM Ontology 1 aids the configuration of networks in a voxelized 3D space in the CAD environment, and accordingly defines and spatially locates design objectives and instructions inferred from the ontology. EIM Ontology 2 will guide changes in maps and spatial distribution of volumes in a voxelized 3D space in the CAD environment according to specific networks, objectives and instructions generated in step 1. EIM Ontology 3 will aid the generation of landform geometry in a voxelized 3D space in the CAD environment according to the networks, objectives, maps and volumes defined in steps 1 and 2. The three ontologies, relevant sources of data and information for each ontology, related design algorithms and envisioned interfaces with CAD, as well as the specific tasks of each purpose-built ontology and corresponding competency questions among other topics are discussed below.

4.7.5 Stage 1: The Translational Process

In the *translational* process requirements of the design brief for a given project and site and additional requirements are analyzed, correlated, spatialized and prepared for design generation. This involves the preparation and correlation of the datasets *maps* and *networks* as the two key datasets of the *translational* process (see Report D5.1).

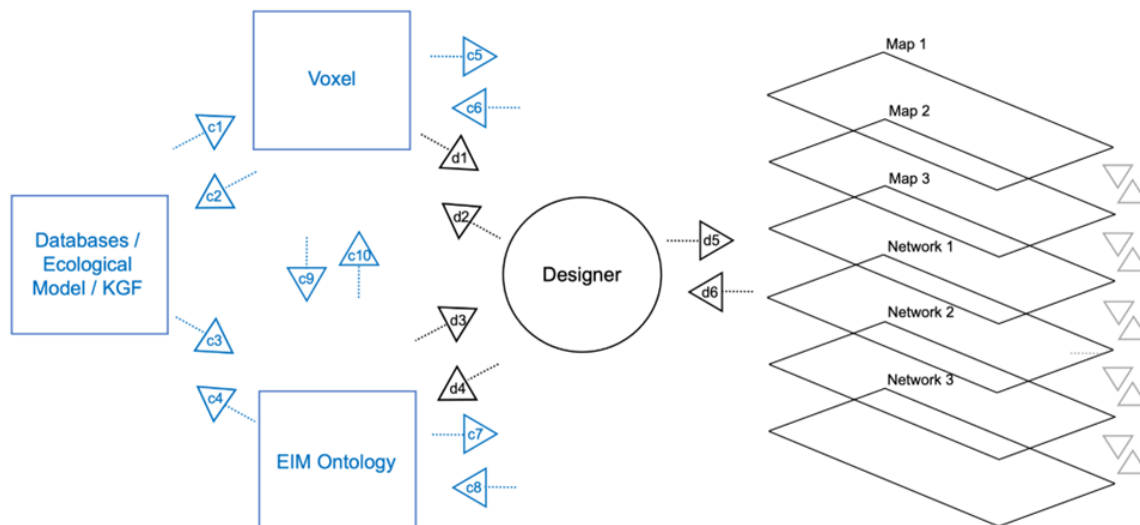


Fig. 4.7.5-1: Schematic representation of the interactions between the designer and the key components that serve the translational process (different data sources, EIM Ontology, voxel model and the design environment (here represented through the datasets maps and networks and their correlations))

Dataset Maps

Analysis in planning and architectural design is typically visualized as a series of *maps* that show existing or predicted conditions that are space and time specific. The dataset *maps* is a visualization of data contained in the voxel model and plays a vital role in the ontology-aided generative computational design process. In technical terms this implies geo-rasters, commonly used in GIS software, which consists of numerical values aligned to a grid or raster that is positioned on the Earth's surface using geographic coordinates (see Report D5.1). Maps can be derived from computational simulations prior to or during the design process and serve (1) as initial input to the design process, and (2) to visualize the consequences of different design solutions, hence enabling analysis and benchmarking of design outcomes. In the translational process this implies: (1) acting on project and site specific performance criteria stated in the design brief; (2) selecting additional performance criteria if required; (3) identifying conditions to be mapped, in case such maps do not already exist; (4) conducting simulations for conditions that are not already mapped; (5) analyzing the simulations and formulating design targets based on the datasets *maps* and their correlations. The correlations between maps may not already exist in every case. Maps need to be made sense of by the designer, often with expert support. This entails spanning a multi-domain problem space for which expert knowledge from multiple domains is required. The ontology plays a key role in enabling the designer to make such determinations.

The primary data used in the voxel model is constructed from the integration of diverse geospatial datasets extended with the geometric information provided by the designer. In the example of the Vienna case study, primary datasets have been retrieved from the municipal geoportal site that are published as a part of the Open Government Data initiative of the City of Vienna. These include the Digital Surface Model (DSM) that conventionally describes the Earth's surface as captured in the airborne 3D scanning process and the Digital Elevation Model (DEM), derived by filtering out the off-terrain objects. Both datasets are examples of



the typical 2.5D representations of the geospatial data, where each 2D coordinate is assigned a single height value. The voxel model addresses this limitation by combining the data describing both the terrain and the off-terrain objects, such as buildings and trees, in a single three-dimensional data structure. Available sources of primary data partially contained data representing past conditions, since the area considered in the Vienna case study has been undergoing heavy development in recent years. Most recent, available data have been identified and converted to a common grid representation. Terrain geometry after the recent modifications has been only available as Triangulated Irregular Network (TIN) and has been converted to the voxel-based representation and a high-resolution mesh to be used e.g., for visualization in the Rhino interface (See Figure X). Geometry describing off-terrain objects have been extracted from the DSM dataset using state-of-the-art terrain filtering methods available in existing geospatial data processing tools. Recently constructed objects and newly planted trees have been manually recreated and converted into the voxel-based representation. Finally, the old data has been manually cleaned and new off-terrain objects have been added to the combined voxel model.

The datasets contained in the voxel model go beyond the geometric representation that can be derived from the existing geospatial datasets. The current version of the voxel dataset contains classification data that is derived from the “Multi-purpose map” published by the city of Vienna. Classification data is extrapolated from the vector dataset and mapped onto the classification codes defined in the Lidar Base Specification (LBS) to assure interoperability. Moreover, any dataset that can be created with available geospatial analysis and simulation tools, can be introduced into the voxel model. Currently, values for slope and aspect are saved in the voxel model to showcase this possibility and test implemented functionalities. In the next steps, required datasets will be added, according to the requirements of the generative design process and functionalities implemented by other Work Packages.

The data contained in the SQL based voxel model is expressed as a series of tables. Single database contains a series of tables representing different spatial scales and additional tables containing metadata that describes the relations between the data in different scales. Tables containing the spatial data in different scales are referred to as levels and numbered sequentially. Each level can contain a different set of properties, which is configured to contain the data that would be used in the design task considered.

Each property encoded in the single level of the voxel model is expressed as a separate column. Each level in the voxel model is indexed with a primary key derived from the nodal coordinates of the individual cells within the voxel model. This assures consistency of the data written in the voxel model and allows for integration of diverse spatial datasets into a common voxel grid.

In collaboration with Task 4.7.3, an interface between the SQL-based voxel model and the GraphDB component used for knowledge modeling has been developed. The interface is implemented using the Ontop Virtual SPARQL functionality available by default in GraphDB. The Ontop Virtual SPARQL functionality allows one-to-one mapping between the tabular data written in the SQL-based voxel model and the graph-based data representation contained in GraphDB. As an outcome, each 3D cell available in the voxel space is mapped into a collection of triples and can be accessed by all ECOLOPES components utilizing the functionalities of GraphDB.



User interaction with the voxel model is happening either directly or indirectly. Direct interaction is triggered when the user requests a visualization of voxel data in the Grasshopper interface. A set of Grasshopper components presented in Figure X was developed to enable such interaction. The aim was to implement a compact but extensible set of functionalities that needs to be inserted into Grasshopper canvas. Presented components allow the user to select an arbitrary “level” present in the SQL database and request either a true color visualization of the existing data or call any available dataset encoded in the voxel model to be visualized using standard Grasshopper color scales. Another set of components was developed to allow the users to input voxelized representations of arbitrary Rhino geometry into the SQL-based voxel model. Moreover, users can pass additional data, such as outcomes of environmental simulations executed in the Grasshopper interface, into the SQL-based voxel model to link the Grasshopper design workflows with the ECOLOPES components that operate on the Knowledge Graph implemented within the GraphDB framework.

Dataset Networks

Architects frequently develop spatial and functional relations through network type visualizations such as, for instance, so-called bubble diagrams that serve to lay out relations between building programs to inform the design process and more specifically spatial organization. Laying out networks is typically based on analyzing the project brief at the onset of a design process. We employ this method and extend it to lay out various relations including required or desired program and microclimate relations, intended human-nature interactions and stakeholder relations (including humans, plants, and animals), etc. The aim is to lay out such networks in the CAD environment with appropriate tools (see Report D5.1). Since laying out such networks that integrate ecology requires expert input the designer needs to be able to acquire this support, which will be provided by the ontology. This implies that corresponding sets of items and relations of which such networks consist need to be present both in the ontology and in the CAD environment. We are developing the dataset *networks* based on graph theory, which describes a graph as a geometrical figure that consists of nodes or vertices and edges or links. Nodes and relations will have direct equivalents in the ontology making it possible for the designer to query the ontology in the process of network selection and / or configuration. This process will be supported by the voxel model that contains corresponding datasets (maps) that can be called by the designer or by the ontology as an outcome of a query, as well as an outcome of a design instance thereby serving as the means to understand whether changes in conditions arising from a given design are positive or negative.

Currently the conceptual specification for the user interaction with *networks* in CAD is carried out. The designer interacts with the dataset *Networks* in Rhino/GH by adding nodes (items) and edges (relations) with pre-defined templates. In this way, the user can give input to the generative design process by defining constraints and design aims and, at the same time, is enabled to apply systems thinking from the early design stage. The designer can choose between different types of *networks* which consist of different types of nodes and edges. Each node and edge type consists of different features that have to be specified by the designer. Some nodes might initiate pre-determined configurations.



In the first stage, two main Node Types have been selected for further development: NodeTypeA refers to functions related to the architectural program, e.g., kitchen, meeting hall, greenhouse, playground, etc. NodeTypeB refers to functions/services related to ecological and environmental processes, e.g., habitat provision, food & water source, CO2 sequestration, natural shading, etc. Depending on the NodeType, user input for each feature might be *mandatory* or *optional*. An initial collection of possible features is displayed in table 1.

Features	Description	NodeType A: Architectural related Function	NodeType B: Ecological related Function (or Service?)	Data Type	Unit
Label	Name Tag given by the user	M	M	String	/
Fixed Location	Fixed location to spatially reference node, could be center point/voxel	M	O	Int/Float	X,Y,Z Coordinates
Associated Location	Location (a point or voxel) to spatially associate a node, if it doesn't have a fixed location	O	M	Int/Float	X,Y,Z Coordinates
Area	X-Y dimensions / radius of the spatial expansion of a function	M	O	Int/Float	cm/m/km
Impact area	X-Y dimensions / radius of the impacted area by the function	O	O	Int/Float	cm/m/km
Height	Z dimensions of spatial expansion of a function	O	O	Int/Float	cm/m/km
Impact Height	Z dimensions of the impacted space by the function	O	O	Int/Float	cm/m/km
Exposure	Determination, if function takes (mainly) place (eg. I=indoor, O=outdoor, T=transitional space)	M	O	String	/
Target Stakeholders	Determination, which stakeholder(s) are targeted by the function (eg. H=Human, A=Animal, P=Plant)	M	M	String	/
Entrance	Determination, if function includes an entrance for human stakeholders (eg. Y=Yes, N=No)	M	O	String	/
Natural Light	Determination, if functions requires natural light (eg. Y=Yes, N=No)	M	M	String	/
Access	Information about access (eg. PR = Private Use, PU = Public Use)	M	O	String	/
Type of Use	Information about frequency and intensity of use (eg. R = residential, C = commercial, H = health facility, E = educational facility etc.)	M	O	String	/

Table 4.7.5-1: Collection of possible features defined through user input: the rows contain the different types of features and a description. Furthermore, it is specified if the user input is mandatory (M) or optional (O) for Type A and Type B nodes and the data type (numeric values or text) in which user input is received.

In the next steps the two NodeTypes will be further specified. This includes the development of templates by selecting relevant combinations of features. At the same time, the definition of use cases makes it possible to develop the templates in a targeted way.

In the next stage of the research, we will address the following questions:

1. What are relevant user inputs for EIM Ontology_1 to initiate reasoning in the translational design process?
2. What are relevant use cases which initiate reasoning in the translational design process?
3. (How) will the information derived through user input be included in the knowledge graphs?
4. How will the information be derived through user input impact the process of the query of the EIM Ontology?
5. Can it be assumed that changing the user input would lead to different results?



EIM Ontology 1 aids the configuration and manipulation of dataset *networks* in a voxelized 3D space in the CAD environment. The instances, objectives and instructions inferred from the ontology will be implemented through a rule-based algorithmic process in the generation of dataset *networks*. In this part of the workflow, the user interface is facilitated by the interoperability between Ontology and CAD. Possible steps that can potentially be automated to improve this process are also being investigated.

In order to develop the interface between Networks and EIM Ontology, a sub-task for WP5 task 5.2 was defined. Task 5.2.1 deals with the technical interface between the Networks in Rhino/GH and the EIM Ontology. For the programming of the interface, required functionalities in Python were identified and suitable modules were searched. The initial search outcome was the NetworkX module (Hagberg et al., 2023). However, since the direct translation into triplets is not possible, the decision was made to use the RDFlib module (RDFlib Team, 2022) instead, which makes it possible to create a graph structure using triplets and directly store it in a knowledge graph. This means that we can create the hierarchical structure of nodes by specifying the triples in RDFlib that capture the same semantics, namely in the subclass case by using directly the RDFS vocabulary for subclass relationship `:A rdfs:subClassOf :B` (W3C specification, RDF Schema 1.1). This approach has the advantage over NetworkX given that we are not creating an intermediate graph structure as in NetworkX, which we would need to maintain and keep in sync, but rather directly exploiting the inherent structure of the knowledge graphs and their standardized semantics.

We created a prototypical implementation of RDFlib using the Grasshopper Hops component. The components are able to perform read/write operations, i.e. write graph structures by using the metadata field of volumes as described in T4.7.4, as well as querying by using SPARQL query as input. As a concrete example, we can query all instances that are of Node Type A and return to the user as feedback. Another item of this task is to investigate possibilities for the user input, which will occur in the Rhino/GH interface and requires the specification of Node Templates. In addition, the user must receive some feedback in order to be able to proceed with the design. Therefore, the User-Network interaction can be subdivided into three main processes: 1) User Input, 2) Processing of User Input and 3) User Feedback.

1: In the current draft the user gives input by changing values through sliders and labels for specific features. As an example, the user specifies the radius of a function through the value slider in GH, which is passed on to the Python script using “Rhino Script Syntax” to create the circles that represent the area for the functions. In the next step, the processing of the user input would take place.

2: In the next step the relation between Node Type A and Node Type B is examined based on specific parameters. As an example, the distance between Node Type A and Node Type B is measured.

3: In order to let the user know how to proceed with the design the user receives the measured value and a text-based assessment of the value, which can lead to further instructions.

The intention is for the network input to be translated as statements in the knowledge graph in the form of a set of triplets. These triplets can be translated in an Answer Set program that computes various outputs.



Answer set programming (ASP) is a programming paradigm based on logic programming for knowledge representation and reasoning. It is declarative programming in which a program is expressed in terms of rules and constraints that specify the potential answers to a given query. The goal of ASP is to find a set of answers, known as answer sets, that fulfill the rules and constraints given in the program.

ASP is effective for combinatorial search, optimization, and constraint fulfillment problems. It has applications in numerous areas, including artificial intelligence, computer science, bioinformatics, and operations research. To find the solution sets of a given program, ASP systems often employ solvers such as Clingo. ASP offers various advantages over other programming paradigms, including its ability to manage incomplete and inconsistent information. It entails realistic modeling of uncertainty and preferences, and its support for non-monotonic reasoning. In addition, ASP can describe complicated problems and domains simply and straightforwardly, making it easier for non-experts to comprehend and apply. Moreover, it has solid theoretical underpinnings through program analysis and verification. One of the essential characteristics of ASP is its ability to handle default reasoning, which is reasoning based on assumptions made when information is insufficient or imprecise. ASP permits the declaration of default rules and exceptions, which may be used to deduce conclusions even in the lack of comprehensive information. Another prominent feature of ASP is its support for optimization, which helps users to find the optimal solution from a set of alternatives. This is very beneficial in scheduling, resource allocation, and route planning applications. ASP has been effectively used in various applications, including illness detection and treatment, natural language processing, planning and scheduling, and robotics. It has also been utilized to address challenging problems in areas like transportation and logistics, energy management, and environmental sustainability ability. ASP is a potent programming paradigm that provides a range of advantages for knowledge representation and reasoning. Its ability to handle partial and uncertain information, support for non-monotonic reasoning, and optimization capabilities make it an excellent tool for tackling complicated problems in various applications.

The following questions will be worked on next:

1. Which GH components are required to get user input?
2. How can the user receive the results of the query, besides text-based feedback? Will the results lead to an automated modification of the user network?
3. Which functions should be developed in the first prototype? What are their requirements?

Correlations between the datasets *Maps* and *Networks*

Maps and *networks* are key datasets in translating design requirements contained in the design brief and additional requirements established by the designer into actionable data that can serve as input into the generative computational design process. For this to be possible and meaningful it is necessary to establish both hierarchy and correlation between different datasets and to derive rules from them that guide the design process. The designer needs to establish priorities to accomplish this task. The *maps* containing the respective data are placed on the first level of hierarchy and *networks* are spatialized accordingly. Likewise, if the stakeholder interaction network constitutes the top priority it is important to guide the design



development in such a manner that the required conditions are provided accordingly. The translational process is completed when a project specific set of maps and networks that represent the translation of ecological and architectural design requirements have been defined and verified by querying the ontology.

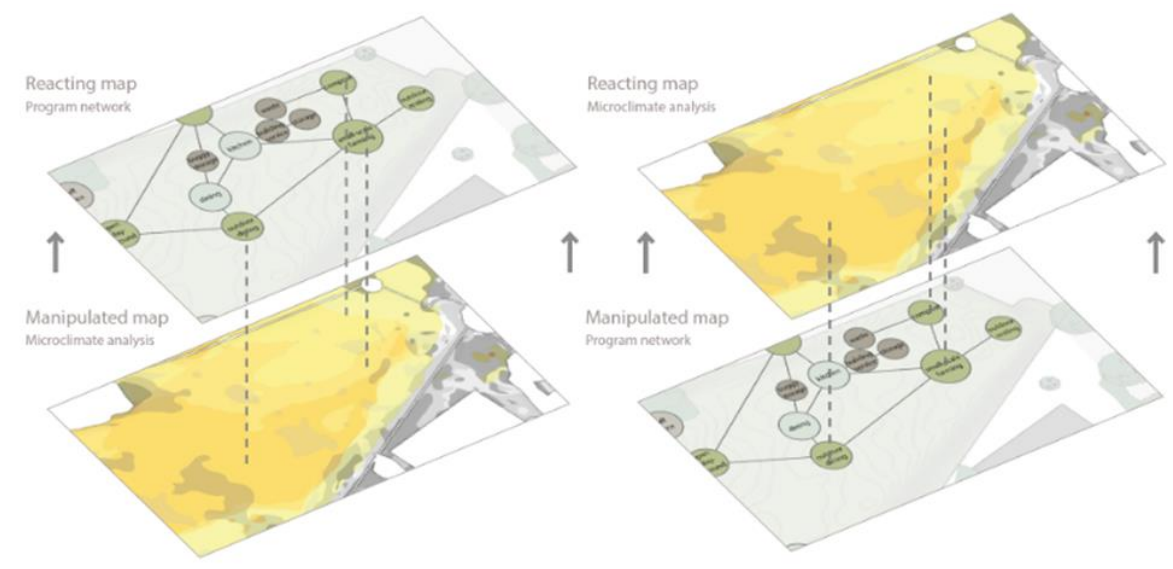


Figure 4.7.5-2: Defining correlations between datasets maps and networks.

The role of the ontology in the translational design process

We are developing three ontologies, each of which are defined by their specific role in the design process. For the *translational* process we are building an Ontology (EIMOntology_1) / Knowledge Graph (KG) of Ecological Networks (ENs) that will aid design in the generation of User Networks (UNs) and provide input for the specification of *volumes* and generation of *landform* in a voxelized 3D space in the CAD model. While we are using the terms ontology and knowledge graphs interchangeably here, it is worth noting that knowledge graphs, according to the most-common definitions, comprise the ontology, instance data and controlled vocabularies or so-called taxonomies. *Volume* specification and *landform* generation correspond respectively to the stages of the *generative* design process.

A knowledge graph is a structured approach to describing knowledge that computers readily understand and process. In architectural design, a knowledge graph may represent design knowledge in a structured manner that can be readily incorporated into a rule-based system. Using a knowledge graph combined with a rule-based approach may improve the accuracy and efficacy of architectural design. The knowledge graph can represent design knowledge, including relationships between various design requirements and constraints (Chen et al. 2022). A knowledge graph or network may be extended and updated over time, ensuring that the design process is always current with the most recent architectural and ecological knowledge.

We are currently conducting a literature review to assess the progress and state-of-the-art in the implementation of knowledge graphs and ontologies in the application of ENs, especially in the context of real-life decision-making. ENs are typically used to describe and compare the structures of existing real ecosystems and the complex biotic and abiotic interactions within



them (e.g., where species (nodes) might be connected by pairwise connections (edges) via trophic relationships for instance). Different methods are used to model ENs for various purposes, such as guiding the design and management of landscapes based on the concept of connectivity and investigating the effects of network structure on ecosystem stability. Recently, ontologies have been applied for representing and reasoning over existing ENs to support planning and the expansion, conservation and improvement of local ENs (Torta et al. 2017). In this work, we are implementing ENs to represent the potential structures of, and interactions and relationships within *ecolope* ecosystems. We are therefore building an ontology and KG model of ENs to aid design and ultimately the planning, conservation, improvement, expansion, and integration of local ENs into building envelopes. With the EIM Ontology_1, we are developing a KG model to infer instance data and network rules for guiding the configuration and modification of UNs in the CAD environment as the *translational* step in generative design. To achieve this goal, we have identified several tasks for ontology development for the *translational* process. These tasks correspond to the subtasks for Task 4.7 of WP4: (T4.7.1) Creation of the ontology, (T4.7.2) Creation of the instance data that populates the ontology, (T4.7.3) Developing interoperability between ontology and volumes, (T4.7.4) Mapping of knowledge graph onto CAD model, (T4.7.5) Ontology testing in operation, and (T4.7.6) Ontology next steps for volume specification. First, we will in principle describe these subtasks and what we are producing and why they are important. In section 6 Task 4.7 below, we elaborate these from a technical perspective.

Before commencing the work on task 4.7, we defined the URI generation method for identifying in a unique way concepts in the ontology, namely classes, properties, instances, etc. The principles of URI generation will set the ground for best practices and to better differentiate between concepts. Hence, it is possible just from the URI to deduce whether a concept is a class, property or instance. This follows a best practice approach when designing a knowledge graph and has an impact on its maintainability and its multi-stakeholder involvement. The URI generation is structured as follows:

For classes, properties and datatype properties we have a pattern that starts with “schema” followed by the domain and separated with “#”:

<https://schema.dap.tuwien.ac.at#{Class/Property/DatatypeProperty}>

The following are examples that demonstrate the approach by using classes, properties and datatype properties respectively:

<https://schema.dap.tuwien.ac.at#Habitat>

<https://schema.dap.tuwien.ac.at#comprises>

<https://schema.dap.tuwien.ac.at#impactHeight>

For instances, we have a pattern that starts with “resource” followed by the domain and separated with “/”:

<https://resource.dap.tuwien.ac.at/{Resource}>

The following is a concrete example (Note that we additionally use “/Species” in order to be able to differentiate individuals based on a group based on the URI):

<https://resource.dap.tuwien.ac.at/Species/bromusCommutatus>



According to the Semantic Web and Linked Open Data best practices (Heath et al.) URIs have to unambiguously/uniquely represent each concept, and have to be dereferenceable - in the sense that the server would return adequate information regarding the definition of that URI based if the requester is a human or agent.

T4.7.1 We have started to construct the core of the ontology including the main classes and class hierarchy, object and data properties, and individuals based on the Vienna use case. This is based on the literature survey, identified best practices, relevant existing ontologies, project-specific data, competency questions, and design and reasoning needs. We will use this as a proof-of-concept and testbed to demonstrate our first prototype for EIM Ontology_1. In parallel, we are developing a task/objective matrix that underlies the competency questions, which we will use to build the ontology. The tasks for the ontology in the translational process includes for example aiding the selection of target (plant and animal) species according to the species pool at the regional and local scales; conservation, human-nature interaction, ecosystem, and management objectives; and environmental features. Accordingly, we are specifying competency questions, which we can use in the demo and identify the data and information that will be needed for inference.

For this task we performed a literature review of the existing body of work that describes ecological networks in the context of urban planning. It is best practice to reuse as much as possible ontologies that are published on the web, in order to achieve better interoperability. We can create specialization of ontological concepts, in the sense that we can import an existing structure - class hierarchy from a given domain that is already published, and then create our own "version", that is specialization, for instance by creating a subclass. This subclass still inherits the superclass and its structure, but it has its own special attributes. The approach presented by *Torta et al. "Representing Ecological Network Specifications with Semantic Web Techniques", 2017* is closely related to our work. From that work we have used a number of ontology concepts. Figure 4 shows an excerpt from Torta et al. depicting ontology concepts.

Furthermore, we designed a set of competency questions that are relevant in our context and for our cases. These questions and the related information and data needs are configured in the Task/Objective matrix. The ontology for instance might be asked to aid the selection of target plant and animal species in a specific location for a specific project according to the regional species pool. For example, the task might to automatically select local endangered and protected plants, while filtering out the invasive ones. The first version of our knowledge graph consists of 95 classes, 26 object properties, and 49 datatype properties.

T4.7.2. We are currently using a placeholder dataset for instantiating the ontology. However, these will eventually be replaced by and/or incorporate data and information generated by the ecological simulation model (regional and local species pool and species distribution and abundance), knowledge generation framework (insights from ecology and architecture correlations), GIS and CAD model (which help produce the dataset maps, constraints etc. where the data is structured and contained in the voxel model) and design brief (which includes the general and project specific objectives and KPIs). We are also considering ways to best express the various types of temporal and spatial data that we will need to incorporate in the ontology.



In this task we investigated relevant datasets such as species, plants, animals. After we gathered the data - mainly in tabular form - we mapped and converted them to a graph in RDF by using the ontology we created in T4.7.1 and defined a set of *mappings*. Mappings are a declarative way to specify how a column (in general form: a query) in a tabular data is converted to a property in the ontology. This means that the data cell in that particular column would be used as an object (note that each triple consists of <subject> <predicate> <object>) by using the property in which the column has been mapped to. For instance, the column “scientific name” has been mapped to the property <https://schema.dap.tuwien.ac.at#scientificName>, which we can more formally describe using “->”:

[scientific name] -> <https://schema.dap.tuwien.ac.at#scientificName>

After the mapping process is executed, we would have the triple created for the specie “Ballota nigra”:

<<https://resource.dap.tuwien.ac.at/Ballota%20nigra>>
<<https://schema.dap.tuwien.ac.at#scientificName>> “Ballota nigra” .

There exist different approaches and declarative mapping languages such as RDB2RDF, R2RML, RML etc. For simplicity we used OntoRefine's GUI to create the mappings. The instance data which is generated by the mappings and tabular data is stored in a GraphDB repository. Given that we have used the same concepts from the ontology, such as property URIs, it is possible now to query instance data based on the ontology and further perform additional reasoning tasks.

T4.7.3 This work involves (1) using a voxel-based approach for exchange of data between the ontology and the CAD model, (2) the manipulation and creation of CAD model data with the aid of the ontology, and (3) a rule-based approach for using the ontology to instruct an algorithmic process in the specification of volumes and for the validation of results produced in the generative process.

In order to be able to develop interoperability between volumes and ontology, we have transformed the Voxel database - which stores data about maps along with coordinates x, y, z - into graph data by applying a set of mappings similar to T4.7.2. The difference here is that instead of materializing the data, i.e. persisting, in this case we are creating a “view” of the data, which contains circa 18 million triples - this data integration approach is called “Ontology-based Data Access” (for more details on this approach and the underlying system called *Ontop* that is used in GraphDB, see Xiao et al., 2020). This means that every time we issue a SPARQL query, it gets translated on-the-fly to SQL in the Voxel database. The advantage of this approach is that we will always have the latest version of the voxel data and we do not need to copy and keep them in synchronization.

T4.7.4 We are using EIM Ontology_1 to represent ENs as a knowledge graph to support reasoning for the configuration and manipulation of UNs in the CAD environment. In principle, the UNs provide the scaffold on which to build the volumes. In the next step, the ontology (EIM Ontology_2) will be enhanced to aid capturing data and the generation of rules for a rule-based algorithmic design procedure for the specification and distribution of *volumes* in the



CAD environment. For this task we connect ontology with the Rhino interface for generating user networks. The pragmatic way to achieve this, is to associate each network node or property to a URI which corresponds to the concept in the ontology. This is possible by exploiting <key, value> property pane in Rhino (“Attribute User Text”), where for a network type we create tuples such as <URI, <https://schema.dap.tuwien.ac.at#NodeTypeA>>.

T4.7.5 The short-term goal is to develop a simplified version of EIM Ontology / Knowledge Graph_1 to demonstrate the approach and methods used to aid the configuration of UNs and to facilitate volume specification. We will build and demonstrate our first prototype based on the Vienna use case. This work will start exploring the ontology-driven workflow and questions related to direct user interface in design and which tasks might be automated to improve it. We will use it in a Vienna case study for testing the knowledge graph in operation in an algorithmic process for generating user networks.

T4.7.6 We are currently identifying the next set of research questions building on the networks related progress in general and T4.7.3 in particular, and preparing for the work coming up in the development of EIM Ontology_2 with focus on volume specification. We plan to extend the ontology in the future in order to take into account the volume specification. Extending on the work done in T4.7.3, we will further enhance the approach where different types of volumes are used and mapped accordingly to different URIs in the ontology. In the future, this would enable us to query and reason in the knowledge graph using different volumes in a more automatic fashion.

4.7.6 Stage 2: The Generative Process

In order to extend the solution space we seek to develop a *generative* process with the aim to derive design variety, that is numerous designs that can be evaluated and ranked. We envision a design process based on a generative algorithm that can serve to advance designs regarding specific performance criteria. Each design will consist of a CAD model with corresponding datasets contained in the voxel model that describe different key performances of the design solution. The CAD model will contain a specific distribution of architectural, green and soil volumes (primary volumes for case 2 and secondary and tertiary volumes for case 2) and an explicit landform geometry (*primary landform* for case 1 and *secondary* and *tertiary landform* for case 2) (see Report D5.1).

The generative process collects direct user input and design brief data from the Rhino / Grasshopper interface. A subset of the data written in the voxel model can be taken and translated into a map representation. The generative process is informed by the data contained in the voxel model and expressed in individual maps. Volume components are given both the direct access to read the voxel data, and to request subsets of voxel data in the form of maps. The generative process can directly use the GraphDB SPARQL endpoint to request data and reason over the knowledge graph.

Input data used in the design process is encoded following the .json specification and interactively sent from the Grasshopper interface to the Python based generative process.



Representative samples are currently saved as a collection of .json files to allow for quick testing of the generative algorithm implementation.

Grasshopper components implemented in the generative design process are using the McNeel Hops Grasshopper component to pass the dynamic inputs derived from user input and the design brief to the generative process component implemented in Python. Inputs are serialized into JSON representation and passed to the generative process utilizing the REST API endpoint as implemented in the McNeel Hops component.

The primary interface linking computational components with the designers' input used in the ECOLOPES Project is the Rhinoceros / Grasshopper interface. The codebase developed for the voxel components is extended to support tasks 4.7 and 5.1. Single REST endpoint is initiated, and user inputs are passed between the Grasshopper and local Python instance utilizing the McNeel Hops component. Architectural designers can use the Grasshopper input components, such as sliders, textual input panels and dropdown lists to set the starting parameters for the generative process. The input parameters include, among others, gross floor area categorized per function, percent of built volume assigned as ECLOPES volumes, as well as geometric constraints. For example, the value of "percent of built volume assigned as ECLOPES volumes" can be set interactively utilizing the Grasshopper slider component. Geometric constraints are manually created by the designers in the Rhinoceros 3D modeling interface and referenced in the Grasshopper interface.

Two types of constraints in the generative design process can be distinguished. BoxConstraints category contains Primary and Secondary Bounding Boxes as well as Exclusion zones. Each of the BoxConstraints is defined by its size and location, expressed as numeric domains (maximum and minimum values for x, y and z dimensions). PrimaryBoundingBox defines the portion of the 3D space where the generative design process takes place. Secondary Bounding Boxes and Exclusion Zones are used to inform the outcomes of the generative design process, by impacting which types of volumes will be placed inside each of the Secondary Bounding Boxes and Exclusion Zones. PointConstraints play a similar role in the process and can be divided into Attractors and Repellers. For each PointConstraint, point location, types of impacted volumes and impact weights are defined. Impact weight is a single numeric value in the range from -1 to 1. It is used to impact the probability that a volume of defined type will be placed close to the PointConstraint by the generative process. Regarding the generative process and the algorithm selection, we aim to employ a rule-based (symbolic, logic-based) approach to reasoning. This is due to the fact that the algorithm has to exploit rules or constraints as input, which are coming for example from the dataset networks. A rule-based approach is a prominent strategy used in artificial intelligence and expert systems to solve issues using logical rules. In architecture and design, a rule-based approach can be utilized for tasks such as generating floor plans and optimizing building performance (Leon-Garza et al. 2021). In a rule-based system for architectural design, for instance, a set of rules may state that a building's design must adhere to certain height and setback requirements to comply with local zoning regulations. Another rule may state that a building's facade must provide a certain level of shading to reduce solar heat gain. Logic programming, expert systems, and decision trees are a few approaches that may be used to construct rule-based systems in architecture. One of the primary benefits of a rule-based approach is that it enables transparent and explicable decision-making since the rules and conditions are openly specified and can be readily understood and modified.



We will conceptualize and formalize the rules in a top-down fashion. They are then further processed by a rule engine – such as Answer Set solver, or Datalog engine. We will then develop to a hybrid approach to reasoning, i.e., integrating ML in our pipeline after the reasoning process takes place. As an instance, such a hybrid approach could use a reasoning process to generate “labeled” data (as in supervised learning) and further to be used by the ML algorithm in prediction/classification. The same applies to genetic algorithms, which we can consider to exploit later in the generative process.

To adopt a rule-based approach for volumes, one must first develop a set of rules that link various design variables. For instance, a rule may suggest that if the building's height is increased by 10%, the number of floors in the building should increase by 2. These rules may be encoded in a knowledge graph, illustrating the relationships between distinct variables and the rules that control them. The knowledge graph may automate the decision-making process by enabling the system to make predictions and suggestions based on the data it receives.

The benefit of a rule-based approach is that it enables a transparent and explicable decision-making process since the rules and relationships between variables can be clearly understood and modified as required. In addition, a rule-based approach may be utilized to find complicated relationships between variables that may be difficult to detect using other approaches. However, a rule-based approach may display some shortcomings. It may not be able to account for all of the intricate relationships between variables that determine volume, nor may it be able to react to new or changing patterns in the data. In such circumstances, a machine learning or deep learning approach may be useful. Combined with a knowledge graph approach, a rule-based approach to volumes may be utilized to find patterns and relationships between variables that impact the design process.

Dataset *Volumes*

The dataset *volumes* comprises architectural, green and soil volumes. Case 1 involves the distribution of *primary* volumes on a given site as part of developing a masterplan for a given site. Case 2 concerns the spatial organization and geometric articulation of an already specified maximum volume of a building. In this case the primary volume needs to be partitioned into *secondary* and *tertiary* volumes. In terms of ecological and architectural aims the datasets *maps* and *networks* serve to determine locations and dimensions during the *generative* design process. The solution space for volume distribution and dimensions can be controlled by selecting fixed parameters, for instance to comply with existing regulations, or variable parameters.

We have identified five types of volumes: (1) architectural, (2) biomass (densely vegetated), (3) open green space (sparsely vegetated), (4) connections (between green spaces to enhance connectivity), and (5) required soil volumes. Volumes of the same or of different types can be spatially related in different ways. We are currently defining different types of spatial relations between the volumes, and we are writing the rules that will underlie the distribution of volumes based on the datasets *maps* and *networks* as inputs. The different types of volumes each feature specific associated parameters that provide a link to project-specific key performance indicators that are either given by design brief or that are selected by the designer. Furthermore, it is necessary to define benchmarks for informing the generative design process and evaluating design outcomes. We analyzed a series of current state-of-the-



art built projects that belong either to case 1 (masterplans or large landform developments) or case 2 (buildings) in terms of the ratio between architectural, green and soil volumes. It is then possible to set benchmarks in terms of volume ratios that go beyond the current state-of-the-art.

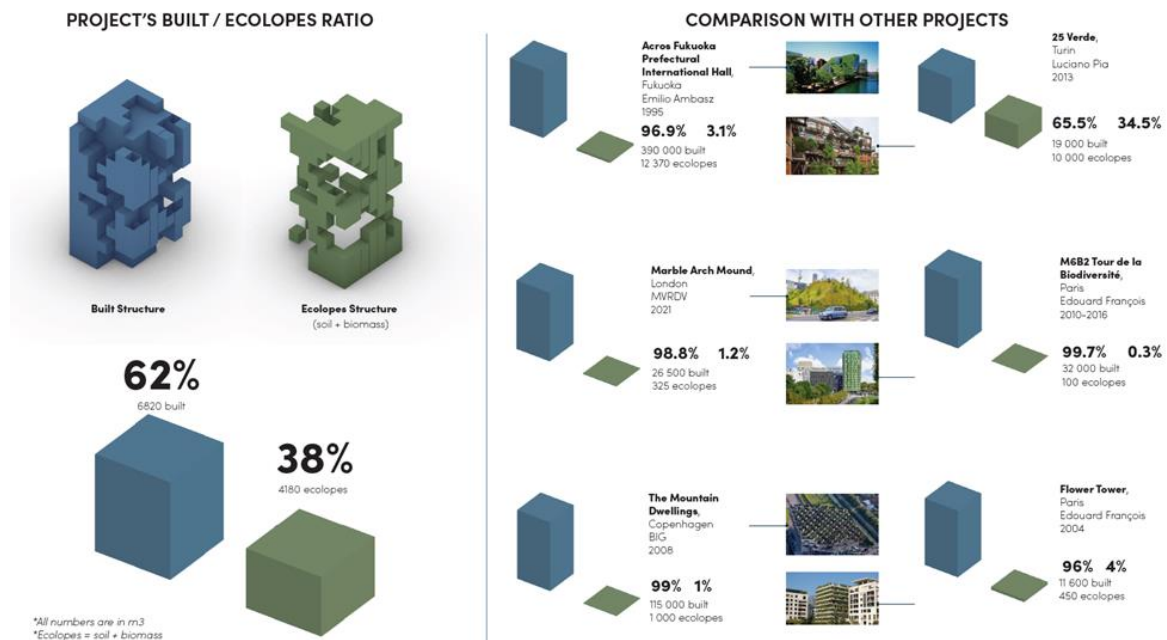


Figure 4.7.6-1: Exemplary analysis of a series of current state-of-the-art built projects representing Case 2, prepared by students to set benchmarks in terms of volume ratios between architectural and biomass volumes. Illustration by Julie Doyen and Blandine Seguin, 2022W

The current state of development of the dataset volumes has concluded with the definition of input parameters to initiate the rule-based, generative design process. Requirements derived from the design brief and geometric constraints of the location chosen for the case study have been translated into a generalized representation. The generalized, JSON based representation can be transmitted between the Rhinoceros 3D / Grasshopper interface and external components, such as the rule-based, generative design algorithm.

In the next steps, the rule-based, generative design process will be outlined to comply with the developments introduced in the Tasks 4.7 and 5.1. This includes the integration with the components developed for networks, maps and knowledge graphs. Requirements regarding intended user interaction and internal logics of the process will be outlined and evaluated.

Dataset Landform

Once *primary* volumes (case 1) or *secondary* volumes (case 2) are defined and localized the second stage of the generative process commences and landform geometry is generated. This will be facilitated by an algorithmic process that combines form generation with analyses through simulations, leading to design variety generation and evaluation and ranking of design outcomes (see Report D5.1). To commence this part of the research we examined different ways of systematizing the approach to landform modeling and selected the so-called



geomorphons approach that operates on a comprehensive set of landform elements (Jasiewicz and Stepinski 2013). Geomorphons constitute a useful method for describing surface topology and were originally introduced in the discipline of geomorphology to map and classify landform elements from terrain models (Jasiewicz and Stepinski 2013). Currently geomorphons analysis is implemented in various open-source GIS packages. We seek to extend the geomorphons approach with the aim to enable full computational analysis of urban fabric as urban landform and the design of urban landform. In reference to surface topography, we refer to the proposed extension of geomorphons as *topographic patterns* (see Report D5.1). We anticipate that adopting the terminology related to landforms will make it easier to relate the geometry to comparable situations in natural landform that determines accessibility, connectivity, available territory and home ranges, etc., as well as to utilize and communicate the formal expression in the design process. A vital feature is the scaling of topographic patterns such that smaller patterns. For design case 1 *primary* landform extends the territorial scale landform across a given site, while in case 2 *secondary* and *tertiary* landform is generated to geometrically articulate buildings (see Report D5.1). In this way buildings can become seamlessly integrated parts of urban landform, described by edges that are an integral part of the terrain.

The EIM Ontology 3 will be developed to aid the generation of landform geometry in a voxelized 3D space in the CAD environment according to the networks, objectives, maps and volumes defined in steps 1 and 2. We will investigate the potential of the ontology to represent topographic patterns based on the concept of geomorphons and guide pattern selection, distribution and manipulation in the third stage of the generative design process. We will explore how instances and instructions inferred from the ontology will be implemented through a rule-based algorithmic process in the generation of landform.

The role of the ontology in the generative process

We modularized the EIM Ontology to consist of three ontologies, which are being built to address the challenges particular to the identified three stages of the design process. EIM Ontology_1 is being developed for the purpose of the *translational* stage as described above. With EIM Ontology_1 and the planned prototype underway, we are currently at the stage of laying down the foundational work for EIM Ontology_2. In the next step the ontology will be advanced to capture data and specification rules that can be implemented in a rule-based algorithmic procedure for the distribution of volumes in 3D CAD model, which is the objective for the second stage in the generative design process. Finally, in the third step, with interactive networks and 3D datasets and volumes having been established and linked with EIM Ontology_1 and EIM Ontology_2, our final mission will be to work on the approach and methods to develop EIM Ontology_3 to aid landform generation in the CAD environment.

4.8 Experimental approaches for data generation

In ECOLOPES, a number of experimental approaches are used to generate missing data to be used in the modelling and design processes.



4.8.1 Field and experimental data for PFG validation

Plant functional groups (PFG, see 4.3.4) will be validated through plot-based plant communities' data from urban green infrastructure (e.g., green roofs) and from urban and peri-urban ecosystems affected by different level of anthropic disturbances, including human management. The same data provide additional information that can feed the ECOLOPES ecological model.

Growing medium effect on green roof plant communities

This experimental green roof study aims to: i) collect plant communities' data for the PFG validation, assessing if the functional groups are representative of plant biodiversity of green envelopes, and ii) to evaluate the response of spontaneous plant assemblages to different growing medium thickness and composition, assessing plant-soil co-occurrence.

This study has been carried out on two adjacent Green Roofs (GR), in the city of Genoa (NW Italy). The first green roof is extensive, with 20 cm thick growing medium composed by volcanic material and organic matter, the second is an intensive green roof, with 35 cm thick growing medium composed by clay. The roof is covered by spontaneous herbaceous plant communities managed through periodic mowing. To characterize the spontaneous plant assemblages, phytosociological relevés has been carried out in June 2022 (t₀) on both roofs. To detect the colonizing plant assemblages, after t₀, the vegetation was completely removed on 1 m² plots (n=14 each roof) and a second relevée was carried out in September 2022 (t₁). At this time, the plot vegetation was removed again and weighted.

Significant differences were highlighted in species composition between the two growing media in both sampling times (see figure 4.8.1-1). The species turnover values were higher on the intensive than on the extensive roof. Moreover, the fresh biomass was significantly higher on the extensive than on the intensive growing medium. Our findings confirm the relevance of the substrate in screening GR plant communities, identifying a set of plant species with functional traits adapted to drought.

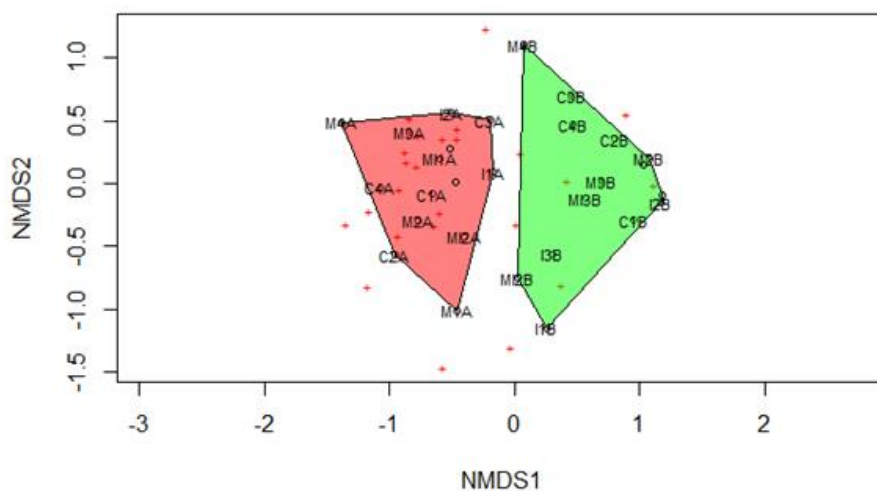


Figure 4.8.1-1: NMDS of plant species assemblages at t₁ between extensive (red) and intensive (green) growing medium.



To assess the impact of the most frequent management practices within green envelopes (i.e., mowing, irrigation), in the next step of this study, vegetation will be removed on the selected plots. After soil stabilization (carbon degradation), plant and microbial communities will be assessed through phytosociological relevès, once a month for one year.

Effect of anthropic disturbances on urban and periurban plant communities

The aim of this urban and periurban field investigation is the collection of plant communities' data to assess if the PFGs used in the ECOLOPES ecological model adequately represent the plant variability of natural plant assemblages. At the same time, this study allows to evaluate the relationship among human disturbances (roads, waste, power lines, etc.) and natural vegetation, in terms of communities' species assemblages, functional diversity and number of alien species.

The study consists of a field investigation on 48 plots with spontaneous plant communities in the urban and peri-urban area of Genoa (NW Italy). Since the investigated communities belong to different vegetational type (thermophilus wood, hygrophilous wood, mesophilic wood, Mediterranean maquis and grassland), they are representative of various environmental condition and, therefore, they include high biological variability (see figure 4.8.1-2). This represents a relevant aspect for the PFG validation in the frame of the ECOLOPES project. Phytosociological relevès and anthropic disturbances has been detected and classified according to the EU list of pressure and threats (Art. 17 - "Habitat" Directive 92/43/CEE). For each detected species of the plots, 7 relevant traits were extracted (e.g., SLA, N leaf content, P leaf content, plant height, mycorrhizal symbiosis, seedbank longevity and seed dry mass) from the global database of functional traits TRY (Kattge et al. 2020) and computed via the Community Weighted Mean (CWM) values. Total anthropic disturbance, slope and altitude are the three significant predictor factors that affect communities' species assemblages. Concerning the number of alien species, a significant higher number of aliens was highlighted in the group of plots affected by high disturbance levels (total disturbance indices from 8 to 12) compared to the group of plots affected by low disturbance levels (total disturbance indices from 0 to 4).

The results confirm the key role played by direct and undirect human disturbances in shaping species composition of spontaneous plant communities.

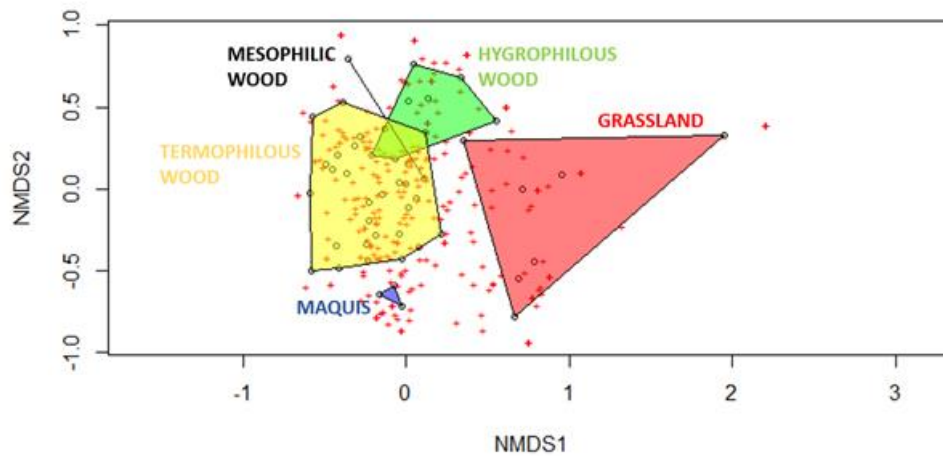


Fig. 4.8.1-2: NMDS of plant species communities analyzed in the urban plots study.

The next step of this study will investigate the relationship between the total disturbance indices of the plots and the CWM values of traits to assess whether a trend in functional traits values distribution can be identified in relation to human impacts.

4.8.2 Microbial diversity in green roof substrates

The objective of this experiment is to identify microbial key performance indicators (KPI), which are specific for:

- Phosphorus mineralization
- Dinitrogen fixation
- Soil stabilization

with the overall aim of establishing a biocontrol effect for plants and to create a good brown infrastructure which support the system and human health.

Green infrastructure offers numerous environmental, economic, and social benefits that make it an excellent option for sustainable building design (Rakhshandehroo et al. 2015) and provide new opportunities for urban biodiversity (Andersson 2006).

Brown infrastructure as a base for vegetation should provide, above all, a good growing medium (Pouyat et al. 2010). Especially green roofs therefore consist of a main part of the so-called technosol or substrate. It is a mixture of artificially modified or recycled materials, organic matter, and natural minerals. Overall, an optimal substrate should balance water-holding capacity, nutrient availability, structural stability, and weight. The specific properties of the substrate will depend on the climate, plant species, and other factors specific to the green roof. (Schad 2018; Friedrich 2008; Ampim et al. 2010)

Substrates are key elements for ECOLOPES. Despite the key role of substrates, their quality improvement via inoculation of effective soil microbiome has so far not been considered in previous studies (Ondoño, Bastida, and Moreno 2014). In this study we wanted to speed up the soil-forming process in relations to different plant diversity levels. Therefore, we



conducted a greenhouse experiment in which we attempted to improve the normally low microbial diversity (Ondoño, Bastida, and Moreno 2014) in typical green roof substrates by adding microbial inocula from grasslands with different plant diversity levels (Roscher et al., 2004). We tested 3 different substrates (Lavender Heath, Lavender Heath light and Roof Garden) from the company ZinCo. To demonstrate the positive effect of a soil inoculum, each substrate was used once as supplied, once mixed with 5 % soil from a monoculture, and once mixed with 5 % soil from a multiculture plot. The treatments were replicated (5 for both Lavender Heath substrates, 4 for Soil garden – with full extensive fertilization amount (2.5 mg/cm² from ZinCo-Pflanzenfit® 4 M) and additional 4 for Soil garden with half extensive fertilization amount (1.25 mg/cm² from the same fertilizer)). To also investigate the interaction with plants, 5 individuals of *Dactylis glomerata* L. were placed in each of the pots (Monoculture plant approach) and the same number of pots was planted with 3 individuals of *D. glomerata* and 1 individual each of *Festuca pratensis* Huds. and *Trifolium pratense* L. (Multiculture plant approach). 78 days (1st sampling timepoint) and 135 days (2nd sampling timepoint) after the plants were placed in the pots, they got harvested and substrate was sampled. Measured parameters include plant biomass, microbial biomass, dissolved carbon and nitrogen, pH, microbial diversity, and community composition.

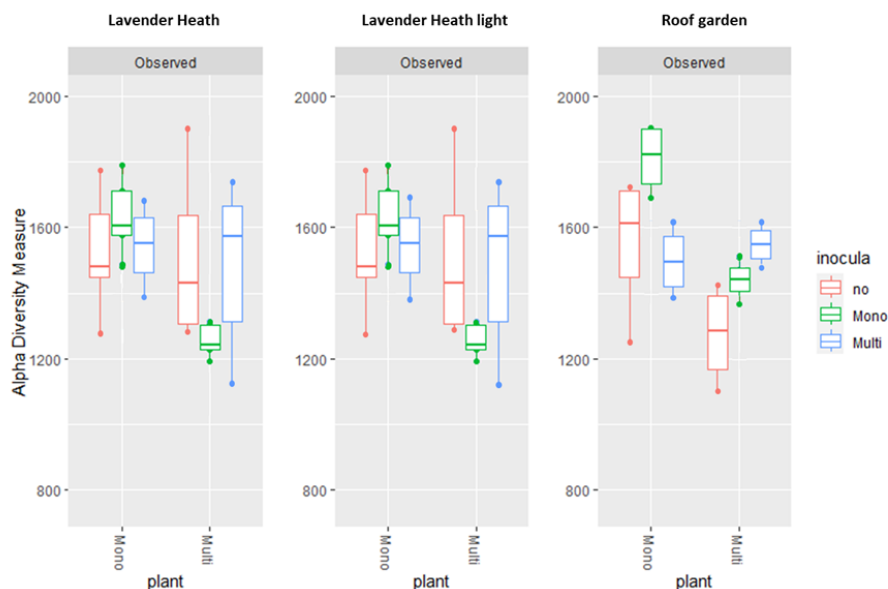


Figure 4.8.2-1: Alpha diversity of observed ASVs as measurement of the “within-sample” diversity. Shown are the 5 replicates of each inoculum treatment (“no” inoculum, inoculum with “mono” culture soil, and with “multi” culture soil) as boxplots of the 3 substrates (Lavender Heath, Lavender Heath light, and Roof Garden) in their own grids. Plotted in the x-axis are the two plant approaches, where “Mono” denotes the monoculture of the grass *Dactylis glomerata* and “Multi” denotes the mixed culture of the 3 plant species.

Our preliminary data (only full fertilizer amount) nicely demonstrates that there is a difference between the plant growth in the substrates per se and that the addition of a grassland inoculum results in a positive effect in two of three substrates. As expected, also microbial



communities in the substrate changed after inoculation, shown in Figure 4.8.2-1. Overall, we could measure a clear increase in richness of bacteria because of inoculation, which indicates a positive impulse of the inoculum on the structure and function of the microbiome of the substrate. The next steps are to verify in detail on the microbial effect through the inoculum for the KPIs. The data analysis is currently in progress.

4.8.3 Human perception of nature

Functional relations between nature components of *ecolopes* and wellbeing

Our methodological scheme included an extensive literature review, aimed to produce a set of quantitative functional relationships between metrics of wellbeing and natural components of *ecolopes*. The review revealed that the literature on the effect of nature on wellbeing suffers from a few discrepancies, which do not allow the analysis of a functional relationship: (i) Studies use vastly different measures of wellbeing; (ii) the effect size of specific natural components is limited in most studies; (iii) natural components are measured simultaneously and their effect cannot be isolated. Therefore, we map and summarized the evidence (presented in the year 1 report) and developed additional survey to explore people's attitudes towards different types of *ecolopes*. This survey also answers some important comments raised by the review committee about the key role humans play in the implantation of the *ecolopes*.

Protocol for the updated methodology and experimental design

Following the above-mentioned challenges in quantitatively identifying the functional relationships between components of nature and wellbeing, our work in year 2 also focused on developing a survey that will include a multi-cultural choice experiment designed to assess:

1. How different types of *ecolopes* (varied in the doses and quality of fauna and flora) is appreciated by the public?
2. How providing knowledge on *ecolopes* functions can influence attitudes, measured as willingness to pay for *ecolopes*?

We apply a Choice Experiment (CE) approach. The CE approach aims to measure the perceived value of the effect of change on fauna and flora doses by eliciting participants' preferences towards the potential variation in the *ecolopes* attributes. The analysis includes a measurement of the participants' willingness to pay (WTP) to initiate a unit change in each attribute. The CE method allows identifying trade-offs in preferences, which prove useful in cases where increasing the perceived value of an attribute is coupled with the reduction of the value of another. In this case the trade-off is between regulating and supporting services to cultural ones. Altogether, this survey will help us understand how people perceive *ecolopes* compare to traditional facades and also identify the extent to which these preferences vary with the dose of nature (e.g., plant diversity) and *ecolopes* function.

The last year was dedicated to set the experimental design and prepare the *ecolopes* that will be studied. The *ecolopes* will include the following parameters: (1) *architectural design*- a single architectural design which serves as a baseline for all flora designs; (2) *plant design*- a



design matrix representing a gradient of plant coverage and biodiversity (see Tables 4.8.3.2-1 for further details). We also selected a list of plant species that will be represented in each design in accordance with the different levels of biodiversity (see Table 4.8.3.2-2). The choice of flora for the designs is based on two metrics: their ecological function and the ecosystem services they provide. For each metric, plants are ranked from 1 (low) to 3 (high). The selected plant species will be then assigned to specific plant functional groups (PFG) produced in 4.3.4 according to specific functional traits values; (3) *Animals*- due to experimental limitations, the choice between animals is binary (*i.e.*- present/absent). Scenarios include animals according to the four main functional groups; (4) *nudging*- a random allocation of participants into two groups: half of the participants will be presented with an explanation regarding regulating and supporting ecosystem services provided by *ecolopes*, while the other half will receive no explanation. Finally, a *willingness to pay*- A normalized price for the alternatives presented in each scenario. This price serves as a proxy to the value of the design, since it propagates the hidden demand for the dose of nature which allows maximal wellbeing.

Table 4.8.3-1. Experimental design of the alternatives ecolopes that will be used in the choice experiment survey.

Plant coverage	Biodiversity level	Examples from real project that used as inspiration
low (10%)	low	Banyan Street Manor Vertical Gardens (& Rooftop Farm) - Greenroofs.com
	low	National Wildlife Federation HQ Green Façade - Greenroofs.com
medium (40-50%)	medium	Sihlcity Shopping Centre Living Facade - Greenroofs.com
	high	https://www.poliflor.net/en/projects/vertical-gardens-at-inps-genova/
	low	https://livingroofs.org/green-walls/
high (90-100%)	medium	Tag Sultan Generator Room Green Walls - Greenroofs.com
	high	http://www.greenroofs.com/projects/caixa-forum-museum-vertical-garden/
	high	https://www.domusweb.it/en/news/2012/12/04/patrocinio-house.html

Table 4.8.3-2. List of species that are used to build different types of ecolopes. Only species that were previously used in green walls and roofs were used, as these species are more likely to survived on the ecolopes. These species were also selected because of their low water needs and their occurrence in the countries where the survey will be submitted. Species names are presented, as well as ranking of ecological functions, ecosystem services provided by each species, and level of maintenance required.



Plant species	Type of ecotope: low, medium and High biodiversity	Ecological functions	Ecosystem services			Maintenance
		Support to local biodiversity	Thermal comfort (shading or light reflectance)	Runoff management	Aesthetic value	Human management
<i>Capparis spinosa</i>	High/Medium/low	3	3	2	3	Low
<i>Cistus salvifolius/C. incanus</i>	High/Medium/low	2	3	1	2	Low
<i>Lavandula stoechas/L. angustifolia</i>	High/Medium/low	3	3	1	3	Medium
<i>Trachelospermum jasminoides</i>	High/Medium/low	2	2	2	3	Medium
<i>Asphodelus fistulosus</i>	Medium/high	3	2	2	3	Medium
<i>Hyparrhenia hirta</i>	Medium/high	2	2	2	1	low
<i>Limonium sinuatum</i>	Medium/high	2	2	1	2	Low
<i>Lotus cytisoides</i>	Medium/high	3	2	2	2	Low
<i>Salvia rosmarinus</i>	Medium/high	2	2	2	3	Low
<i>Tymus serpyllum</i>	High	2	2	2	2	Low
<i>Bifora testiculata</i>	High	2	1	1	1	Low
<i>Carex divulsa</i>	High	1	2	2	2	Low
<i>Coronilla scorpioides</i>	High	3	2	2	2	Low
<i>Echium plantagineum</i>	High	2	2	2	2	Low
<i>Festuca glauca</i>	High	1	3	2	2	Low
<i>Hedera helix</i>	High	2	2	1	2	Low
<i>Lonicera pileata/ L. nitida</i>	High	2	2	2	2	Low
<i>Lotus tetragonolobus</i>	High	3	1	2	1	Low
<i>Myrtus communis</i>	High	2	2	2	3	Low
<i>Phillyrea latifolia</i>	High	2	2	2	2	Low

Action items and timeline

Using this preliminary work, we have designed several images of *ecolopes* that vary in plant diversity (number of species and cover; see Fig. 4.8.3.3-1 for few examples). We are now in the final stages of deciding about the designs. We are also currently working on constructing the questionnaire. The questionnaire is based on a Choice-Experiment experimental design constructed with Prof. Anat Tchetchik, from Bar Ilan University Israel, a specialist in the field. We still need to make some decisions and formulate nudging intervention, which and how functional groups of animals will enter the survey. We are aiming to distribute this survey by the end of June 2023. The questionnaire will be distributed in at least three countries (Israel, Italy and Spain) using a market-research company. The questionnaire will be translated from English to each Hebrew, Italian and Spanish and back translated to ensure consistency.



Figure 4.8.3-3 – examples of different greening strategies that potentially represent an ecolopes intervention: (a) reference, no vegetation; (b) low plant diversity, low coverage; (c) medium plant diversity, medium coverage; (d) high coverage, low plant diversity; (e) high coverage, medium plant diversity; (f) high coverage, high plant diversity. Notice these are only preliminary images that will serve as a basis for discussion about the approach taken.



5 WORK PACKAGE 1

5.1 Work package description, tasks and deliverables

WP no.	1	WP title					Project management and coordination					
Lead partner	TUM		Start month	1		End month	48					
Partner no.	1	2	3	4	5	6						
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel						
PMS/partner	22	8	8	8	4	10						
<p>Objectives: WP1 deals with all coordination and management aspects of the project including project coordination, communication with EC and reporting, risk management and ICT management, and the elaboration and maintenance of the DMP and DEP. The coordinator (CO), Wolfgang Weisser (TUM), will have overall responsibility for WP1, assisted by all other partners including technical management (McNeel).</p> <p>Task 1.1: Overall project and financial management (M1-48, 33PMs) Lead: TUM. Participants: All. The CO will organise and control the activities of the consortium and ensure attainment of goals and delivery of project deliverables and milestones. Duties include monitoring of compliance by participants with their obligations, responsibility for timely and accurate submission of all reports, financial claims, costs statements. On completion of the project, a final report to the EC will be prepared. Task will also oversee other activities such as management of gender aspects and ethical issues arising from implementation. Tangible outcome: Interim and final reports (D1.3).</p> <p>Task 1.2: Data Management and ethical framework (M1-48, 11PMs), Lead: TUM. Participants: All. Ensure legal and ethical standards for data handling throughout the whole project, including determining data to be shared in the open data initiative. A formal Data Management Plan (DMP) will be produced covering procedures for identification, collection, indexing, access, maintenance, transfer and potential public archiving of all data, including metadata. Tangible outcome: Data Management Plan and Ethical Framework (D1.1).</p> <p>Task 1.3: Risk management & quality assurance (M1-48, 16 PMs) Lead: McNeel. Participants: All. Our quality assurance plan will guide and monitor scientific and technical outputs, detect risks and take corrective measures as necessary with the help of a Quality and Risk Manager (QRM). QRM will establish a platform to support knowledge sharing, transfer and storage of key documents, document lifecycle management and internal communication between consortium partners. After each major stage of the project, the QRM will conduct a risk assessment. Tangible outcome: Risk log and quality assurance plan (D1.2).</p>												
No.	Description					Month(s)						
D1.1	Data management plan					6						
D1.2	Preliminary risk and quality assurance plan					9						
D1.3	Report of year 1					12						
D1.4	Technical/scientific review meeting documents 1st meeting					13						
D1.5	Report after 2nd year					24						
D1.6	Technical/scientific review meeting documents 2nd meeting					31						
D1.7	Risk and quality assurance plan					36						
D1.8	Report after 3rd year					36						
D1.9	Technical/scientific review meeting documents 3rd meeting					48						
D1.10	Final reports					48						



5.2 Work in the second year

5.2.1 General overview

WP1 is responsible for overall project organisation including meeting deadlines for the submission of deliverables. Up to the time of writing this report (M 24), all deliverables have been submitted in time. These included:

- D1.1 Data Management Plan (M6)
- D1.2 Preliminary Risk and Quality Management plan (M9)
- D1.3 Report of first year (M12)
- D2.1 Website and project logo (M9)
- D2.2 First report on dissemination and communication activities (M12)
- D2.3 First dissemination and exploitation plan (M12)
- D3.1 Prototype technical requirement report (M12)
- D3.2 Draft ECOLOPES platform architecture (M12)
- D3.2 Draft ECOLOPES platform architecture (Month M 19)
- D4.1 Preliminary EIM Ontology (M12)
- D5.1 Development process for ECOLOPES algorithmic tools (M12)

In the second year, we have basically followed the procedures laid out in the first year of the project. There were only a few changes:

- The meeting structure has been changed. While there are still monthly online meetings of the entire consortium, the individual WP meetings that used to take place basically every month now only take place every three months or so. Instead, we have created several conceptual and technical meetings, that take place regularly. The underlying reason is that because of the very integrated nature of the ECOLOPES project, many developments take place needing contributions from different work packages. Instead of creating “Inter-WP” meetings, we have bundled topics in a new meeting structure that is described in the following sections.
- The responsibility for the development of the ontology has been transferred to the TU Vienna where personnel resources are provided to this purpose (task 4.7)

5.2.2 Project organisation

The organisational structure in ECOLOPES is described in some detail in deliverable D1.2. Basically, the structure was designed in such a way that it:

- (i) provides an efficient decision-making structure;
- (ii) ensures the involvement of all partners in the decision-making processes;
- (iii) provides efficient management procedures that will keep the project performing on time, with high quality of results and within the budget;
- (iv) ensures smooth communication with the European Commission;
- (v) involves key experts from outside into the project steering procedure; and
- (vi) provides a mechanism for the prevention and resolution of disputes.



Figure 5.2.2-1 describes the project management structure that is unchanged. All responsibilities and competencies are divided among: The Coordinator (CO), the Exploitation and Dissemination Manager (EDM), the Quality and Risk Manager (QRM), and the Work Package Leaders (WP Leaders). Furthermore, three groups are formed that include members of the Consortium or external partners that have specific responsibilities: The General Assembly (GA), the ECOLOPES Project Management Board (PMB), and the End User Advisory Board (EUAB). A more detailed description of the role of each of the groups, and the names of the people leading the WPs is given in deliverable D1.2.

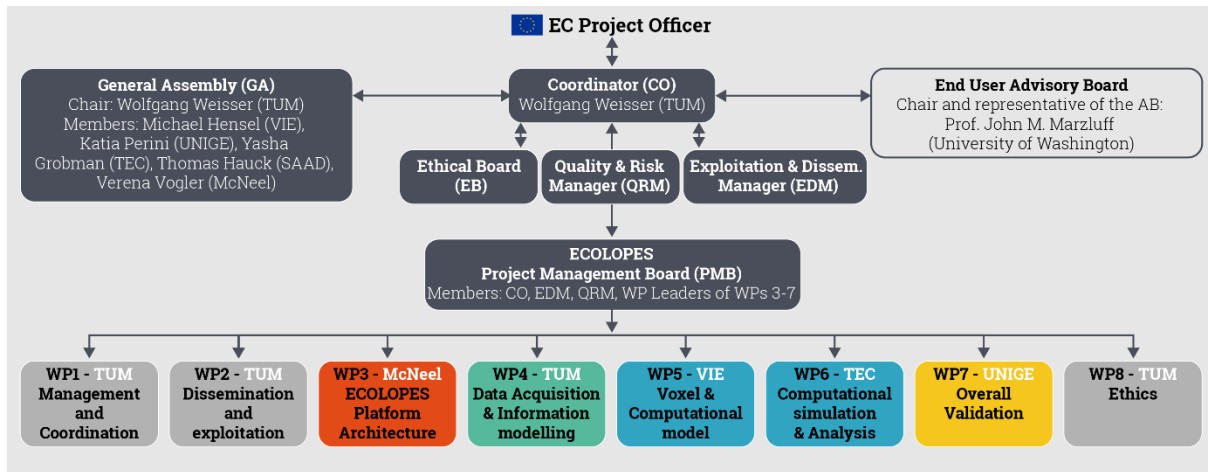


Figure 5.2.2-1: The project management structure of ECOLOPES.

5.2.3 Advisory board

ECOLOPES recruited several external experts to obtain regular feedback on the work (Table 5.2.3-1). Prof. J. M. Marzluff currently acts as head of the advisory board (AB). There are some changes in AB membership compared to the proposal. The members of the AB have complementary expertise in both theoretical and practical aspects of sustainable design related to human-nature interactions.

Table 3.2.3-1: Advisory Board members.

Member	Company/ University	Field of Expertise	Short description
Prof. John M. Marzluff	School of Environmental and Forest Sciences University of Washington Seattle	James W. Ridgeway Professor of Wildlife Science, Ecology, human ecology	Prof. Marzluff studies the relationship between humans and birds to discover how best to conserve wildlife in our modern, human dominated world. Partnering with colleagues in urban planning, medicine, and natural resource agencies he strives to make our research relevant to policy makers, managers, and citizens.



William Myers	Guest Curator: Science Gallery Rotterdam MIT Museum	Architecture, Ecology, Dissemination, Biodesign	William Myers is a curator, author, and teacher based in Amsterdam. His book <i>Biodesign</i> (2018) identifies the emerging practice of integrating biological processes into design and architecture.
Stefania Manca	Municipality of Genoa; Urban Agenda & Green Transition Office	Urban planning, Smart cities	Stefania Manca is the Resilience Manager of the Municipality of Genoa and head of the Urban Agenda & Green Transition Office; Technical Coordinator Partnership on Adaptation to Climate Change; project leader of the Action Plan of Genoa considering the current global changes. She currently works in the Innovation, Quality and Economic Development Department of Genoa Municipality.
Dr. Timothy Beatley	Department of Urban and Environmental Planning School of Architecture University of Virginia	Urban planning	Timothy Beatley's work focuses on the subject of sustainable communities, and creative strategies by which cities and towns can fundamentally reduce their ecological footprints, while at the same time becoming more livable and equitable places.
Sophie Deramond	Cartier Dalix	Architecture	The famous French practice ChartierDalix architecture is well-known for extensive greening of their buildings and for integrating biodiversity into their design.
Chiara Wolter	Project Manager - Energy and Renewables, Architect Ambiente Italia Srl Energy Department	Energy, Architecture	Architect, with main experience in energy saving in residential buildings as well as in commercial and industrial plants, set-up of development scenarios for the impact of energy efficiency measures at urban and territorial level, as well as monitoring systems.
Dr. Marie Standl	Head of Research Group 'Allergic Disease Epidemiology', Helmholtz Centre Munich	Epidemiology	Dr. Marie Standl background is in statistics with focus on statistical modelling of high dimensional data. The current research focus includes the potential role played by gene-diet interactions and health, primarily chronic diseases during childhood, and the interplay of lifestyle, environment (e.g., greenspace and air pollution), genetic and metabolic factors.



Dr. Isabelle Boulangeat	PhD, Chargée de recherches LESSEM (Laboratoire Ecosystèmes et Sociétés en Montagne) INRAE Lyon Grenoble	Ecology, Plant modelling	Her research aims to understand the dynamics of socio-ecosystems, from a theoretical viewpoint to conservation issues in alpine ecosystems. She seeks to improve biodiversity models of species distributions and community dynamics in mountain ecosystems, without neglecting the interactions with the society. She is the creator of the FateHD model, used for modelling plant dynamics in this project.
Dr. Cédric Pruski	Senior Researcher ITIS Department Luxembourg Institute of Science and Technology (LIST)	Ontologies	Cédric Pruski's research interests are Artificial Intelligence and knowledge representation and reasoning. He successfully coordinated national and international research projects that have generated many publications in major conferences and peer-reviewed journals of the field Artificial Intelligence and knowledge representation.

5.2.4 Microsoft Teams platform

In year 1 of the project, we have introduced the Microsoft Teams platform for internal communication and document sharing (Fig. 5.2.4-1). The consortium uses Teams for calls, chats, and scheduling meetings (calendar function). Meeting protocols, notes and internal progress reports are also shared through Teams. The platform links to MIRO boards that are used to develop workflows.

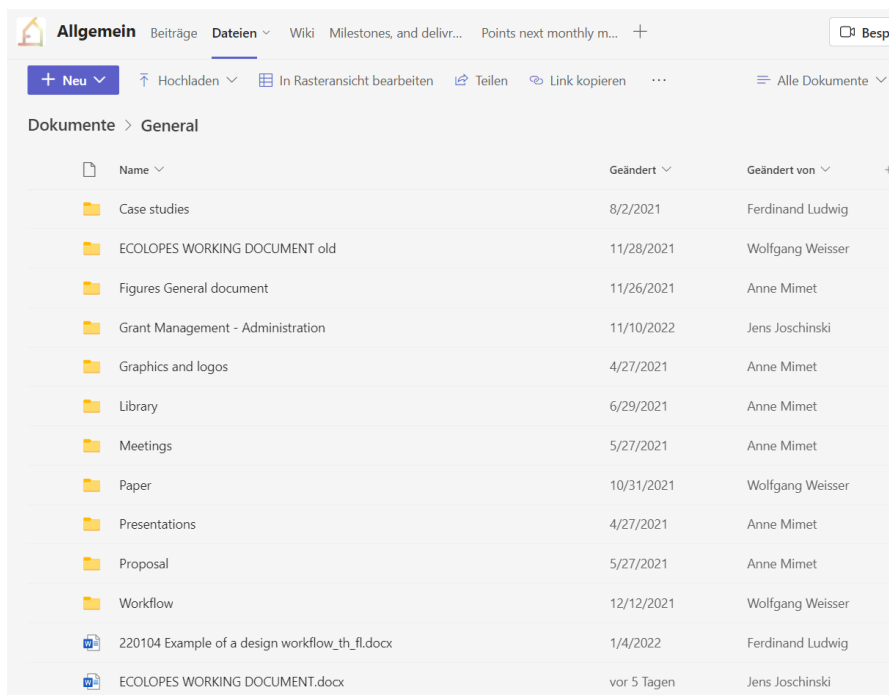


Figure 5.2.4-1: Screenshot of the TEAMS management platform (19.3.2023)



5.2.5 Meeting structure

In addition to the Project Management Board meetings (every three months, see Deliverable D1.2) and the annual General Meeting (see below), the consortium has established a number of other regular meetings. These include a monthly meeting for all members of the consortium, as well as topical meetings, both WP-related and on cross-cutting issues. As the project has progressed, these cross-cutting meetings has become more important and largely replace the WP meetings and discussing project progress. In mid-2022, the coordinator introduced a new meeting structure with topical conceptual and technical meetings, see below.

5.2.6 Monthly consortium meetings

The consortium meets every month, on the first Tuesday of the month, via Teams. Originally, the time was 15.00-18.00, but because of the introduction of the ECOLOPES Talks series, the time has been shifted to 1400-1700. The monthly meetings are used to report on the progress done with respect to particular topics. There also used to discuss fundamental issues that have been brought up in one of the conceptual meetings. The meetings are important for overall communication, exchange of ideas and for making progress in topics of general relevance.

5.2.7 Regular topical meetings

In order to facilitate communication within the ECOLOPES project, a fixed time-slot per week has been reserved on Mondays 9-11. This time-slot is used for many of the meetings on cross-cutting topics, and also for WP meetings.

Following discussions on the need to better integrate the work of different work packages while at the same time minimising the number of meetings necessary, a new meeting structure was introduced in mid-2022 (Table 5.2.5-1).

Individual WP meetings still occur at the frequency fixed by each WP leader according to the WP needs, mostly at 3-months intervals, to review progress task by task.

An exception are WP2 meetings that occur at least monthly, to ensure smooth communication and dissemination activities.

WP1 uses the monthly general meeting and the PMB meetings discuss administrative and organisational issues.

All meetings (except the PMB meeting) are open to all members of the consortium, but it is the responsibility of the responsible persons for meeting to make sure that all relevant people are involved.



Table 5.2.5.-1: Structure of topical meetings in the ECOLOPES project (without the monthly consortium meeting, the project management board meeting, and yearly general meeting)

Meeting (responsible person)	Content
Conceptual meetings	
Computational workflow conceptual meeting (Verena Vogler - McNeel)	Further development of computational platform, conceptual issues
Design and optimisation, and KGF conceptual meeting (Shany Barath- Technion, Verena Vogler-McNeel, Anne Mimet and Wolfgang Weisser-TUM)	Further development of the design process Definition of next step of KGF simulations/development Discussion of results
Ecological model conceptual meeting (Anne Mimet- TUM)	Further development of ecological model based on demands of KGF Discussion of ecological results
User workflow meeting conceptual meeting (Thomas Hauck-SAAD, Ferdinand Ludwig-TUM)	Conceptual development of workflow, identification of challenges and opportunities for design process
Generative design conceptual meeting (Michael Hensel-VIE)	Development of generative design process Ontology development
Technical meetings	
Design and Optimisation and KGF technical meeting (Verena Vogler-McNeel, Shany Barath-Technion)	Technical realisation of computational workflow and Knowledge Generation Framework
Ecological and environmental models technical meeting (Enrica Roccotiello-UniGE, Anne Mimet-TUM)	Realisation of requirements for ecological and environmental models set by KGF Discussion of results
Plant-soil model technical meeting (Jens Joschinski-SAAD)	Further development of plant soil model Plant functional groups, data generation
Animal model technical meeting (Victoria Culshaw-TUM)	Further development of animal model Animal functional groups

5.2.8 General Assembly

The General Assembly takes place once every year. It aims to present the current state of the project, identify emergent problematics and solutions, and get feedbacks and recommendations from the advisory board. So far, three general assemblies have been held.

The next General assembly will take place in April 2023 in Genoa, Italy, and will be organised by the team of the University of Genoa.



Figure 5.2.8-1: Photo of the General Assembly post-work Dinner at the Bräustüberl Weihenstephan in Freising, 9.5. 2022.

Table 5.2.8-2: ECOLOPES meetings during the second year of the project.

Meeting	Participants	Host	Venue	Date	Project Month
Kick-off meeting 2021	Consortium and Advisory Board members	TUM	Online meeting hosted on the Zoom platform.	12.– 13.04.2021	M1
General Assembly 2021	Consortium and Advisory Board members	MCNEEL	Hybrid meeting held in Barcelona.	30.11.– 02.12.2021	M8/ M9
General Assembly 2022	Consortium	TUM	Hybrid meeting held in Freising	9.5. – 11.5.2022	M14
PMB in-person meeting 2022	PMB	TUM	In-person meeting held in Freising (in addition to 4 online meetings)	8.10. 2022	
General Assembly 2023	Consortium and Advisory Board members	UniGe	University of Genoa (partly hybrid)	17. -19. 5.2023	M25



6 WORK PACKAGE 2

6.1 Work package description, tasks and deliverables

WP no.	2	WP title					Dissemination and exploitation				
Lead partner	TUM		Start month		1	End month		48			
Partner no.	1	2	3	4	5	6					
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel					
PMs/partner	12	10	10	10	6	3					
<p>Objectives: WP2 addresses the engagement activities towards our Stakeholder Networks (SNs), incl. actors in the AEC sector and the policy/regulatory framework. It includes disseminating and communicating the project results - especially the EIM Ontology and simulation platform, and outcomes of the validation activities - through different communication channels incl. peer-reviewed publications, articles in technical journals, conference presentations, social media post success stories, organization of workshops and seminars, content production downloadable from our project website, as described in our preliminary DEP.</p>											
<p>Task 2.1: Establishment and dialogue with Stakeholders (M1-48, 13PM) Lead: TUM, Participants: All</p> <p>Identify and engage the relevant stakeholders for the AEC sector (e.g., professional organisations) and key supporting actors (e.g., local administrations and environmental bodies), as per our preliminary DEP. Define a strategy for identifying and engaging each stakeholder type, including the most adequate dissemination channels and key messages to reach them. Tangible outcome: Key stakeholder Network directory and engagement strategy.</p>											
<p>Task 2.2: Dissemination implementation and evaluation (M1-48, 18PMs), Lead: TUM, Participants: All</p> <p>This task will implement, regularly monitor and evaluate the impact of dissemination activities (Tables 1,2). Dissemination efforts will be adjusted where needed. The written (e.g., media partners, newsletters, academic and technical journals), online (social media, e-news and project website) onsite (e.g., conferences and workshops) dissemination channels will be mapped, to define their best use within ECOLOPES project. Contents and outputs of WPs 3-7 will be disseminated using relevant formats. Tangible outcome: DEP and Report on dissemination and communication activities</p>											
<p>Task 2.3: Exploitation plan (M1-48, 20PM), Lead: TUM, Participants: All</p> <p>Ensure full exploitation of the project results from both the economic and scientific perspective, with special reference to ECOLOPES' key outputs, i.e., EIM Ontology and simulation environment. All potential exploitable assets and IP arising from the project will be identified and categorized according to their potential impact at commercial/academic research levels, including a detailed roadmap for addressing potential IP issues (e.g., property and IPR distribution among partners). Tangible outcome: Dissemination and Exploitation Plan (feeds into D2.1).</p>											
No.	Description					Month(s)					
D2.1	Website and project logo					2					
D2.2	First report on dissemination and communication activities					12					
D2.3	First dissemination and exploitation plan (DEP)					12					
D2.4	Second dissemination and exploitation plan (DEP)					30					
D2.5	Second report on dissemination and communication activities					30					
D2.6	Final Dissemination / exploitation plan (DEP)					48					
D2.7	Final report on dissemination and communication activities					48					



6.2 Work in the second year

Deliverable D2.3 “First dissemination and exploitation plan” describes the dissemination and exploitation strategy of the consortium. All activities of WP2 in year 1 have been described in deliverable D2.2 “First report on dissemination and communication activities” which was submitted along with this document. In the following we describe the work done in regard to dissemination and exploitation since these reports, especially focusing on the activities addressing the reviewer's feedback.

6.3 Dissemination

6.3.1 Website

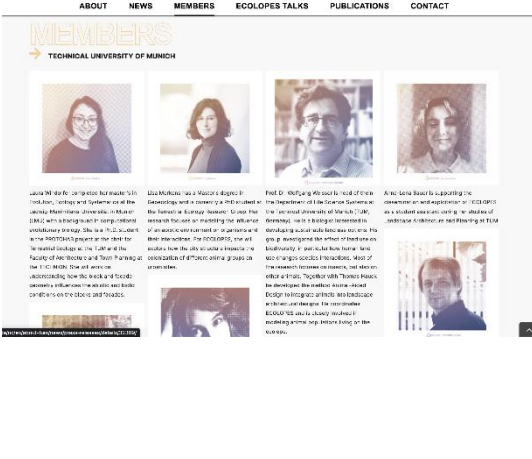
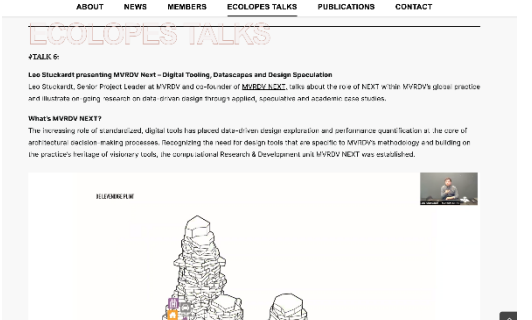
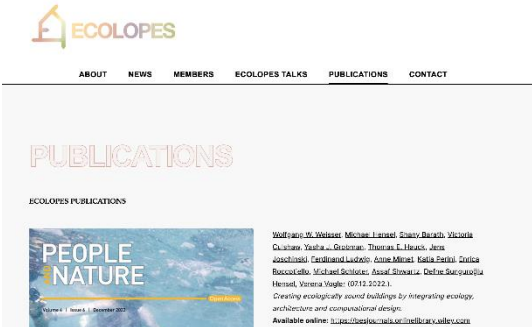
The ECOLOPES website can be accessed here: <https://ecolopes.org/>

During the process of redesigning the website, emphasis has been placed on aligning ECOLOPES’ graphic language with the website and increasing the interactivity of it. The ECOLOPES colour scheme is represented by the headings of the different tabs. Social Media Buttons as well as partners and involved institutions are more visible by displaying them in the header and footer, respectively. In general, the interactivity of the website has been improved by including non-rigid elements, changes in sizes of elements and layout structure.

Table 6.3.1-1: Description of the ECOLOPES website.

Website Tab	Description of Content	Screenshot
ABOUT – First page	The first page gives an overview about the project’s main goals via a graphic and text. The graphic will be replaced with an animated explanatory video about the project, which is currently under development	
NEWS	The tab links to the project’s Social Media Channels on which news are shared on a regular basis. It gives the visitor the option to follow the project on the different social media platforms	



<p>MEMBERS</p>	<p>The member section distinguishes between the involved institutions, the members of each institution, and the members of the advisory board. Emphasis is placed on the operationally active members via an interactive layout that presents each member with a photo and link for further information.</p>	
<p>ECOLOPES TALKS</p>	<p>The tab displays all ECOLOPES TALKS that have been taken place with a short description and the embedded video recording of the TALK. Furthermore, announcements for upcoming TALKS are posted.</p>	
<p>PUBLICATIONS</p>	<p>Publications are displayed with a picture and citation. Publications can be accessed via link or by clicking on the picture.</p>	

6.3.2 Social Media

Facebook

So far, we have been able to reach more than 30.000 users on a daily basis (around 10.000 cumulated) on Facebook, as shown in figure 6.3.2-1. Figure 6.3.2-2 shows key events/posts that lead to an increase of outreach. It becomes evident that especially the ECOLOPES TALKS announcements led to an increase of the outreach. This means that the project benefits from the reach of the speakers that are tagged in the post. Moreover, this could be explained by the fact that the TALKS announcements have been shared in Facebook groups identified as relevant target groups for the project.

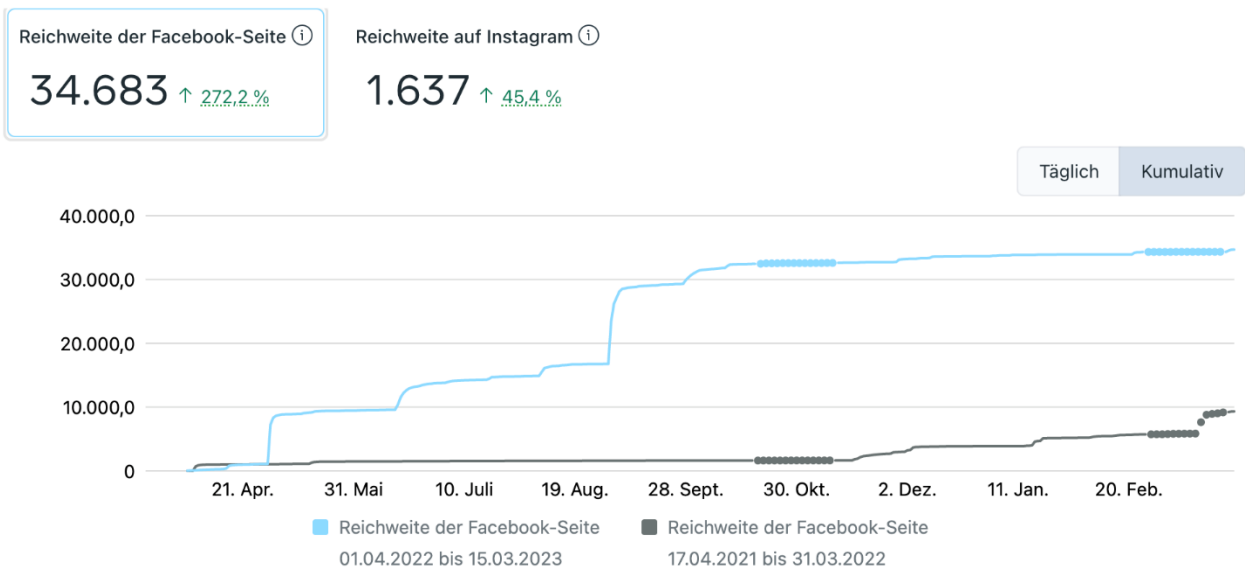


Figure 6.3.2-1: Development of the outreach on Facebook (19.3.2023)



Figure 6.3.2-2: Key events/posts that increased outreach on Facebook (19.3.2023)

Instagram

On Instagram we could reach around 1.600 users on a daily base (around 1.200 cumulated, see 6.3.2-3).

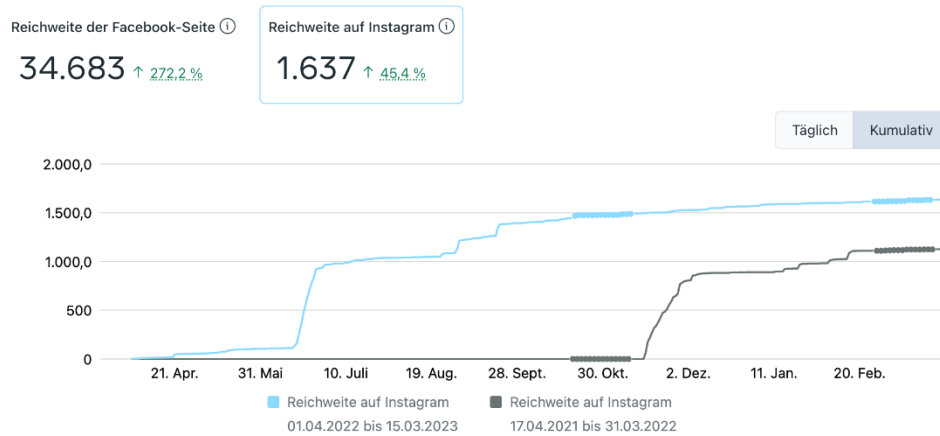


Figure 6.3.2-3: Development of the outreach on Instagram (19.3.2023)

LinkedIn

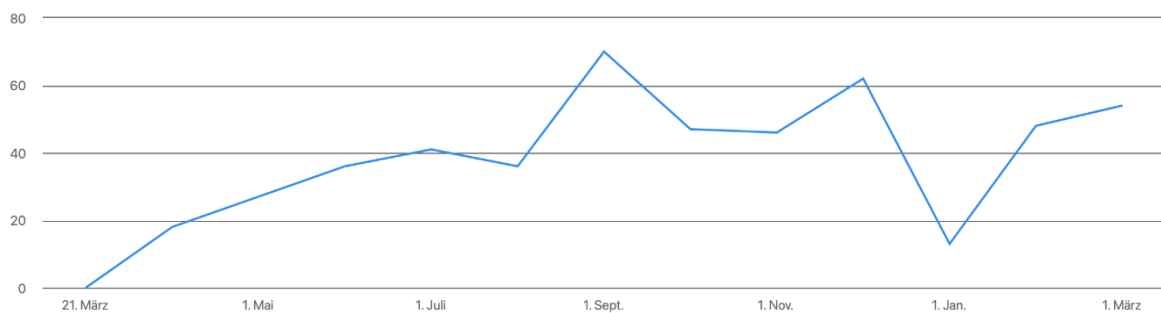


Figure 6.3.2-4: Site visits from 21.03.2022- 20.03.2023

- 966 Page visits
- 1287 Follower
- 19 Posts

Top locations of visitors:

- 8% Munich (Metropolitan Region)
- 7% Genoa (Metropolitan Region)
- 6% Berlin (Metropolitan Region)
- 5% Austria
- 4% Zurich (Metropolitan Region)
- 3% Barcelona



Career level of site visits (from 20.03.2022-20.03.2023)



Figure 6.3.2-5: Career level of site visits from 20.03.2022-20.03.2023

6.3.3 ECOLOPES Talks

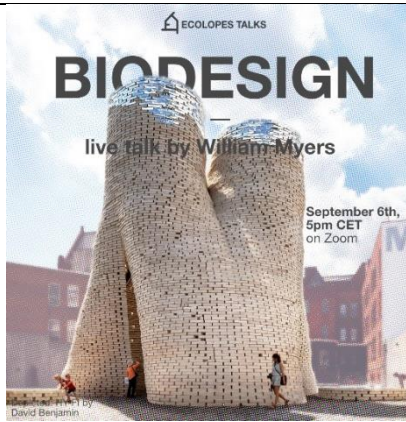
The ECOLOPES TALKS series has been launched in April 2022 with the presentation from Helga Fassbinder about the “Biotope city”. During the following year, five more TALKS have been taken place with hosts spanning from architecture to ecology, computer sciences and beyond. The TALKS provide a platform for an exchange across disciplines, but also significantly contributed to an increase of the project’s outreach, as elaborated under section 6.3.2. Participants can join the online events via the livestream on Facebook or directly on zoom by registering to our [online platform](#). In total, 360 people subscribed to the project’s newsletter. The average number of participants in the TALKS is around 50. We are looking forward to hosting the first ECOLOPES TALKS hybrid event at the Genoa-Meeting in April with Andrea Balestrini, a landscape planner based in Italy.




Table 6.3.3-1: ECOLOPES talks given in 2023-2023

TALK Nr. & Date	Description	Poster
#1 4/5/22	Helga Fassbinder is the founder of the journal and the concept “Biotope City”. The Biotope City concept is based on the realization that we and our cities do not form an antagonism to nature, but that our cities are nothing else but one other of the many forms that constitute nature. Helga presented and discussed the concept as well its implementation in the “Biotope City Wienerberg” in Vienna.	
#2 5/3/22	Professor John Marzluff from the University of Washington spoke about his book “Welcome to Subirdia” in which he reveals findings from his long-term research on birds along urban gradients and gives insights how species are adapting in the face of urban development. We also got some surprising perspectives about the role of semi-urban environments in keeping common birds common.	
#3 6/7/22	The french architects ChartierDalix aim to bring architecture and ecosystems to harmonious coexistence. They presented their visionary research and designs in the ECOLOPES July Talk	



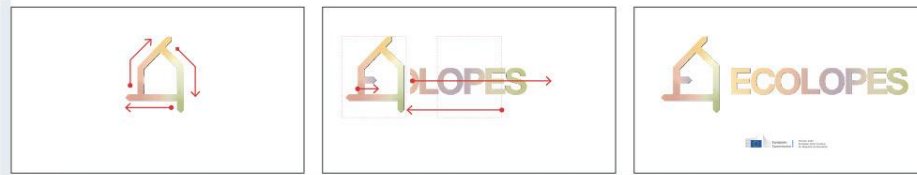
<p>#4 9/6/22</p>	<p>William Myers is a curator, author, and teacher based in Amsterdam. His book Biodesign (2012 and 2018 editions) identifies the emerging practice of integrating biological processes into design and architecture. It is published by the Museum of Modern Art (MoMA) in New York and Thames & Hudson worldwide. Biodesign is the next step beyond biology-inspired approaches to design and fabrication. It refers to the incorporation of living organisms as essential components in design, enhancing the function of the finished work. The depicted structure is made by David Benjamin and consists out of Mycelium bricks grown from agricultural waste and fungi, reflective plastic molds, repurposed scaffolding boards.</p>	
<p>#5 10/4/22</p>	<p>In the fifth ECOLOPES TALK, Chiara Catalano spoke about the habitat template approach which considers nature as a model for the designing of Urban Green Infrastructure. The ecological understanding of natural habitats is essential to mimic them in cities and to design niches providing refugia and alternative habitats to certain plant and animal species. The monitoring of urban habitats gives insights on their adaptive dynamics over time and provide for guidelines for new projects and retrofitting of existing greened areas. The design for nature, having a net-positive impact on biodiversity, requires multidisciplinary teams and thinking driven by the analysis of spatially explicit ecological data and supported by integrative and modelling tools.</p>	
<p>#6 11/1/22</p>	<p>Leo Stuckardt, Senior Project Leader at MVRDV and co-founder of MVRDV NEXT, talks about the role of NEXT within MVRDV's global practice and illustrate on-going research on data-driven design through applied, speculative and academic case studies.</p>	



<p>#7 planned</p>	<p>Andrea Balestrini is a landscape planner with experience in nature-based solutions, public space design and landscape governance within international R&I projects and consultancies. He will talk about the role of the quantification of ecosystem services within the process of sustainability certifications and decision-making. Combining this knowledge with data-driven planning procedures, LAND developed its own methodology to quantify and communicate performances of ecosystems services from soil and vegetation, thus contributing to natural capital accounting procedures.</p>	
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6.3.4 Explanatory Video

We have developed the narrative and storyboard to disseminate the ECOLOPES research project to a general scientific audience through an Explainer video format. We will be coordinating the development of the video with ProLehre, the media department in TUM. The animated video is expected to be approximately three minutes long. The general overview of the video will highlight the general research context, the existing knowledge gaps and challenges, a description of an *ecolope*, an overview on the ECOLOPES Work Packages, the ECOLOPES Vision, and a call-to-action that will direct viewers to the official website and social media platforms. The following images depict the finalized storyboard which showcases representative imagery of the animation sequences.



SCENE 1 [Intro] (Duration: 5s)

-no narration-

-no narration-

-no narration-

ECOLOPES Logo Animation
Arrows are animated simultaneously and centered on screen.

ECOLOPES Logo Animation
Arrow in logo center is animated while the text slides in behind the logo.

ECOLOPES Logo Animation
Horizon 2020 logo fades in at the bottom



SCENE 2 [Research Context] (Duration: 25s)

Urbanisation...

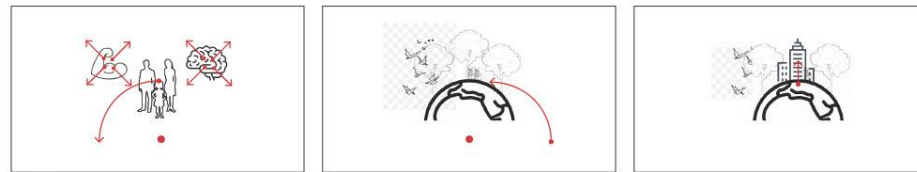
...a major 21st century global environmental issue that...

...affects our...

Image layers on top of the animated logo

Block text appears as the script is read - layered on top of the image

Image is cropped using a circle



SCENE 2 [Research Context] (Duration: 25s)

...physiological and psychological well-being.

It also alters natural ecosystems which...

...significantly impacts urban biodiversity.

Human icons are revealed in the back with muscle and brain icon appearing according to the text timing. Human icons rotate out of frame.

Semi-circle world appears with trees and birds and mammals of our choice.

Some of the birds, trees and mammals of our choice are removed. While buildings appear in the background.



SCENE 2 [Research Context] (Duration: 25s)

For more sustainable,...

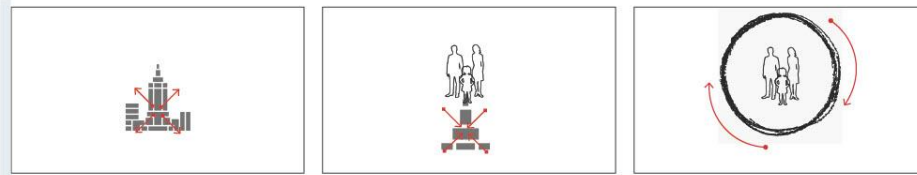
...resilient, and livable cities...

...we need holistic and interdisciplinary design solutions.

All the other icons fade out and Buildings fall on a "floor". More buildings slide in to create a cityscape. Building outline turns ecolopes green during "sustainable"

Outlines turn ecolopes purple and peach with each mention of the text. Right pulse of the cityscape with each keyword. Cityscape moves out of frame to the bottom.

Circles appear when "holistic" is mentioned and arrows appear when "interdisciplinary" is mentioned. Circles scale down to the center.



SCENE 3 [Knowledge Gaps] (Duration: 30s)

However, our dependence on Grey Infrastructure and attempts at Green and Brown Infrastructure...

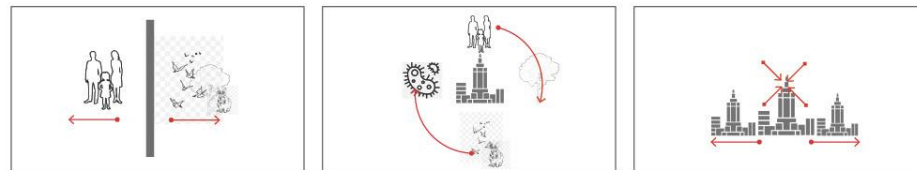
...are primarily anthropocentric solutions.

This places humans in the center of the design space...

Building blocks (outline) appear from where circle is scaled down.
Blocks turn grey, green, and brown when the infrastructure is mentioned.

Zoom in to the top of the tower to reveal human icons from before

Pencil circle stroke appears around the human icons.



SCENE 3 [Knowledge Gaps] (Duration: 30s)

...perpetuating the human-nature dichotomy.

We need cities that equally prioritise our needs, and those of plants, animals, and even associated organisms such as microbiota

This will enable nature to co-evolve with us in an integrated ecosystem within the urban environment.

Human icon moves left.
Nature icons appear right.
Hard line appears in between.

Line breaks into city building blocks.
All the icons appear to the same scale and rotate around the city blocks.

Icons scale into the cityscape and the building blocks change.
More building blocks appear to form a larger cityscape.



SCENE 4 [An Ecolope] (Duration: 20s)

We propose a radical new approach to architecture...

...a new paradigm for the urban fabric and its vast urban surfaces;

The transformation of building envelopes into...

Building blocks colours change into the Ecolopes gradient colour scheme.

The borders of the cityscape is outlined in the ECOLOPES gradient.
Zoom into the city scape to reveal Fig 1.

Only "black" outlines are seen.



SCENE 4 [An Ecolope] (Duration: 20s)

...living spaces for multi-species cohabitation...

...called Ecological Building Envelopes.

ECOLOPES.

Image grows to reveal landscape.
Coloured lines appear to show interconnectivity between stakeholders.

Text appears above image in ECOLOPES gradient.

Rest of the text disappears except "ECO" and "LOPES".
Text joins together to form the ECOLOPES text.



SCENE 5 [ECOLOPES Research] (Duration: 50s)

In ECOLOPES, we will provide the core technology to design an ecotope.

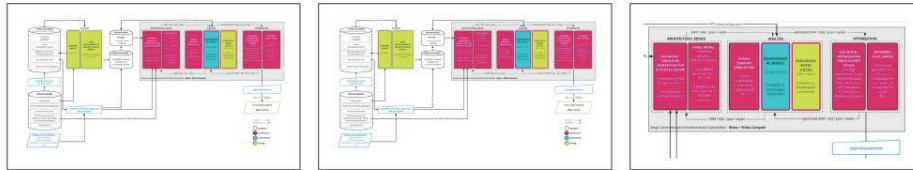
ECOLOPES text is centered.
Gear appears behind it and rotates.
Gear scales down to the center.

With our interdisciplinary research team...

Logos of the institutions and SMEs appear around the text.
All the images scale down to disappear.

...we aim to integrate architectural and ecological...

Architecture and Ecological colours appear in relation to its location on the computational workflow.



SCENE 5 [ECOLOPES Research] (Duration: 50s)

...knowledge, data, and models into a...

Each box will be represented by a simple icon.
Each icon will correspond to the text.

...design recommendation system.

Arrows appear to connect all the containers in an animated way.

This system drives Generative Design and Multi-criteria Decision-making processes...

Zoom into the Generative Design and Multi-criteria Decision-making containers.



SCENE 5 [ECOLOPES Research] (Duration: 50s)

...within a computational modelling and simulation environment.

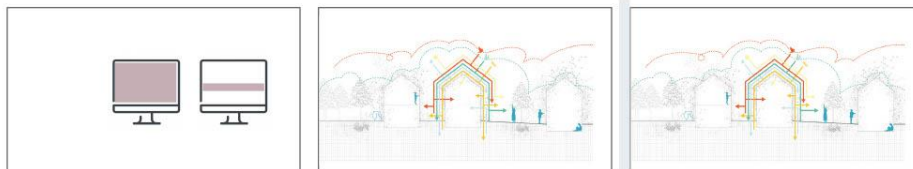
Workflow scales down to reveal a software window.
Box appears as a 3D model in the screen.

At its core, an ECOLOPES Information Model Ontology will guide the system...

Box disappears and EIM appears in typewriter effect.

...to make architectural and ecological knowledge available for design.

Architecture and Ecological icon slide out from the back of the computer.



SCENE 5 [ECOLOPES Research] (Duration: 50s)

This integrated knowledge allows us to identify synergies and trade-offs...

Icons slide back into the computer and the screen turns into the ECOLOPES gradient colour scheme.
Screen "turns off" and computer fades out.

...between the biotic, abiotic, and built environment for more sustainable solutions.

Middle building outline appears.
Biotic: People and animals and plants appear.
Abiotic: Sun, wind and rain appears.
Built environment: Other building outlines appear.

SCENE 6 [ECOLOPES Vision] (Duration: 15s)

Our research in ECOLOPES aspires to restore beneficial human-nature relationships...

Whole scene is animated.

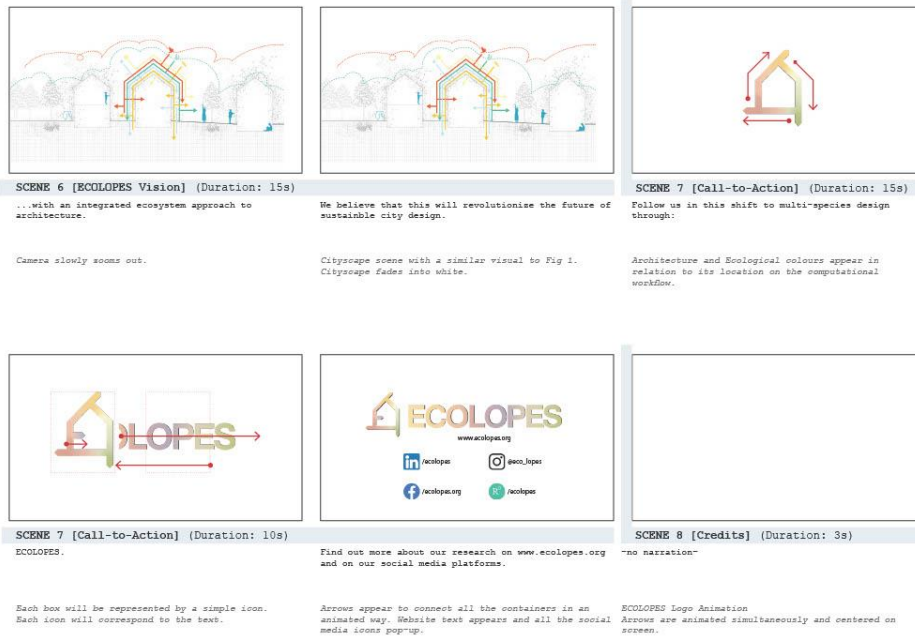


Figure 6.3.4-1: Storyboard illustrating the animation sequences for the ECOLOPES Introductory Explainer video

6.3.5 Team Videos

Short videos – informal to semi-formal

As was suggested by the reviewers, we are enhancing our ECOLOPES project outreach in social media by adding short videos by students, PhDs and PostDocs into our [project website](#) and the various social media platforms where we are currently present (Facebook, LinkedIn, Instagram, Twitter). These short informative videos will facilitate presenting the studio works, individual researchers’ areas of research, thematic focus and interests to a wider audience while capturing their enthusiasm for the project. This will help promote the ECOLOPES studios and researchers as well as raise awareness and interest for the project.

We will adopt three types of videos tailored for students and PhDs, PostDocs and Institutions, ranging from semi-formal, formal to professional.



Figure 6.3.5-1: Screenshot of the repeating elements of the short videos



We encourage the students and PhDs to use the semi-formal format to produce quick and effective videos for publishing online. This involves preparing a personal video focused on individual and group engagement with the project and experience, featuring researcher(s)/PhDs, student(s), team(s), work item(s) and event(s) in their chosen workplace. The video can be about individuals or groups and can feature events, experiments, meetings, studio presentations of interest and can document lab work. It can be executed as an interview.

The first video was shared on social media in September, presenting Francesca Mosca, Unige-DAD PhD student. Other two videos are in post-production (Alexandra Schroeder from TUM and Marta Pianta from UNIGE-DISTAV).

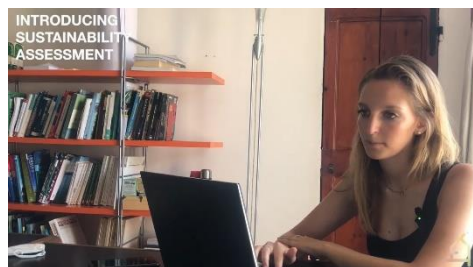


Figure 6.3.5-2: Presentation sequence of young researchers

Genoa video – formal to professional

We're preparing an official promoting video in occasion of the General Assembly in Genoa next April, coordinated by UNIGE e-learning service office.

We will produce a short video (3.00-6.00 min) with:

- Interviews
- Moments from the meetings/presentation
- Talk about future challenges and expected results

6.3.6 Stakeholder Network

Table 6.3.6.-1 Excerpt of the stakeholder network. Names and email can also be extracted, but are not shown in this excerpt.



D1.5. V.03

Id	Professional background	Institution	Keep me updated about ECOLOPES
452dc3e8-d798-42ba-	Masters in Landscape Architecture	LUB	Yes
09539604-373a-42aa-	Student B.arch at Technion, Israel.	Technion	Yes
792d6920-ef54-4b51-t		Technion	Yes
767c2777-5e7b-4536-	Recent Architecture graduate from TU Delft.		Yes
4e6f2e2e-fb1a-4d21-b	architect researcher lecturer	zhaw	Yes
f4ef3987-ad71-48a9-a	journalist	www.gruenes-pre	Yes
8821d02b-05e9-428d-	Architektur	TUM	Yes
838da4f5-4f62-4e37-9	Landscape planning, urban green infrastructure pl	Technical Univer	Yes
421a4931-7281-4541-	Landscapearchitect	selfstanding	Yes
f83d6407-6f23-449d-9	Architecture and Computational Design	CITA (Royal Dani	Yes
651a38c2-fc77-4df0-8	Bachelor's degree in architecture	Universidad de Li	Yes
eefd0dc5-9077-4c71-e	Architect Researcher	EPFL	Yes
639fec58-4623-4723-€	architect + landscape architect		Yes
9474b83d-b38c-467f-€	Postdoctoral research project "Designing and Livi	Swedish School c	Yes
b357192c-3ae6-4ee0-	Consultant	Landsiedlung Bac	Yes
9c9c876b-d2a2-44a9-	Masters in Architecture Masters in landscape arch	LU	Yes
c68d5c65-d51d-4752-	Transdisciplinary researcher focusing on GI and e	TUM/The New Sc	Yes
1054b0cb-e039-4d10-	PhD Candidate Urban planning	TUM	Yes
224e5fd6-a8ce-4582-ac56-c840e506a340		Environmental Me	Yes

Our outreach activities, and in particular our ECOLOPES TALKS have already attracted a high number of interested stakeholders. Contact details of the subscribers, along with a short description of their professional background, can already be extracted and collected in an excel table (Fig. 6.3.6-1), but as subscribers and contacts increase, we will require more efficient systems for managing contacts to fully profit from this network. We are currently in the process of setting up a contact management system that uses google contacts as platform. Tagging contacts according to their role within our network (e.g., “consulting firms”, “architects and engineers”, “Ecologists”, fig. 6.3.6.-2) allows efficiently contacting stakeholders and amplifying our reach. Emails incoming to our Project’s address, as well as participants of the ECOLOPES TALKS are being added to the contact management system, and we plan to identify and add further contacts over the course of the next year. The expansion of the contact management system in alignment with our stakeholder network and dissemination and exploitation plans will be a key objective of the next year, coordinated with our engagement of key decision makers and publication activities (see also table 6.3.8-1).

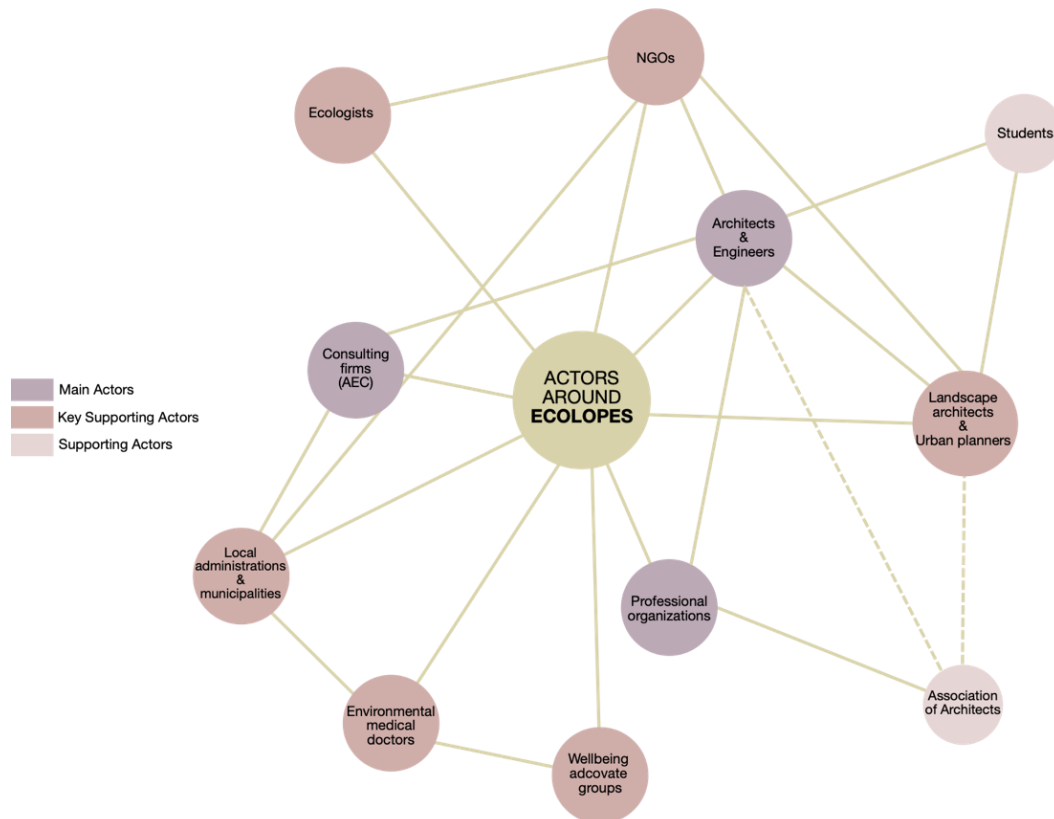


Figure 6.3.6-2. Overview of the stakeholder network. The actors are color-coded according to their role in our network (see deliverable D2.3)

6.3.7 Press Release and Newspaper Article

On the 08.12.2022 there was a press release from the Technical University Munich with the theme "sustainability" and "research" about our project in German with the exciting title "*Ecologes* to promote biodiversity in the city - buildings with ecological envelope". The book chapter "Creating ecologically sound buildings by integrating ecology, architecture and computational design" was also presented. <https://www.tum.de/aktuelles/alle-meldungen/pressemitteilungen/details/gebaeude-mit-oekologischer-huelle>

There was a report in the Mitteldeutscher Rundfunk (mdr) on 21.12.2022 "For more biodiversity in cities: This is how architecture can help", by presenting the necessity of the project. <https://www.mdr.de/wissen/tu-muenchen-mehr-biodiversitaet-staedte-architektur-helfen-100.html?fbclid=IwAR399rTZGQ-OcEokUlcSqjFzZaBxLiBW68QydSzSlFq1qOcytI8-t-Q6LQY>

6.3.8 Overview of communication activities

The analysis of the social media channels after year 2 showed that the performance has been more than sufficient in terms of quantity (number of postings) and the amount of people reached. This means that ECOLOPES has achieved to establish a solid base with their closest stakeholders via social media channels. These are, as underlined by the LinkedIn analysis,



young and experienced professionals in the sectors of (landscape-)architecture, ecology and research institutions in general. With respect to the exploitation of the project, however, there is a need to further strategize the way the audience is reached in the communication of the project in order to connect with specific groups that have been identified as important stakeholders. These are especially key decision makers such as politicians, as well as environmental groups with an influence on policies.

Table 6.3.8-1: Overview of communication activities

Activity	KPI	% reached after 1. year	% reached after 2. year	Comments
Number of ECOLOPES project website visits	9,000		7,217 - 80%	
Average ECOLOPES project website visit duration	2 min		1:56 min - 78%	
Number of ECOLOPES website material downloads	360	0		So far, no materials for direct download on website have been provided
Social media actions on LinkedIn, Twitter, Facebook, Instagram (tweets, blogs, posts, etc.)	360	ca. 25% (90)	69 (insta) + 19 linkedin + 38 twitter + ca. 49 Facebook 79% (285 including year 1)	
Social media followers, across channels	1,200	Ca. 95%	1287 LinkedIn 195 insta 623 fb (52 twitter) 175%	
Number of key decision makers engaged (e.g. Ministry of Planning Bavaria)	20			Activity not started yet
Number of leaflets (short pdfs, summaries, digital)	20			Activity not started yet



presentations) generated				
Number of peer-reviewed research papers generated	15	1 (6,6%)	+5 - 40%	Including Conference Proceedings (2)
Number of technical articles	20		1 - 5%	1 Book chapter
Number of press releases created	6		1 - 17%	
Number of participants in scientific/academic conferences/seminars	10		24 - 240%	
Number of participants in trade and industry events/fairs/shows	4			Activity not started yet
Number of participants in workshops organized (20 workshops)	400			Activity not started yet
Showcase ECOLOPES in third-party events: eco-architecture, environmental planning, urban design, sustainable architecture, environmental health conferences and symposia	15			Activity not started yet
Number of participants in online streamed events (5 events)	250		108% (270)	Participants in total of the 6 ECOLOPES TALKS
Number of participants in the final closing conference	100			Activity not started yet



Based on the lessons learned about the communication of the project, the following table is currently under progress to adjust the communication strategy. The table gives an overview of all social media channels and their main goal, audience, message conveyed, and content. This allows the team to scope the content provided via each medium and hence more strategically target specific stakeholders of ECOLOPES. While LinkedIn and Twitter are set up by the project to follow similar aims and target groups, LinkedIn has been proven to be a more efficient/suitable medium for the project since most members are better connected on this platform than on Twitter. To focus energies on the most useful tools, we are currently considering to stop our activities at Twitter to make best use of the resources we have.

Table 6.3.8-2: ECOLOPES objectives on the different social media.

Objective	Facebook	Instagram	Twitter	LinkedIn	ResearchGate	Website
Goals & Objectives	Spreading news/ Updating Create network by posting in relevant groups/sites	Create/ display inspiring and coherent story about ECOLOPES Spread news	Building network	Building network	Provide access to published papers	Provide overview of project description, objectives and involved partners
Audience		Semi-professionals / Amateurs: - Students of related disciplines	Professional audience: - H2020 Projects - Higher Education	Professional audience: - Higher Education - Governmental administrations		all parties from other channels, press, Governmental institutions
Further specification		- Bachelor and Master Students of Architecture, Landscape Architecture (and Ecology?) (with focus on countries of involved institutions)	- recently (last 1-2yrs) started H2020 projects focusing on NBS - PHDs and Post-Docs researching in the field of green/ sustainable architecture, terrestrial ecology or NBS			
Message		ECOLOPES gives you interesting insights about the project and related projects inspiring you for your studies	ECOLOPES is an innovative approach relevant for your research	ECOLOPES is an innovative approach relevant for your company/ institution/ professional undertaking ECOLOPES is an attractive employer	ECOLOPES is a serious scientific undertaking	ECOLOPES is a research project working on a breakthrough technology which offers a innovative approach to housing/ buildings within cities



Content	everything produced and or connected to ECOLOPES, as post and in story	post: everything directly connected to ECOLOPES - events, seminar, talks - partners - updated in project story: related/ associated things (everything else)	- everything produced and or connected to ECOLOPES - Retweets	- seminars/ studios - talks - team/ team updates - job postings - reposts of relevant/ associated projects - reposts of undertakings from ECOLOPES members?	- published papers	Education: TALKS, Studios Research: Papers, Conferences, Exhibition About Us: Team, Job posts
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6.4 Exploitation

Exploitation is a specific term for the H2020 Programme, and it means “to make use of the results produced in an EU project in further activities (other than those covered by the project, e.g., in other research activities; in developing, creating and marketing a product, process or service; in standardisation activities).” (European Commission 2018) Within the project, an exploitation strategy will be developed by all partners to identify the potentials for exploitation and application of the results in different societal fields for different users. In order to achieve this, the exploitation potentials in different social fields are first explored and defined. The exploitable key results are blended with the potentials, positioned in the social fields and thus sharpened. With the help of this blending, the relevant stakeholder groups can be precisely identified according to the exploitable key results. (cf. iSCAPE 2019). An Exploitation Workshop will be held at the next General Assembly to identify the exploitable key results and position them in the societal fields. The relevant stakeholder groups will be identified accordingly.

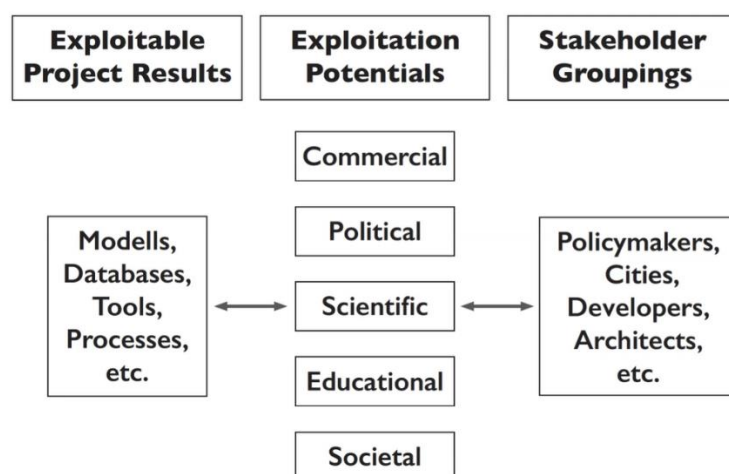


Figure 6.4-1 Structure of the Exploitation Strategy (cf. iSCAPE 2019)



6.4.1 Commercial Exploitation Potentials

For a potential commercial exploitation four fields of actions were identified by the consortium while processing the EC Innovation Radar:

- A. **ECOLOPES Multispecies Design Workflow for regenerative urban ecosystems**
The ECOLOPES Multispecies Design Workflow makes it possible to integrate non-human stakeholders (plants, animals, microbiota) and their interaction with each other and with the built environment of humans in planning and design processes of architecture. Architectural design processes are thereby expanded from an anthropocentric to a multispecies perspective. The new design workflow enables and organizes the cooperation of the disciplines to be able to take a multispecies perspective when planning architecture: architecture, biology and landscape planning. The new design workflow creates the procedural framework for linking the various methods, ways of acting and technical language of the disciplines into a common routine that can be offered as a methodically stringent planning service. The new Design Workflow is closely linked to existing planning processes and design workflows in architecture, so that the change to a multispecies perspective can be completed without major procedural breaks in architecture.
- B. **ECOLOPES Urban Landform Framework for Interdisciplinary Trans-scalar Urban Planning and Architectural Design.** The conceptual and methodological framework links planning and design scales and associated interdisciplinary datasets with particular focus city-nature and architecture-ecology relations. It enables shifting from the current understanding of urban form (urban morphology) as a set of discrete systems (i.e., infrastructure) and objects (i.e., buildings) that foreground divisions to an understanding urban form as landform, as continuous terrain with distinct features that serves connectivity analysis, planning and design on multiple scales and long-term accumulative changes of the city fabric and its consequences for urban environments and urban ecology. It makes it possible to develop a “topographic pattern” (extension and adaptation of the “geomorphon” approach presented by Jasiewicz and Stepinski 2013) and a computational algorithmic toolset for modelling urban landform in a CAD environment to facilitate analysis, simulation and evaluation of diverse city-nature and architecture-ecology relations.
- C. **ECOLOPES Design Platform and front-end toolset (stand-alone/or plug-in)**
The design platform translates the conceptual framework (see B) into a computational framework and integrates the knowledge generation framework to enable a knowledge driven design process for the development of urban building envelopes/facades. It is an open access design platform for generating, analysing and optimizing building envelopes that are developed based on combined knowledge from ecology and architecture. It allows the integration of ecological modelling into a CAD environment. The cloud-based platform integrates all technical components such as open and expert datasets, the ecological model, the knowledge base, an ontology, KPIs, as well as algorithms for design generation and optimization. The Front-end is



provided by an ECOLOPES Grasshopper plugin that allows designers to base their design decisions on ecological analysis and the sustainability rating system (see D).

- D. ECOLOPES Sustainability Rating System. The ECOLOPES Sustainability Rating Systems allows to evaluate building projects from a nonhuman perspective. It evaluates the positive and negative impacts of a project for human and non-human stakeholders (plants, animals, microbiota), considering their relation to each other, e.g., human-nature interaction. Thus, it allows to rate projects from a multi species perspective. It is a novel tool for decision makers involved in the design, planning and implementation of buildings, especially building envelopes. It can be closely linked to existing rating systems and opens new applications for those (such as e.g., LEED, DGNB, living building challenge).

6.4.2 Political Exploitation Potentials

These potentials will be identified in a workshop at the next General Assembly of the project in Genoa in April 2023.

6.4.3 Scientific Exploitation Potentials

These potentials will be identified in a workshop at the next General Assembly of the project in Genoa in April 2023. For the time being we are referring to the list of scientific publications (section 3.1) and conferences attended (section 3.2).

6.4.4 Educational Exploitation Potentials

The exploitation of educational potential was a key focus of the consortium from the beginning on. All university partners make excessive use of the possibilities to test preliminary results and to explore potentials of the ECOLOPES conceptual approach and tools in different teaching formats. In the following we give an overview and some impressions of the teaching activities.

TUM

Bachelor Thesis in Landscape Architecture

Two bachelor theses were supervised at the Chair of Green Technologies in Landscape Architecture in collaboration with the Chair of Terrestrial Ecology (A. Mimet), investigating how tools for determining ecological connectivity (graphhub) can be used to develop urban development concepts from a landscape architecture-ecology perspective. For this purpose, graphical representation methods as well as design scenarios for different target species were explored.



Figure 6.4.4-1: Comparison of urban design variants. Left developed for heat-loving insect species, right for forest-dwelling birds and mammals. (Design and illustration: D. Höhnel)



Figure 6.4.4-2: Connectivity for European tree frog habitats left before urban expansion, middle with conventional urban planning, right with urban development focused on the target species (design and illustration: L. Kiermeier).

Master Thesis in Landscape Architecture

The thesis by Florian Fischer takes up the idea of designing roof surfaces as biodiverse habitat areas with diverse vegetation. A parametric design approach is sought that analyses the environmental factors associated with the building and calculates a proposal for greening based on a reinterpretation of Ellenberg's indicator values. In addition, structural elements are identified that enhance the quality of the habitat area. The theoretical concept for the evaluation of suitable plant species is validated at the end of the thesis by five case studies.

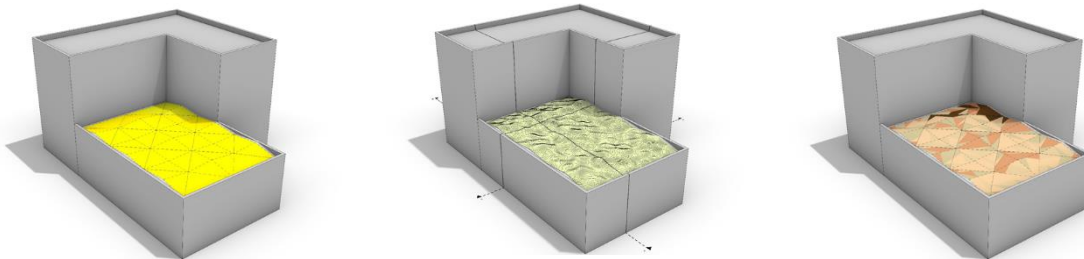


Figure 6.4.4-3: Analysis of the growth parameters light (left) and substrate strength (middle) as well as the resulting species distribution according to Ellenberger (right). (F. Fischer)

UNIGE

Master Degree in Architecture

During the last Summer Semester, within the design studio “Project, Technology, Environment”, the design object was the functional and energy refurbishment of a large building, used for public social housing, partly dismissed due to inadequate performance. The course aimed to put the student in a design context as realistic as possible, from a normative and environmental point of view, according to different meanings (physical, climatic, ecosystems point of view).

A focus on the ECOLOPES approach was developed asking students to use green envelope solutions such as to attract local fauna (avifauna and entomofauna), to improve the biodiversity of the area). The target site was a building located in a peri-urban area of Genoa, close to (and the proximity) to natural core areas.

Students were supported by two professors in Architecture and by an engineer and a botanist respectively for the design, the energy modelling and for the ecological part. The following images show some results from the studio.



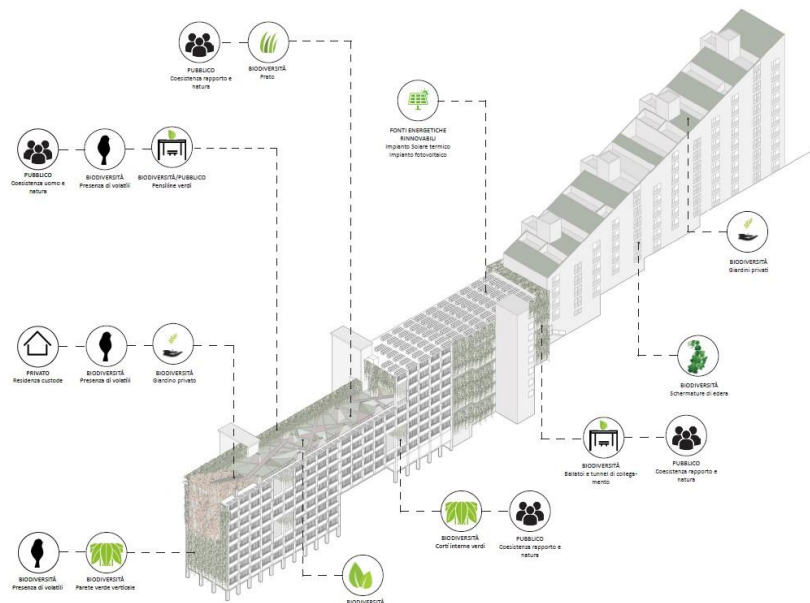


Figure 6.4.4-4: Results from the Genoa Master studio



During the current semester, the design studio “Design Technology and Environment”, with Professor Adriano Magliocco and Francesca Mosca, is dealing with the ECOLOPES approach focusing on new strategies for ecological building envelopes within a new construction for a residential building in Genoa. In addition, students will run CFD simulations of the design output to explore the contribution of vegetation to reduce urban heat island effect and improve local thermal comfort.

Bachelor Degree in Architecture and Landscape Architecture

During the last summer semester, in the "design of green technology for architecture" course held by Katia Perini with Francesca Mosca (Unige DAD), and the “Botany Applied to Landscape” held by Enrica Roccotiello with Marta Pianta (Unige DISTAV), bachelor students from architectural, design, and applied botany background worked together on a design exercise. The aim of the activity was the design of a green envelope able to promote multitrophic networks (e.g., plant-insect-bird's interactions) and improve the local biodiversity by favouring native species. The target site was a university building of the Engineering Department of Genoa. The exercise started with the creation of interdisciplinary working groups of students and the definition of architectural and ecological design objectives. These objectives led the development of the design of the envelopes during the entire course. Moreover, a list of native plant species suitable to be employed on green envelopes was provided to students. For each species were also reported some characteristics (e.g., life form, ecological needs, etc.,) and ecological functions (e.g., interaction with pollinators, soil formation promotion, etc.,), to support students during the plant species selection according to the defined ecological objectives and the local site conditions. The result were technical plans in which each group demonstrated a simultaneous evaluation of architectural, ecological, and design aspects. The following images show some results from the exercise.



We aimed to make the building envelope hospitable to all forms of life, improving both thermal and aesthetic quality of the building. We chose native plant species that could attract both insects and birds. They help interspecies coexistence and supports the biodiversity. The materials of the structures are recycled and recyclable.

In the logo there are three hexagons in the upper part representing plants, insects and birds. Below them there's a house, symbolising the anthropic environment. This suggests how man, without respect and care for nature, can only lose in the near future. "Coesa" which means "cohesive" is the ambition of the project.

The facade holds a hexagonal mesh structure anchored to the wall made of wood and metal. On it are fitted container pots for plant species, insect hotels for attract pollinating insects and nests for birds. We opted for a 'green roof', calls to mind the waves and the hills: a renaturalised place with as little maintenance as possible.



OBJECTIVES:

- Aesthetic improvement
- Energy efficiency
- Improvement of air quality
- Accessibility

NEUTRALITY TO PROMOTION:
The facade is made of recyclable materials which can be recycled more than once. The facade is made of wood and metal.

BUILDING EFFICIENCY:
The facade is made of wood and metal. It is made of wood and metal.

PERFORMANCE OF THE GREEN WALL:
The facade is made of wood and metal. It is made of wood and metal.

ACCESSIBILITY:
The facade is made of wood and metal. It is made of wood and metal.



LEGEND:

- CURTAIN WALL
- CONCRETE
- STEEL
- WOOD
- PLASTER
- GLASS
- WALL
- ROOF
- POLES

CHARACTERISTICS:

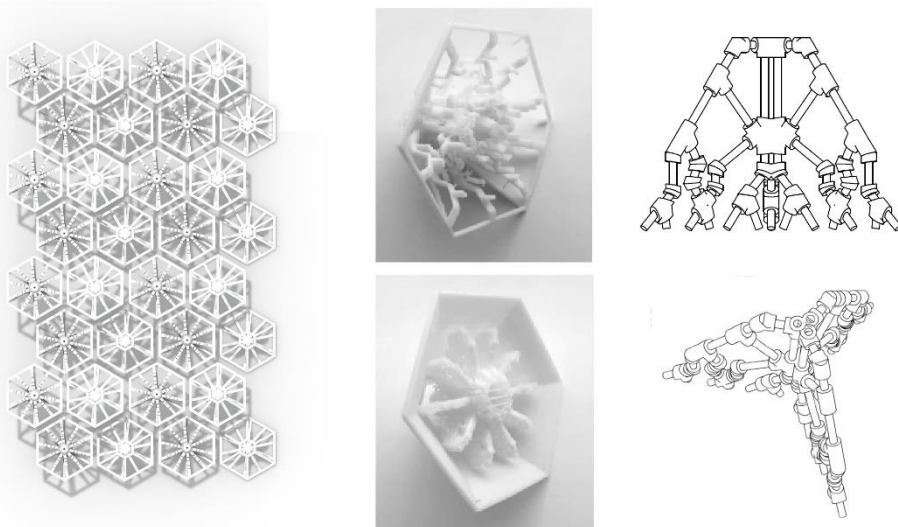
- INTEGRATES BIODIVERSITY FAUNA AND FLORA
- HEXAGONAL BIRD HOUSES MAKE THE FACADE MORE DYNAMIC
- INTERUSIONS AND EXTRUSIONS ADD DEPTH TO THE PROJECT
- GEOMETRIC SHAPES CREATE SHADES FOR THE ANIMALS
- GREEN WALL REDUCES TEMPERATURE NEAR THE BUILDINGS
- INTERESTING FACADE TO CONTEMPLATE

Figure 6.4.4-5: Results from the Genua Bacher studio - green facades designed during the course and relative design and ecological objectives.

TECHNION

During the Spring 2022 semester, a digital fabrication course was conducted with 6th year Master's in Architecture students in the Faculty of Architecture and Town Planning. The course was led by Yasha Grobman, Guy Austern and Arielle Blonder with Ezra Ozeri and Surayyn Uthaya Selvan as the teaching assistants. The main objective of the course was for the students to gain hands-on digital fabrication experience by designing and fabricating a façade tile for multi-species cohabitation. The course was divided into two phases throughout the semester: a) introductory exercise and b) final exercise.

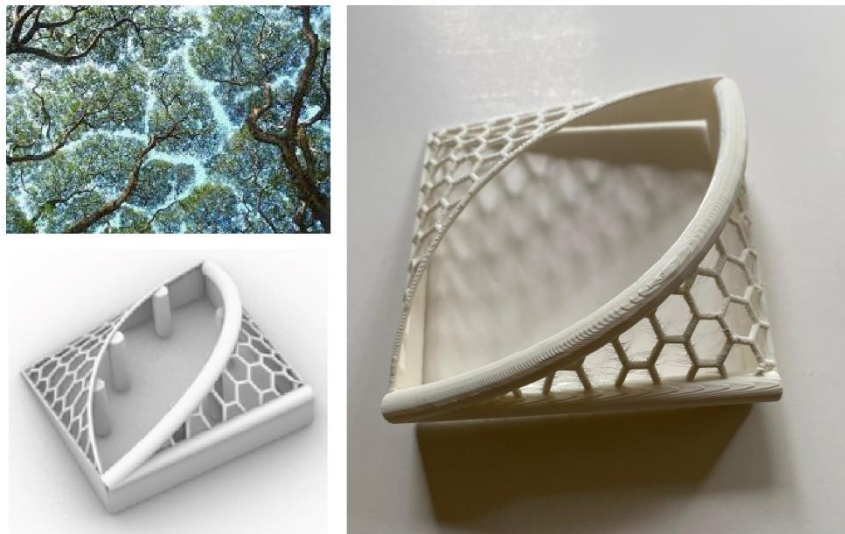
For the introductory exercise, groups of three students were asked to select two to three *ecolope* stakeholders (e.g., humans, animals, plants, microbiota) and identify one to two features correlated to the stakeholders (e.g., **Humans** = Shading and Privacy + **Birds** = Shelter or **Humans** = Sound Insulation + **Plants** = Sunlight + **Microbiota** = Growth). Each group identified various geometrical strategies to be implemented onto a tile to equally meet the features of the selected stakeholders. The chosen design would then be fabricated through 3D printing to function as the scaled model of their final *ecolopes* tile. The students were then asked to present and discuss the differences and similarities between the 3D printed tile and their digital models. Finally, they were asked to propose a mould design for the final tile fabricated using CNC Machining and Laser Cutting.



Raz, O. & Hudesman, L. (2022). Bees on the Wall. Computer-based Fabrication Methods in Architecture Seminar. Pupose: Yasha J. Grobman, Guy Anstern, and Arielle Blonder, Teaching Assistants: Ezra Ozeri and Surayyn Uthaya Selvan.

bees and pollination

Figure 6.4.4-6: Student work for the introductory exercise presenting their digital model (left), 3D printed model (center), and proposed mould design (right) (Raz, O. & Hudesman, L., 2022)



Arkind, T., Kheir, H., & Najjar, R. (2022). Crown Shyness. Computer-based Fabrication Methods in Architecture Seminar. Pupose: Yasha J. Grobman, Guy Anstern, and Arielle Blonder, Teaching Assistants: Ezra Ozeri and Surayyn Uthaya Selvan.

crown shyness

Figure 6.4.4-7: Student work for the introductory exercise presenting their concept (top-left), digital model (bottom-left), and 3D printed model (right) (Arkind, T., Kheir, H., & Najjar, R., 2022)

For the final exercise, the students were assigned the respective digital fabrications machine appropriate for their initial tile designs. Then, they were asked to improve upon their designs for a 1:1 scale *ecolope* tile of 48cm X 48cm X 20cm. With their respective machines in mind, students were required to prepare geometrical strategies to accommodate the limitations of their assigned machines. Finally, students were required to fabricate the mold and cast the final *ecolope* tile using concrete. Each group presented their final tiles and discussed the



assembly of the mould, the casting and the extraction process. They also discussed the comparisons between their original tile designs and the final product.



Figure 6.4.4-8: Students preparing their digitally fabricated moulds made out of polystyrene (CNC Machining) and wood or acrylic panels (Laser Cutting) for concrete casting



Figure 6.4.4-9: Students presenting their concrete casted ecolume tile for bird and human cohabitation alongside their initial 3D printed design (Zajfman, N., Kenzi, S., Galinka, R., Bell, Y., 2022)



Figure 6.4.4-10: The display of all the concrete casted ecolumes tiles

TU Vienna

At Vienna University of Technology, we use master-level studios and master thesis projects extensively as a laboratory for the development of the conceptual approach to designing ecological building envelopes and as a testbed for the conceptual and methodological approach as it develops. We commenced with master-level studios during the winter semester 2021-22 and have conducted four studios since then. The first two studios focused on the conceptualisation and use of spatialised data (voxel model) and the datasets maps and networks. This was done on the design case of an ECOLOPES kindergarten. The next two



semesters we continued this development and added the dataset volumes as a key element into the design process with focus on informing volume distribution with the datasets maps and networks. This was done utilizing the design cases outlined for the development of the ontology-aided generative computational design process, namely the development of masterplans for the overall site and the development of individual building designs. This was done for the site of the Vienna case study, the Nordbahnhof Freie Mitte. Furthermore, we offered a master thesis program for an ECOLOPES sculpture museum for the ecological site Wienerberg. A first thesis project was completed in February 2023 and a second will be completed this summer. The master-level studio projects for the ECOLOPES kindergarten and for Nordbahnhof Freie Mitte will be published in two separate books by TU Wien. The master thesis project “NARTURE – Sculpture Museum Wienerberg – An ECOLOPES Project” is print ready and will be published in April 2023 by TU Wien.

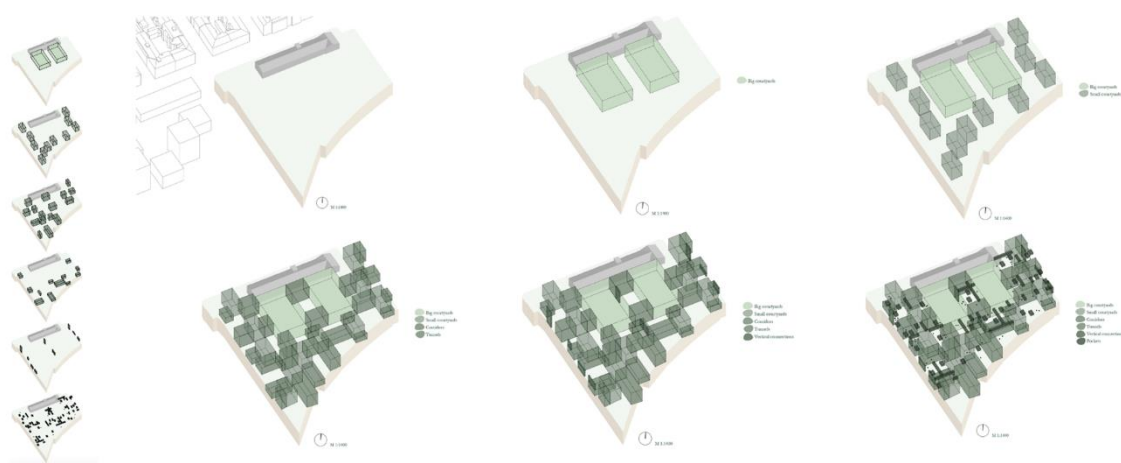


Figure 6.4.4-11: Winter-semester 2022/23: Vienna case study site Nordbahnhof Freie Mitte, design case 1 (masterplan) by Vera Neulinger and Ela Trojar. Sequence of axonometric views showing the placement of different types and sizes of green volumes and the resulting architectural volume distribution.

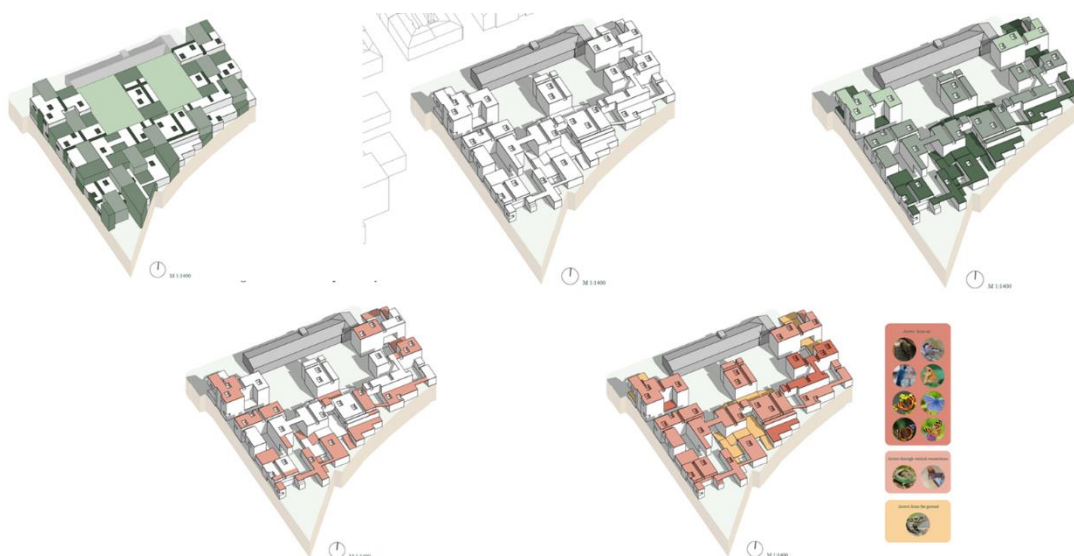




Figure 6.4.4-12: Winter-semester 2022/23: Vienna case study site Nordbahnhof Freie Mitte, design case 1 (masterplan) by Vera Neulinger and Ela Trojar. Sequence of axonometric views showing the volumes and surface areas that are accessible for different species.



Figure 6.4.4-13: Winter-semester 2022/23: Vienna case study site Nordbahnhof Freie Mitte, design case 1 (masterplan) by Vera Neulinger and Ela Trojar. Schematic sections and details of the masterplan.

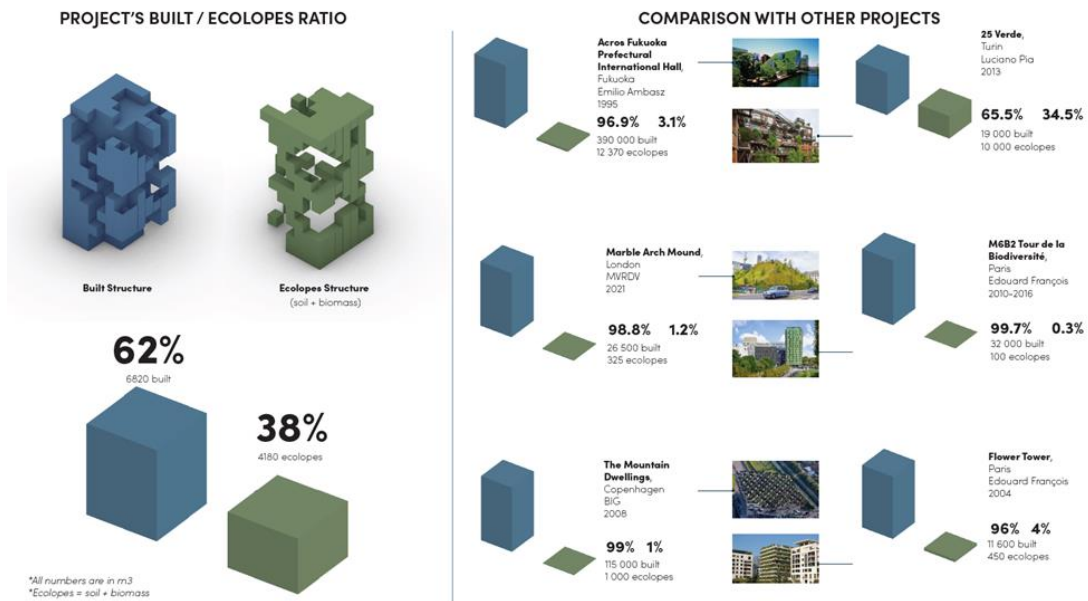


Figure 6.4.4-14: Winter-semester 2022/23: Vienna case study site Nordbahnhof Freie Mitte, design case 2 (building design) by Julie Doyen and Blandine Seguin. Partitioning of a building envelope into architectural and green/soil volumes and comparison of ratio with state-of-the-art existing green buildings.

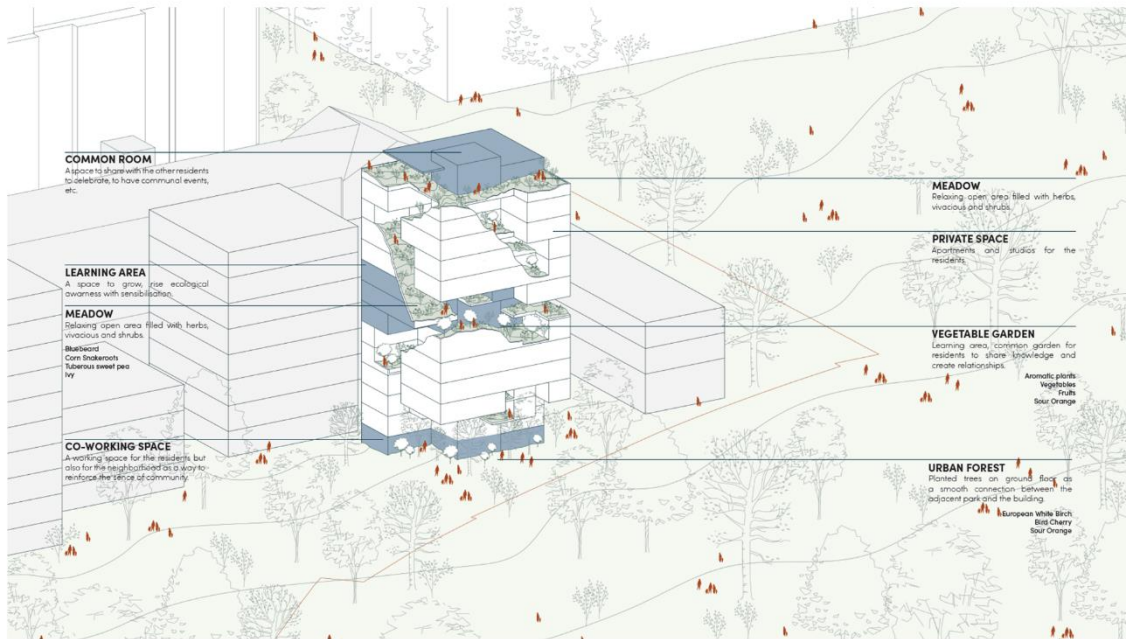


Figure 6.4.4-15: Winter-semester 2022/23: Vienna case study site Nordbahnhof Freie Mitte, design case 2 (building design) by Julie Doyen and Blandine Seguin. Axonometric view showing the selected distribution of secondary volumes (architecture, green, soil) and the programming of the green spaces.

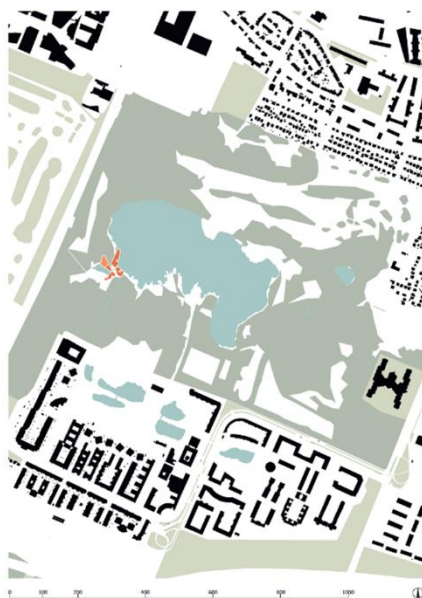


Figure 6.4.4-16: Master thesis project 2023: Livia Dirnboeck, "NARTURE – Sculpture Museum Wienerberg – An ECOLOPES Project", site plan and ground floor plan.

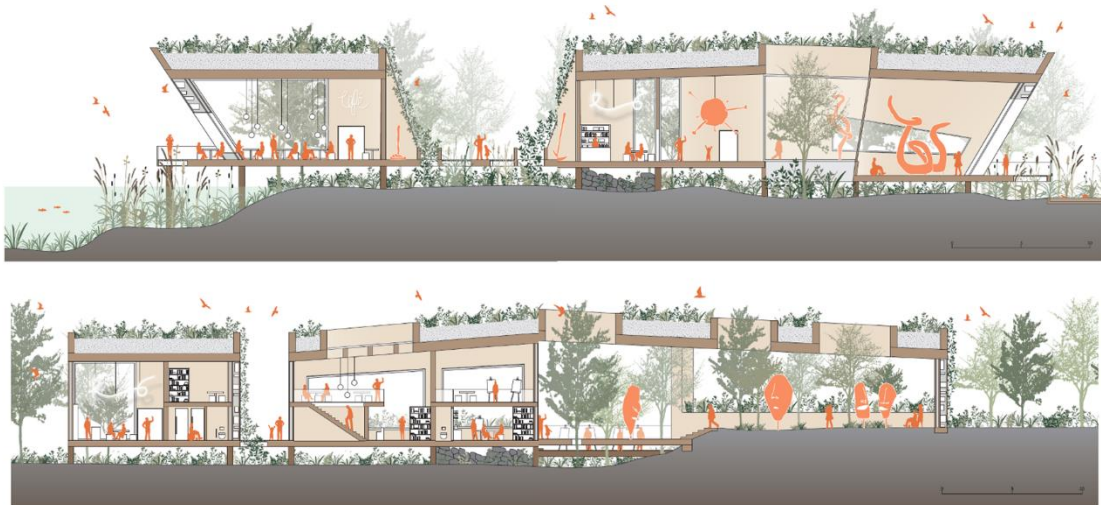


Figure 6.4.4-17: Master thesis project 2023: Livia Dirnboeck, “NARTURE – Sculpture Museum Wienerberg – An Ecolopes Project”, longitudinal sections.

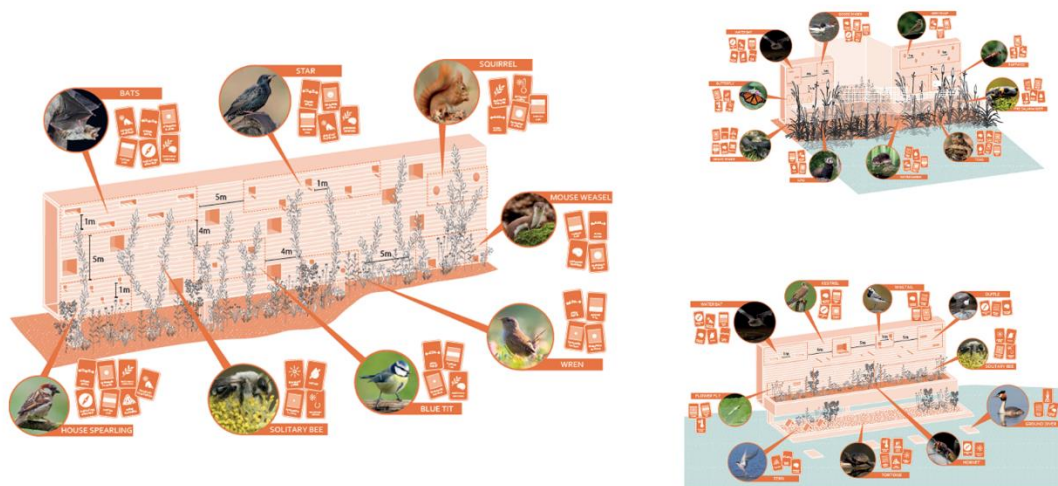


Figure 6.4.4-1: Master thesis project 2023: Livia Dirnboeck, “NARTURE – Sculpture Museum Wienerberg – An ECOLOPES Project”, typical wall layouts with provisions for selected species taking into consideration species compatibility and required distances between provisions.

7 SOCIETAL EXPLOITATION POTENTIALS

These potentials will be identified in a workshop at the next General Assembly of the project in Genoa in April 2023.



8 WORK PACKAGE 3

8.1 Work package description, tasks and deliverables

WP no.	3		WP title		ECOLOPES Platform Architecture		
Lead partner	McNeel			Start month	1	End month	38
Partner no.	1	2	3	4	5	6	
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel	
PMs/partner	1	2	3	3	0	27	
<p>Objectives: WP3 creates the ECOLOPES computational platform including data warehousing capabilities, as a basis for integrating the components from WP4-5, thus enabling modelling in WP6-7. WP3 develops and connects two front-end tools to a) visualize simulated output of the ontology, b) apply it to a building.</p> <p>Task 3.1: ECOLOPES system architecture (M1-12, 7 PMs) Lead: McNeel. Participants: TUM Definition of technical requirements of the ECOLOPES platform. Design of a detailed system architecture for integrating backend services (data stream analytics, semantic integration, AI and reasoning, etc.) and frontend tools with standard open interfaces. The architecture design will outline the security framework to be implemented in T3.2. Tangible outcome: ECOLOPES system architecture.</p> <p>Task 3.2: ECOLOPES data warehousing (M5-29, 5 PMs), Lead: McNeel. Participants: TUM, TEC Development of the cloud infrastructure for storing information, especially in relation to WP4, including the ECOLOPES database that includes all data, including spatio-temporal, voxel and 3D models. Tangible outcome: ECOLOPES data warehousing infrastructure.</p> <p>Task 3.3: Backend development and integration (M5 -38, 5 PMs), Lead: McNeel, Part.: TUM, VIE, TEC Development of backend services for data management, processing, analytics and visualisation. Definition of communication protocols based on identified and documented endpoints amongst modules, components, backend services of the platform. Continuous integration and improvement of the platform according to T3.1. Tangible outcome: ECOLOPES backend services and integrated platform.</p> <p>Task 3.4: Frontend development (M9-38, 10 PMs) Lead: McNeel. Part.: SAAD, UNIGE, VIE, TEC Development of two frontend tools based on the Rhino3D platform to visualize the simulated output of the ontology, and to apply it to a building, through 3D modelling and VR. Tangible outcome: ECOLOPES frontend tools.</p>							
No.	Description					Month(s)	
D3.1*	Prototype technical requirements report					12	
D3.2*	Draft ECOLOPES platform architecture					19	
D3.3	Interim ECOLOPES platform architecture					29	
D3.4	Prototypes and applications, frontend tools					38	

* submitted.



8.2 Work in the second year

The achievements of WP3 in year 2 are described in deliverable D3.2 Draft ECOLOPES platform architecture that is submitted along with this document. The report includes the developments and component integration of the ECOLOPES platform, and it presents first results of the elaborated frameworks such as the computational framework (see section 4.2), the knowledge generation framework (see section 4.4), and the cloud-based Rhino.Compute framework with the ECOLOPES Grasshopper plugin (see section 4.2). Additionally, to contextualise the ECOLOPES computational platform, the conceptual framework is briefly introduced.

Task 3.1: ECOLOPES system architecture (M1-12, 7 PMs) Lead: McNeel (Dr.-Ing. Verena Vogler)

COMPLETED: The task was completed by the end of the first year and reported in D3.1 and in the report of the first year.

Task 3.2: ECOLOPES data warehousing (M5-29, 5 PMs), Lead: McNeel (Dr.-Ing. Verena Vogler)

COMPLETED/ REQUIRES TESTING & MAINTANCE: The cloud infrastructure for storing information was put into practice in the second year. It includes the Knowledge base (KB), data storage for KFG in- and outputs as well as the generated 3D models (.3dm file format), and storage for algorithms written in the visual programming editor Grasshopper. Data is stored on a Linux cloud server where SQL and MongoDB are installed. The task is completed but requires more testing with respect to upscaling, as the main datasets will be generated during the third year (see D3.2, M19).

Task 3.3: Backend development and integration (M5 -38, 5 PMs), Lead: McNeel (Dr.-Ing. Verena Vogler)

ONGOING: The backend of the computational system in ECOLOPES was built by utilizing McNeel's .NET APIs as well as web applications leveraging Rhino.Compute and JavaScript APIs on a Windows cloud server hosted by McNeel (D3.1, D3.2). The purpose of this setup is to bring process-intensive algorithms into the cloud. With the help of the Grasshopper Hops components algorithms can communicate with Rhino.Compute. The developed backend is put into practice for the KGF.

In the third year, once more data is generated, backend services for data management and analytics need to be developed.

Task 3.4: Frontend development (M9-38, 10 PMs) Lead: McNeel (Dr.-Ing. Verena Vogler)

ONGOING: In the second year, the first version of the ECOLOPES Grasshopper plugin was developed and tested (see section 4.2.3). For the development, Rhino as an open development platform was used, allowing to write a library of custom algorithms in Grasshopper and C++, as well as development of a frontend tool. The greatest achievement is the integration of the ecological C++ model in the 3D CAD system Rhino/ Grasshopper. Obstacles such as interoperability between 2D raster and 3D geometry data were overcome as the plugin provides components for data exchange between 2D raster and 3D voxel data, data conversion for the generation of JSON files, components for ecological and environmental analysis, and preview components to display community dynamics between soil, plants and animals in a 3D CAD environment. The ECOLOPES plugin enables the required computational processes to run the KGF.



In the third year, the plugin will be further developed with respect to projecting back more precisely ecological analysis results to the 3D geometry and to integrating algorithms for geometry-related water runoffs. Furthermore, ecological analysis results for 3D models of building envelopes also requires validation with data from real-world prototypes.

In summary, the ECOLOPES plugin visualizes the spatial dynamics of FGs for any building form as a 2D analysis grid in Rhino/Grasshopper. However, the data needs to become more precise for visualization in 3D, meaning to get more precise analysis results for the vertical parts (façade) of the building envelope.



9 WORK PACKAGE 4

9.1 Work package description, tasks and deliverables

WP no.	4	WP title			Data acquisition and information modelling		
Lead partner	TUM			Start month	1	End month	36
Partner no.	1	2	3	4	5	6	
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel	
PMs/partner	53	25	3	30	14	3	
<p>Objectives: WP4 will develop the EIM Ontology (D4.1) that integrates architecture with abiotic environment, soil/substrate, and requirements, impacts and dynamics of humans, plants, animals and microbiota. Tasks 4.1 to 4.6 will model relationships of each component of the <i>ecolope</i> ecosystem with the other components, building on existing data bases and experiments to feed the ECOLOPES database.</p> <p>Task 4.1: Abiotic environment and architecture (M1-15, 14 PMs), Lead: TECH. Participants: UNIGE International and national georeferenced datasets (climatic conditions, urban form, etc.), local building features, normative constraints and design aims and uses (e.g., residential) will be created to support the baseline site and environmental conditions, 3D building geometry and envelope design boundary limits. Data on abiotic conditions will be included, that represent cross cutting boundary conditions for all inhabitants (T4.3 to T. 4.6).</p> <p>Tangible outcome: Dataset for database, role of abiotic parameters and architecture for D4.1.</p> <p>Task 4.2: Soil (1-22, 14 PMs), Lead: SAAD. Participants: TUM.</p> <p>Substrate solutions for ECOLOPES from soils in the areas of the design cases as well as artificial substrates will be obtained from databases, expert knowledge and local sampling, and evaluated. Variables important for plant growth, carbon sequestration and filtering of pollutants will be collected including abiotic measures like texture, pH, volume, water storage capacity, organic carbon and nutrient content, pollution levels (mainly heavy metals). Positive feedback loops for the development of niches for biota living in soil will be evaluated.</p> <p>Tangible outcome: Dataset for substrate/soil and its role in D4.1.</p> <p>Task 4.3: Plant and Vegetation (M1-33, 20 PMs), Lead: UNIGE. Participants: SAAD, TUM.</p> <p>Georeferenced datasets and artificial plant combinations from the building industry and horticultural practice will be used to obtain data on plant occurrences for design cases. Plant traits, related to resource and abiotic requirements (e.g., N-fixation), life-cycle strategies, and human acceptance (e.g., appearance) will be integrated at the plant functional group (PFG) level. PFG dynamics will be spatially and temporally modelled as a function of soil, architecture, abiotic conditions, animals, and human management (e.g., mowing, weeding) using an adapted version of the FATE-HD model.</p> <p>Tangible outcome: Dataset for plants and their role in D4.1.</p> <p>Task 4.4: Animals (M1-33, 20 PMs), Lead: TUM. Participants: SAAD</p> <p>Data on animal presence in and around design cases will be collected from databases (eBird, Ornitho, GBIF, governmental). We focus on birds, mammals, reptiles, amphibian and insects. Lifecycle traits related to habitat, food preferences, and life-history strategies (e.g., dispersal, fecundity, survival probability) will be collected and integrated at the functional group level. RangeShifter model will be used to model the probability of occupancy of the <i>ecolope</i> for each functional group based on local soil, plant and architectural variables and regional conditions.</p> <p>Tangible outcome: Dataset for animals and their role in D4.1.</p> <p>Task 4.5: Microbiota (M1-33, 20 PMs), Lead: TUM. Participants: SAAD</p> <p>Data on microbiota composition in soil, plants and animals will be acquired from molecular databases like EMBL or NCBI and own assessments at the design cases using high throughput molecular methods. Functional microbial groups will be described including catalysts for nutrient/carbon cycling and plant growth promotion to establish the relationships with soil, plants and animals. Feedback loops at the soil-</p>							



root and leaf-air interface (rhizo-/phytobiomes) will be considered. We will focus on the role of soil, plants and animals as vectors for human microbiota and health status. Relationships will be analyzed using generalized linear regression models.

Tangible outcome: **Dataset for microbiota and their role in D4.1.**

Task 4.6: Humans (M1-33, 20 PMs), Lead: TECH. Participants: UNIGE, SAAD, TUM.

Data on 1) human comfort conditions, 2) physiological, psychological and social benefits of nature to humans and 3) management and anthropogenic use of the *ecolope* will be compiled from the literature and from experimental work on human responses to vegetation and animals in a virtual environment. Data will be used to quantitatively identify the different forms of functional relationships (with a dose-response modelling approach) between various components of nature, and various health and well-being and comfort outcomes (including ecosystem services). Tangible outcome: **Dataset for humans and their role in D4.1.**

Task 4.7: ECOLOPES EIM Ontology (M1-36, 20 PMs), Lead: TUM. Participants: TEC, VIE, McNeel.

The EIM Ontology will be the key element of the data-driven recommendation system. It is tailored to configure the ECOLOPES Knowledge Base. Results of Tasks 4.1-4.6 will be integrated. The EIM Ontology will index and fuse data to form the basis of WP5-WP7, as it will be queried to retrieve data references for the composition of the voxel models. Tangible outcome: **EIM Ontology to feed development of WP5-7 (D4.1).**

No.	Description	Month
D4.1	Preliminary EIM Ontology	12
D4.2	Interim EIM Ontology	30
D4.3	Final EIM Ontology in Protégé	36

9.2 Work in the second year

WP4 plays an important role in the ECOLOPES project. WP4 is, on the one hand, responsible for obtaining most of the data that will be used in the project, and on the other hand, it develops the algorithms to process much of the data. This concerns, in particular, data on architecture, site conditions, data on ecological aspects, from soil to animals including microbes, and data on humans. Major algorithms include the ecological model, the analysis of those data including the relationship between architecture and ecology, and the ontology in which these relationships will be encapsulated. Because the tasks of WP4 are intertwined with overarching activities of the ECOLOPES project, most of the achievements of the second year are described in separate sections further up in the document. Here, we briefly summarise progress and referred to the particular sections.

Task 4.1: Abiotic environment and architecture (M1-15, 14 PMs), Lead: TECH (Prof. Shany Barath)

Most of the work identifying international and national georeferenced datasets were conducted in the first year and are included in D1.3 Report of first year that was delivered in M12. In the second year, a major activity was to obtain and summarise the data for the first case study in Vienna.

Task 4.2: Soil (1-22, 14 PMs), Lead: SAAD (Dr. Jens Joschinski)

Task 4.3: Plant and Vegetation (M1-33, 20 PMs), Lead: UNIGE (Prof. Enrica Roccotiello)

Task 4.4: Animals (M1-33, 20 PMs), Lead: TUM (Dr. Victoria Culshaw).



The progress of these tasks is described in the sections on the ecological model (section 4.3) and the Knowledge Generation Framework (KGF, section 4.4).

Task 4.5: Microbiota (M1-33, 20 PMs), Lead: TUM (Prof. Michael Schloter)

Progress in obtaining data on the microbiota composition in soil and the role of plants in the accumulation has been investigated in experiments that are described in section 4.8.2.

Task 4.6: Humans (M1-33, 20 PMs), Lead: TECH (Prof. Assaf Shwartz)

Progress in year 2 is described in section 4.8.3.

Task 4.7: ECOLOPES EIM Ontology (M1-36, 20 PMs), Lead: VIE (Prof. Michael Hensel).

The EIM Ontology will be an important outcome of the ECOLOPES project. In the project, the responsibility of the development of the ontology has been transferred to the TU Vienna. The aim of the task is to develop the EIM Ontology for the ontology-aided generative computational design process. The EIM Ontology consists of three ontologies tailored for the different stages of this process, and will integrate data and information coming from WP4 to WP6.

The task 4.7 is divided into six sub-tasks 4.7.1-6:

1. T4.7.1: Creation of the ontology, i.e., schema for conceptualization of the domain;
2. T4.7.2: Creation of the instance data that populates the ontology;
3. T4.7.3: Development of interoperability between ontology and volumes;
4. T4.7.4: Mapping of knowledge graph onto CAD model;
5. T4.7.5: Testing the ontology in operation;
6. T4.7.6: Ontology next steps towards volume specification.

The work on the ontology and more specifically on the subtasks is described in section 4.6.



10 WORK PACKAGE 5

10.1 Work package description, tasks and deliverables

WP no.	5	WP title					ECOLOPES Voxel Model & Computational model				
Lead partner	VIE		Start month		3		End month		38		
Partner no.	1	2	3	4	5	6					
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel					
PMs/partner	2	9	39	5	2	2					
<p>Objectives: WP5 has three key objectives: 1) development of a Voxel model that integrates, spatializes and visualises ecological and architectural data, and links the EIM Ontology from WP4 with the computational model;</p> <p>2.) development and integration of algorithmic processes and tools in Rhino3D and VR; 3) validation of algorithmic processes and tools that deliver the basis for the work in WP6 and WP7.</p> <p>Task 5.1: ECOLOPES Voxel Model (M3-30, 20 PMs), Lead: VIE. Participants: TUM, McNeel. Development of a voxel model as a link between EIM Ontology (WP4) and computational model. The voxel model will contain different types of data. The geometric data in the voxel model provides the link to the computational model in Rhino3D. Tangible outcome: ECOLOPES Voxel model (D5.1).</p> <p>Task 5.2: ECOLOPES Computational Model (M3-36, 20 PMs), Lead: VIE. Participants: McNeel. Development and integration of algorithmic processes and tools for the design of ECOLOPES in Rhino3D leading to the ECOLOPES Computational Model. This will be related to work on the design cases for Munich, Vienna, Genoa and Haifa. Tangible outcome: Algorithmic processes and tools.</p> <p>Task 5.3: ECOLOPES Computational Model Validation (M13-38, 19 PMs), Lead: VIE. Participants: All. Validation of algorithmic processes and tools in terms of the integrated ecological and architectural design output. Tangible outcome: Validated algorithmic toolset (feeds into D5.2).</p>											
No.	Description										Month(s)
D5.1	Development process for Ecolopes algorithmic tools										12
D5.2	ECOLOPES Voxel Model										30
D5.3	ECOLOPES Voxel Model report										30
D5.4	Preliminary ECOLOPES computational model										30
D5.5	ECOLOPES Computational model in Rhino 3D										38

10.2 Work in the second year

The achievements of WP5 in year 1 with specific focus on the description of the algorithmic modelling approach are described in deliverable D5.1 Development process for the ECOLOPES algorithms that is submitted along with this document. This includes elaboration of the conceptual and methodological approach to the algorithmic design process up to the detailed design stage, which will constitute a subsequent extension of the algorithmic process. Furthermore, this includes detailed elaboration of the specific types of datasets (terrain, maps, networks, volumes) that form part of the algorithmic process, as well as aspects concerning the links of the algorithmic process to the voxel model and the EIM ontology.

Task 5.1: ECOLOPES Voxel Model (M3-30, 20 PMs)

The voxel component is introduced to integrate diverse spatial datasets that are relevant for the design process. The implemented components are establishing both human-computer



interfaces and machine to machine interfaces to access the fully-three-dimensional, voxel-based data stored in the SQL database. Subsets of the data written in the voxel model can be selected and translated into a *map* representation. The map representation can be both used by other ECOLOPES components and visualized within the Rhino / Grasshopper interface through which the designer can interact with the data contained in the voxel. The detailed development of the voxel model is described in section 4.7.5.2 in relation to the dataset maps above above.

Task 5.2: ECOLOPES Computational Model (M3-36, 20 PMs)

In order to extend the solution space we seek to develop a *generative* process with the aim to derive design variety, that is numerous designs that can be evaluated and ranked. We envision a design process based on a generative algorithm that can serve to advance designs regarding specific performance criteria. Each design will consist of a CAD model with corresponding datasets contained in the voxel model that describe different key performances of the design solution. For the computational model we are developing a series of related algorithmic approaches. A first algorithmic approach has been identified to connect ontology 1 to the generative process via an Answer Set solver or Datalog engine. We seek to develop to a hybrid approach to reasoning, i.e., integrating ML in our pipeline after the reasoning process takes place. Such a hybrid approach could use a reasoning process to generate “labeled” data (as in supervised learning) and further be used by the ML algorithm in prediction/classification. The same applies to genetic algorithms, which we will exploit later in the generative process, as described in section 4.7.6 above.

Task 5.3: ECOLOPES Computational Model Validation (M13-38, 19 PMs)

Essential part of the validation of the computational model is the Vienna case study. All tools will be tested on a design case for the development site Nordbahnhof Freie Mitte. We have drafted a design brief that we also used for two master-level design studios at Vienna University of Technology. The team at TU Wien will test and further develop the various tools of the ontology-aided generative computational design process during the second half of 2023.



11 WORK PACKAGE 6

11.1 Work package description, tasks and deliverables

WP no.	6	WP title					Computational Simulation and Analysis				
Lead partner	TEC			Start month	7	End month	42				
Partner no.	1	2	3	4	5	6					
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel					
PMs/partner	2	4	3	42	2	2					
<p>Objectives: Development of the data-integrated computational model (WP5) into computational simulation environment by: 1) computational simulations, multi-criteria analysis and rating strategies that enable decision-making processes for the selection of ECOLOPES design cases; 2) validating the computational workflow to ensure integration and interoperability through design cases in preparation of design validation (WP7).</p> <p>Task 6.1: Generating design iterations (M7-22, 15 PMs), Lead: TEC. Participants: McNeel, All. Generating the design iterations of the building envelope based on the EIM recommendations. Tools developed in WP5 to generate design alternatives will be employed based on both trade-offs and synergies among the different inhabitants' perspectives and material organisation of the building envelope, suggested by the EIM recommendations. Tangible outcome: Design iterations (feed into D6.1).</p> <p>Task 6.2: Developing multi-criteria evaluation (M7-42, 15 PMs), Lead: TEC. Participants: McNeel, All. KPI's will be defined for inhabitant and architectural requirements, based on the recommendations of the EIM (WP4). The measuring and rating of envelope design cases will be developed by defining interrelationships and hierarchies between KPI's. Importance factor will be calculated and assigned to KPI's based on EIM recommendations. Selected cases per inhabitants (based on top scores) will be submitted for validation through expert knowledge. Tangible outcome: ECOLOPES KPI's list (D6.1).</p> <p>Task 6.3: Multi-criteria simulation for validation (M20-42, 25 PMs), Lead: TEC. Part.: McNeel, All. Iterative multi criteria simulation, results analysis and optimisation of design cases. Validation of the computational workflow through the generation of design cases on the scale of the envelope and the envelope building block. Tools will enable recursive modelling of dynamic inhabitant relations. Simulation and evaluation techniques will be based on interoperability with the EIM Ontology. For the prototype the objective is to design building blocks extracted from the design cases for validation (WP7). Tangible outcome: ECOLOPES design cases per site of building blocks & envelopes (D6.2).</p>											
No.	Description										Month(s)
D6.1	Draft KPI descriptions										30
D6.2	KPI's report - performance results										42
D6.3	ECOLOPES design cases per site										42

11.2 Work in the second year

The primary focus of Work Package 6 (WP6) in the second year was to fulfill the future developments described in Section 8.2 of D1.3. As such, WP6 has concluded the conceptual understanding of the proposed hybrid multi-criteria decision-making (MCDM) methodology through a systematic literature review publication (Selvan et al., 2023a). Conclusions derived from this publication facilitated the computational development of the proposed methodology in the Rhinoceros and Grasshopper environment. The methodology was tested for interoperability using a selected multi-objective optimization (MOO) algorithm and multi-attribute decision-making (MADM) technique. Furthermore, a conceptual framework to identify ECOLOPES-specific key performance indicators (KPIs) was proposed. This framework



was tested within the proposed MCDM methodology in a computational experiment using an architectural, ecological, and design objective. Further details of all the activities conducted in WP6 for Year 2, with a focus on the ECOLOPES KPIs, will be described in deliverable D6.1 due on Month 30. Here, we briefly summarize progress and refer to the particular sections.

Task 6.1: Generating design iterations (M7-22, 15 PMs), Lead: TEC.

Most of the work to generate iterations of the building envelope has been described in Section 4.5.7. Progress in year 2 included the identification of two potential multi-objective optimization (MOO) algorithms and their associated Grasshopper plugins for experimentation. We also identified the maximum number of computable criteria for MOO efficiency.

Task 6.2: Developing multi-criteria evaluation (M7-42, 15 PMs), Lead: TEC.

Most of the work in relation to KPI identification was described in Section 4.5.3 while the employment of these KPIs were described in Section 4.5.7. Some of the achievements in Year 2 was in relation to the development of a nested hierarchical set framework to identify and priorities potential *ecolopes*-specific KPIs. We also constructed an initial nested hierarchy to establish connections between an architectural and ecological objective using common abiotic-related KPIs.

Computationally, we also identified the maximum number of computable criteria for multi-attribute decision-making (MADM). We also identified two potential MADM algorithms that were constructed in Grasshopper for experimentation. Future developments include validating the MADM algorithms (TOPSIS and AHP) constructed in Grasshopper using external software. A literature review study is also being conducted to identify potential *ecolopes* objectives and KPIs as well as their respective computational methods. This will be detailed in D6.1.

Task 6.3: Multi-criteria simulation for validation (M20-42, 25 PMs), Lead: TEC.

The overall framework to conduct the iterative multi-criteria simulation, results analysis, and optimization for the design cases were discussed in Section 4.5.7 and presented in Section 3.3 in D3.2. Some of the achievements of Year 2 was the interoperability testing of the hybrid methodology in the Grasshopper environment using a generic case study. We have also integrated an initial nested hierarchy of KPIs into the methodology to generate and rank optimized design based on varied objective priorities. Future developments include testing the methodology using site-specific data as well as testing querying strategies from the Knowledge Database into the Grasshopper environment.



12 WORK PACKAGE 7

12.1 Work package description, tasks and deliverables

WP no.	7	WP title	Overall Validation			
Lead partner	UNIGE		Start month	26	End month	48
Partner no.	1	2	3	4	5	6
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel
PMs/partner	9	18	3	7	3	3
<p>Objectives: WP7 will demonstrate the effectiveness of ECOLOPES multispecies design and of the ECOLOPES design platform developed across WP3-WP6. The design process will be validated through specific design cases for selected sites to determine whether adequate outcomes for inhabitants are obtained and if the ECOLOPES design platform is adequately integrated. WP7 will provide feedback for optimization.</p> <p>Task 7.1: Human comfort and wellbeing (M28-45, 14 PMs), Lead: UNIGE. Participants: TEC, McNeel Validation for humans: a) virtual 3D experiment to assess people’s response to different building envelopes. Assessment of well-being, health responses, people’s perceptions of these envelopes to validate theoretical functional relationships (WP4) and compare design outcome benefits to health and well-being. b) assessment of thermal comfort of ECOLOPES area (outdoor + indoor) via 3D simulation/modelling of designs for all sites to validate/compare outcomes. Tangible outcome: Reports on people’s perception and comfort (in D.7.1).</p> <p>Task 7.2: Building blocks exposure & analysis (M28-45, 13 PMs), Lead: TUM. Part.: UNIGE, SAAD, TEC Building blocks (BB, 5-9 blocks of 1m²) (WP6) will be produced and placed in all sites along with a reference block (i.e. a common envelope, as plaster façade or brick wall). To allow comparison BB will be exposed for 12 months and analysed in terms of occurring plants, microbes, and insects and in terms of water management, maintenance and use. Tangible outcome: Report on BB analysis (in D7.1).</p> <p>Task 7.3: Identification of the best design outcomes (M28-48, 16 PMs), Lead: UNIGE, Participants: All. The multifunctionality of the <i>ecolope</i> will be tested with empirical approaches, experiments and simulations. Design outcomes (WP6) will be evaluated considering all inhabitants in relation to ecosystem services provided and estimated maintenance needs, by way of Cost-Benefit approaches and in relation to the built context. Design outcomes will be analysed via ECOLOPES multicriteria approach. KPI (WP6) will be weighted and modified based on expert assessment. Tangible outcome: Report on best design outcomes (D7.2).</p>						
No.	Description					Month(s)
D.7.1	Report on the methodology for ECOLOPES multifunctionality evaluation					30
D7.2	Report on evaluation of inhabitants' responses					45
D7.3	Report on the best design outcome for each site					48

12.2 Work in the second year

Work Package 7 will officially start in month 26. The main activities which will be implemented in the first active year of WP7 were presented and discussed during the General Meetings and the Project Management Board Meetings. In particular, specific meetings were organized in months 23 and 24 to discuss about: 1) the conceptual approach to the overall validation to identify its main focuses and specific aims; 2) conceptual and technical aspects of the human comfort and wellbeing assessment; 3) building blocks specific objectives, technical aspects



and analysis. In addition, WP7 leader and participants actively collaborate with WP3-WP4-WP5-WP6 leaders and participants in order to set the ground for the development of each WP7 specific task, for example by drafting the design workflow, which will be validated in WP7, and defining Key Performance Indicators.



13 WORK PACKAGE 8

13.1 Work package description, tasks and deliverables

WP no.	8	WP title		Ethics requirements		
Lead partner	TUM	Start month	1	End month	48	
Partner no.	1	2	3	4	5	6
Short name	TUM	UNIGE	VIE	TEC	SAAD	McNeel
Objectives: WP8 addresses the ethical issues that were addressed during review of the grant proposal						
<p>Task 8.1 Addresses ethics requirement 4: Treatment of animals in building blocks (M1-28) Lead: TUM, Participants: All</p> <p>The consortium must clarify the plans how the protection of the animals in the installed blocks will be ensured and describe the plans how the animals will be treated after project termination. This report must be submitted as a deliverable D8.1</p> <p>Task 8.2: Harm to environment due to <i>ecolope</i> design (M1-28) Lead: TUM, Participants: All</p> <p>Further information about the possible harm to the environment caused by the research, and the measures that will be taken to mitigate the risks at least about the prevention and control of overpopulation of animals (including insects) and spread of zoonotic and vector-borne diseases, uncontrolled plant growth and inappropriate microbiota development and the measures that will be taken to mitigate the risks must be submitted as a deliverable D8.2.</p>						
No.	Description					Month(s)
D8.1	Report on protection of animals in building blocks					28
D8.2	Report on avoiding harm to environment due to <i>ecolope</i> design					28

13.2 Work in the second year

WP8 will assess ethics requirements for animals and the harm to environment linked to the *ecolope* with the challenge that there are no existing data on this topic. We plan to overcome this challenge in three ways.

- We will make use of the exposition of the building blocks to understand which animals are likely to colonize the building blocks when exposed: the consortium is still in the process of developing the design of the building blocks. This knowledge will be used as a basis for the animal protection framework.
- We will develop worst case scenarios to evaluate the health-related increased risks that an *ecolope* could bring, e.g. invasion of animals carrying new viruses
- We might use the soil, the plant and animal models to assess potential risks to humans and livestock of microbes and pests settling or brought close to buildings by the *ecolope*.

The ethics framework will be developed at the beginning of the 3rd year (reports due M28).



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