ECOLOPES

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

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D5.4

ECOLOPES Computational Model

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Abstract

This deliverable describes the development of the ECOLOPES Computational Model for the ontology-aided generative computational design process, which comprises the *translational* and the *generative* process. The *translational* process involves preparation of datasets that serve as input for the *generative* process. The *generative* process involves generating (1) design output concerning spatial organisation and (2) geometric articulation for each design output. Stage 1 of the deliverable focuses on the development of an Answer Set Programming (ASP) approach for the generative process. Stage 2 comprises preparation for utilising additional classes of algorithms (e.g., ASP approach for the translational process and extending the generative process with a Genetic Algorithm and a Machine

Learning algorithm. While stage 2 will not reach the required TRL it will set out a clear path for future development of the ontology-aided generative computational design process.

Furthermore, this deliverable describes the approach to the validation of the ontology-aided generative computational design process. This includes technical functionality of (1) the key components of the ontology-aided generative computational design process, the ECOLOPES Information Model (EIM) Ontology (*D4.2 Interim EIM Ontology*), the ECOLOPES Voxel Model (*D5.3 ECOLOPES Voxel Model*) and the ECOLOPES Computational Model, as well as (2) their various interactions. Secondly, this includes validation of the soundness of the design output of the various stages of the design process. The Vienna Case Study outlined in this deliverable is currently in preparation and will serve this purpose. Finally, given the aim of the ECOLOPES research project to develop a design approach and computational design workflow for use in architectural practice, it is necessary to validate the robustness and usefulness of the approach in a simulated practice context. We operate on the understanding that given a reasonably compact amount of training, an architect with a first degree (BA) in architecture should be able to utilise the conceptual, methodological, and computational aspects of the ontology-aided generative computational design process. For this reason, we use master-level design studios and master thesis projects at TU Wien as testbeds for this purpose. This serves to (1) establish the training that is necessary to enable master-level students to work with the Ecolopes approach, and (2) evaluate design outcomes of Ecolopes projects undertaken by the students.

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EXECUTIVE SUMMARY

This deliverable describes the development of the ECOLOPES Computational Model, a key component of the ontology-aided generative computational design process, together with the EIM Ontologies (*D4.2 Interim EIM Ontologies*) and the ECOLOPES Voxel Model (*D5.3 ECOLOPES Voxel Model*).

The "ontology-aided generative computational design process" comprises the *translational* and the *generative* process. The *translational* process involves preparation of datasets (Loop 1) that serve as input for the *generative* process. The *generative* process involves generating design output concerning spatial organisation (Loop 2) and generating geometric articulation (Loop 3). We recognise that the ontology-aided generative computational design process would benefit considerably from a combination of different classes of algorithms with different functionalities. However, purpose-configuring different classes of algorithms with different functionalities and ensuring proper functionality and interoperability is a complex undertaking that exceeds what is possible in the ECOLOPES research project. To address this challenge, we pursue a two-stage development.

For the development of the ECOLOPES Computational Model we focus on the development of an Answer Set Programming (ASP) approach for the *generative* process (Loop 2 and Loop 3). Lifschitz explained that "the idea of answer set programming is to represent a given computational problem by a logic program whose answer sets correspond to solutions, and then use an answer set solver … to find an answer set for this program" (Lifschitz, 2002). Mueller elaborated further that "answer set programming is an approach to knowledge representation and reasoning. Knowledge is represented as answer set programs, and reasoning is performed by answer set solvers." (Mueller, 2015) The ASP solution for the generative process (Loop 2 and Loop 3) will be technically implemented by the end of the project at the required Technology Readiness Level (TRL). Furthermore, we outline additional classes of algorithms for advancing the ontology-aided generative computational design process. This involves conceptualising an ASP approach for the *translational* process (Loop 1) and a conceptual outline for extending the *generative* process (Loop 2 and Loop 3) with a Genetic Algorithm (GA) and a Machine Learning (ML) algorithm. These additions will not reach full technical implementation, i.e., the required TRL, yet set out a clear path for future development of the ontology-aided generative computational design process.

In Section 1 the role of the ECOLOPES Computational Model in the ontology-aided generative computational design process is elaborated.

In Section 2 we describe the selected algorithmic processes in relation to the two processes that together make up the ontology-aided generative computational design process: (1) the *translational* process and (2) the *generative* process (*D 5.1 Development Process for ECOLOPES Algorithms*).

Section 2.1 describes the task in Loop 1. In the *translational* process requirements elaborated in the design brief for a given project and site and additional requirements are analysed, correlated, spatialised and prepared for design generation (Loop 1). Stage 1 of the development of this deliverable does not include an implementation of an additional algorithmic process. We develop for stage 2 a conceptual extension of the initial approach with an ASP algorithm, the purpose of which is to convert design-related information into structured datasets for the translational process in Loop 1. ASP is useful for knowledge representation and reasoning tasks, enabling designers to make well-informed choices, and facilitating the conversion of design requirements and constraints into computationally interpretable data.

Section 2.2 describes the task in Loop 2, the selected algorithm(s), and the related interfaces with the EIM Ontology and ECOLOPES Voxel Model. Stage 1 of the development of this deliverable includes the technical development of an ASP algorithm. ASP is useful for knowledge representation and reasoning tasks, enabling designers to make well-informed choices, and facilitating the conversion of design requirements and constraints into computationally interpretable data. Furthermore, we describe for stage 2 a conceptual extension of the initial approach with a GA and a ML (K-means) algorithm to enhance the capacity to generate variations of spatial organisation for the task of architectural, biomass, and soil volume distribution (see Appendices 1 and 2).

Section 2.3 describes the task in Loop 3, the selected algorithm(s), and the related interfaces with the EIM Ontology and ECOLOPES Voxel Model. Stage 1 of the development of this deliverable includes only an ASP algorithm. Furthermore, we describe for stage 2 an extension of the approach with a GA and a ML (K-means) algorithm to enhance the capacity to generate variations of geometric articulation (dataset *landform*) for the task deriving a coherent geometry for buildings and sites that can be understood and evaluated in terms of terrain features and hence in terms of geodiversity.

Section 3 outlines the validation of the ECOLOPES Computational Model in the context of the ontology-aided generative computational design process. Overall, we address four aspects of validation: (1) technical validation of the key components of the ontology-aided generative computational design process: EIM Ontology (*D4.2 Interim EIM Ontology*), ECOLOPES Voxel Model (*D5.3 ECOLOPES Voxel Model*) and ECOLOPES Computational Model (*D5.4 ECOLOPES Computational Model*), (2) technical validation of component interaction, (3) validation of soundness of design output based on the Vienna Case Study, and (4) robustness of the approach for use in practice.

Section 4 outlines the intended further development of the algorithms that make up the ECOLOPES Computational Model, including the intended development stage at the end of the project, taking into consideration the required TRL and addressing FAIR principles.

Section 5 includes the current publication plan.

ABBREVIATIONS AND ACRONYMS

ASP	Answer set programming
CAD	Computer Aided Design
EA	Evolutionary Algorithm
EIM	Ecolopes Information Model
EN	Ecological Network
GA	Genetic Algorithm
GCD	Generative Computational Design
GDB	Graph Database
GH	Grasshopper
JSON	JavaScript Object Notation
KG	Knowledge Graph
KGF	Knowledge Generation Framework
KPI	Key Performance Indicator
ML	Machine Learning
OWL	Web Ontology Language
RDB	Relational Database
RDF	Resource Description Framework
SQL	Structured Query Language
TRL	Technology Readiness Level
UI	User Interface

UX	User Experience
UN	User Network
WP	Work-package

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1 INTRODUCTION: THE ROLE OF THE ECOLOPES COMPUTATIONAL MODEL IN THE ONTOLOGY-AIDED GENERATIVE COMPUTATIONAL DESIGN PROCESS

The ECOLOPES computational framework, its technical components, and data flow between the latter (computational workflow) was elaborated in WP3 and the updated version presented in D3.3. (M29) (Fig. 1).

The ECOLOPES Computational Framework facilitates informed multi species design for ecological building envelopes, that we term *ecolopes* (Fig. 1) (D3.3, Weisser et al. 2022). It includes technical components such as the Ecological Model, the Knowledge Base, the design generation environment, which we term "*ontology-aided generative computational design process*", the Optimization Environment (D6.1), and components for validation. The Ecological Model, developed in WP4 (D4.1, D1.5), simulates plant, animal and soil dynamics. The Ecological Model was integrated in a 3D CAD system (Rhino/ Grasshopper) (D3.3 Chapter 3), which facilitated the generation of relational data (architecture, environmental, and ecology) for building envelopes in a resolution of 1 cubic metre. In the next step, this data was stored in the Knowledge Base (D3.3. Chapter 4). The KB was then analysed using a ML model which extracts rules for decision making for WP5 (D3.3, Chapter 4). The design generation environment (ontology-aided generative computational design process), which is developed in WP5 (*D5.2 ECOLOPES Voxel Mode*l and *D5.3 ECOLOPES Computational Model*) facilitates design generation and the generation of design search space populated with alternative solutions that can be analysed, evaluated, and ranked. The optimization environment, which is developed in WP6 aims to facilitate optimization based on the search space produced by the ontology-aided generative computational design process (WP5) and selection of the final *ecolope* design solution based on KPIs (D6.1). The ECOLOPES Computational Model provides input for optimization, the output of which provides the basis for the overall validation (WP7) of the ECOLOPES Computational Framework.

During development it became clear that the Ecological Model output is far too complex for integration into the design generation algorithms, and that the development of a comprehensive EIM ontology takes time. It was therefore decided to pursue parallel workflows: One workflow focuses on the development of the ontology-aided generative computational design process and the EIM Ontologies (TU Vienna), while the second workflow uses the Knowledge Generation Framework (KGF, D3.3) to provide correlational (ecology-architecture) information for design decision support (MCNEEL, TUM, SAAD). The KB is the joint interface of the two workflows.

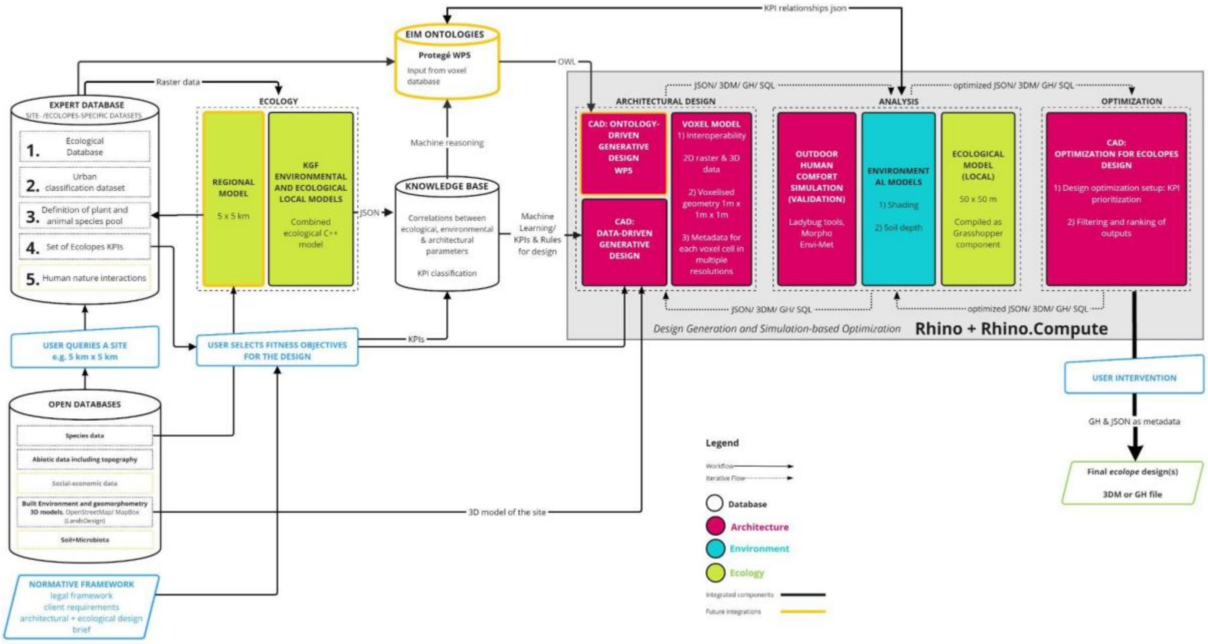


Fig. 1: Ecolopes computational framework showing integrated (black frame) and non-integrated technical components (yellow frame) (D3.3). The figure shows where the ontology-aided generative computational design is located within the Ecolopes computational framework.

This deliverable focuses on the development of the ECOLOPES Computational Model consisting of and facilitated by algorithmic processes that are conceptualised and tailored for the ontology-aided generative computational design process, with the aim to facilitate specified CAD Model output as described below. The design generation environment is conceived as an ontology-aided generative computational design workflow comprises three key components: (1) the EIM Ontologies (D4.2) that guide the design process in its different stages and can be queried by the designer, (2) the ECOLOPES Voxel Model (D5.3) that integrates relevant datasets for the design process, and (3) the ECOLOPES Computational Model in the Rhinoceros CAD environment in which selected algorithmic processes are implemented that are linked with and guided by the EIM Ontologies.

The ECOLOPES Computational Model is located between the EIM Ontology and the optimization environment. From an information flow perspective, this can be represented in the following way, although feedback, interactions, and interfaces alter this simplified schema:

→ *Ecological Model* → *EIM Ontology* → ***ECOLOPES Computational Model*** → *optimization environment* →

Two distinct processes are combined to make up the ontology-aided generative computational design process: (1) the *Translational* Process and (2) the *Generative* Process (*D5.1 Development Process for ECOLOPES Algorithms*).

In the *Translational* Process, requirements elaborated in the design brief for a given project and site and additional requirements are analysed, correlated, spatialised and prepared for design generation. In the *generative* process, variants of spatial organisation and geometric articulation for the different design outputs are generated. This entails numerous design outputs that can be evaluated and ranked. The ontology-aided generative computational design process consists of three loops (Tab. 1, Fig. 2).

Loop 1 comprises the development of EIM Ontology 1 (knowledge graph) that aids the Translational Process. This entails preparing the datasets that are key inputs into the design generation process via a knowledge graph that can be queried by the designer.

Loop 2 comprises the development of EIM ontology 2 that aids the generation of the spatial organisation utilising generic (cuboid) volumes (dataset *volumes*) for each case-specific design output.

Loop 3 comprises the development of EIM ontology 3 to aid the generation of the geometric articulation (dataset *landform*) for each case-specific design output. Loops 2 and 3 will be facilitated by an Answer Set Programming (ASP) approach.

This deliverable is characterised by a two-stage approach. Stage 1 describes the level that will be technically implemented at the end of the project. Stage 1 entails implementation of an ASP approach for the generative process including Loop 2 and Loop 3. Stage 2 comprises a conceptual development for future advancement of the ontology-aided generative design process. This entails conceptual development of an ASP approach for Loop 1 and a conceptual outline for extending Loop 2 and Loop 3 with a Genetic Algorithm (GA) and a Machine Learning (ML) algorithm. Stage 2 will not reach the required Technology Readiness Level (TRL) yet sets out a clear path for future advancement of the ontology-aided generative computational design process.

Table 1: Overview of the three key stages and involved components of the generative computational design process, including purpose of each stage, as well as involved datasets, inputs and outputs, involved computational components and degree of designer involvement in each stage.

Ontology-aided generative comp. design process	**Purpose**	**Datasets**	**Inputs**	**Outputs**	**Involved Comp. Components**	**Designer involvement**
Loop 1 Translational Process	Translation of design brief and designer defined requirements into inputs for the generative process	Datasets maps and networks, (Open) Knowledge Graphs	Design Brief, Designer Inputs, etc.	Datasets maps and networks in CAD environment	EIM Ontology 1, Voxel Model, Ecological Model, CAD 1 algorithms, GraphDB querying and reasoning	high
Loop 2 Generative Process 1	Computational generation of spatial organisation	Volumes	Constraints, Maps, Networks, etc	Volume distribution in CAD environment Voxel data Ontological output	Volume distribution in CAD environment Voxel data Ontological output ASP	variable
Loop 3 Generative Process 2	Computational generation of geometric articulation	Landform	Constraints, Maps, Networks, Volumes, etc	Site and building geometry in CAD environment, Voxel data Ontological output	Site and building geometry in CAD environment, Voxel data Ontological output, KGF, ASP	variable

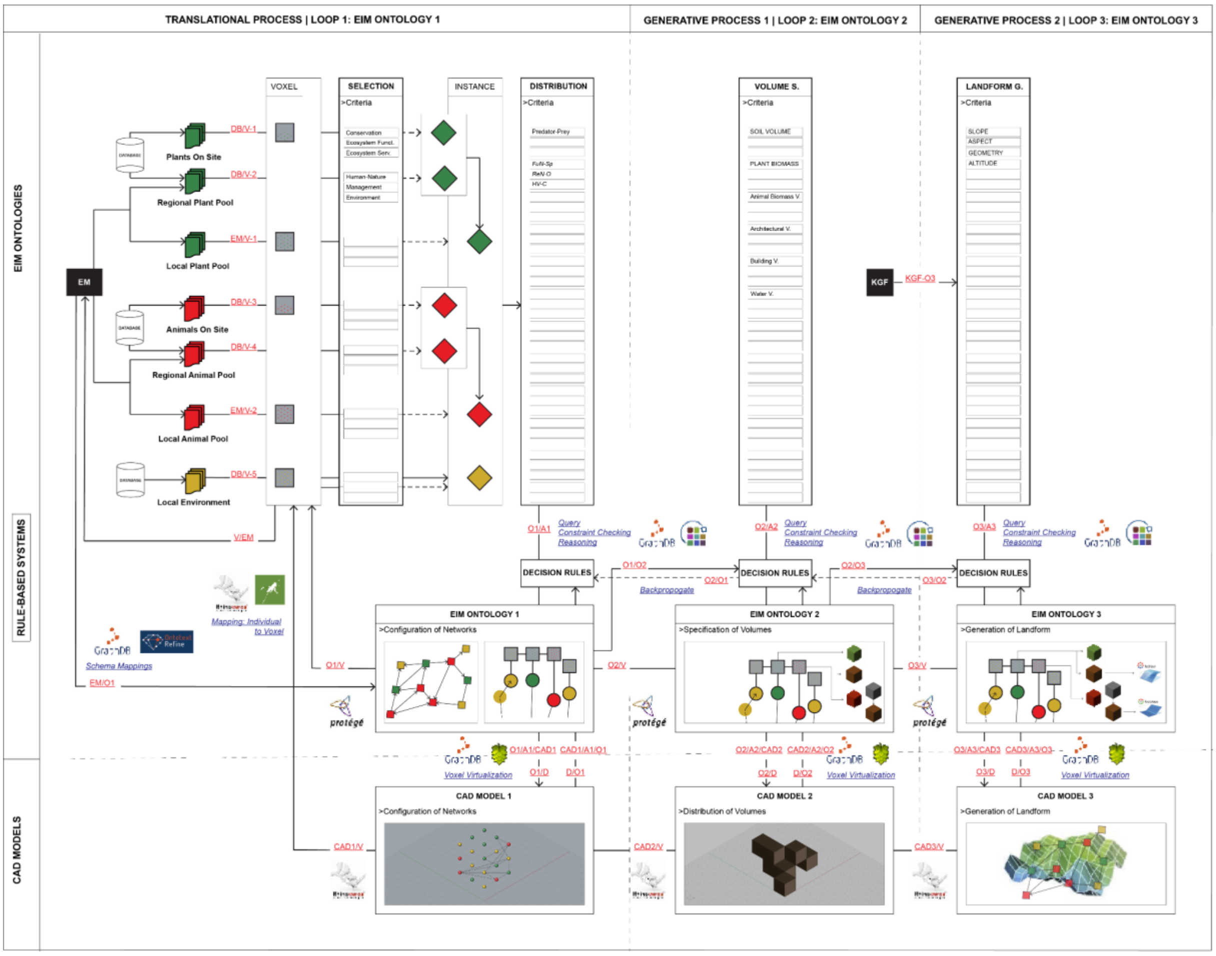


Fig. 2: Ontology-aided generative design process for ECOLOPES showing the system architecture with its main components and interfaces. This includes the three process loops (Loop (1, 2, 3)) with the main interfaces (in red) and allocated methods (in blue) mapped along the three design stages (Translational Process, Generative Process 1, Generative Process 2) (x-axis); and the main components (EIM Ontologies, Rule-Based System, CAD models) of each loop (y-axis).

The output of the ontology-aided generative design process consists for each generated design variant of (1) CAD Model output, (2) related data in the ECOLOPES Voxel Model, and (3) ontological output. The CAD Model output comprises (1) spatial organisation (dataset *volumes*) (*D5.1 Development Process for ECOLOPES Algorithm*), and (2) geometric articulation of selected variants of volume distribution (dataset *landform*) (*D5.1 Development Process for ECOLOPES Algorithm*). Spatial organisation entails the distribution of different types of generic (cuboid) volumes. Geometric articulation entails the articulation of specific landform geometry for selected spatial organisation output, according to specified requirements contained in the various inputs into the process including project brief and determinations made by the designer.

To define spatial organisation, we initially conceptualised three types of volumes: (1) architectural volumes, (2) biomass volumes, and (3) soil volumes (*D5.1 Development Process for ECOLOPES Algorithm*). Together these three types of volumes constitute the spatial organisation of an *ecolope* and depending on the design case also of the entire plot or extended site (*D5.1 Development Process for ECOLOPES Algorithm*). During further development steps it showed that in future more diverse types of volumes may be beneficial. Currently we consider distinguishing between different types of green volumes, e.g., dense biomass and sparse biomass (for instance as corridors for movement of animal species). Furthermore, it is useful to distinguish in future steps between different types of architectural volumes, e.g., fully enclosed spaces and transitional spaces, and to assign further attributes, e.g., including openings in volumes that connect exterior and interior spaces.

For geometric articulation, we developed an approach to what we term *urban landform* (*D5.1 Development Process for ECOLOPES Algorithm*). The latter is based on specified types of terrain features with the aim to instrumentalise recent research on the correlation between geodiversity, microclimate variation (Vernham et al., 2023), biodiversity (Brazier et al., 2012; Tukiainen et al., 2019, 2022) and ecosystem services (Alahuhta et al., 2018) (*D5.1 Development Process for ECOLOPES Algorithm*). For this purpose, we initially selected the *geomorphons* approach, a pattern-recognition based approach to classify and map landforms (Jasiewicz & Stepinski, 2013) (*D5.1 Development Process for ECOLOPES Algorithm*). Geomorphons are organised as a library of terrain features (e.g., flat, valley, shoulder, ridge, etc) and are based on a 2.5D definition of the terrain surface. However, we seek to modify this approach to enable the design of a continuous landform geometry, while at the same time deriving a systemic approach to terrain features for the purpose of design. We realised that it is disadvantageous to initially consider terrain features as a set of components or tiles, since the edges of neighbouring geomorphons may not align and therefore not result in a continuous surface, at least not without significant modification of tiles, thereby leading to geometries that are not the intended ones and hence to suboptimal results. We are currently revising our approach, basing it on the process of actual landscape analysis with geomorphons. In other words, existing continuous surfaces are rationalised through geomorphons. For our purpose the process of geometric articulation will proceed from the horizontal and vertical surfaces of the generic (cuboid) volumes distributed in Loop 2, as well as the surface geometry of the site. These form a continuous surface that is iteratively modified to result in coherent *urban landform* characterised by geodiversity.

To reflect the types of projects occurring in architectural practice, the ontology-aided generative computational design process will facilitate two distinct design cases (*D5.1 Development Process for ECOLOPES Algorithm*, *D5.4 ECOLOPES Computational Model Validation*).

Design Case 1 entails the design of a master plan for the development of a given site. In such cases the number and distribution of building volumes, including footprint, floor area ratio, maximum volume, and maximum height, are not yet defined. In the context of this research this entails that spatial organisation is generated through the distribution of architectural, biomass and soil volumes, which we term for case 1 *primary volumes*, as well as geometric articulation of site and buildings leading to what we term for case 1 *primary landform*. Landform can therefore be coherently designed across the entire site, with all volumes adhering closely to the landform scheme.

Design Case 2 entails the design of an individual building for which all constraints, such as footprint, floor area ratio, maximum volume, and maximum height, etc. are already established by a municipal master plan. Since the generic maximum allowed primary volume is already given by the masterplan, the task is to partition the primary volume into *secondary* and *tertiary* architectural, biomass and soil volumes. To enable different species to inhabit the envelope it is useful to develop the building geometry as a *secondary* and *tertiary landform* (hierarchical nesting of terrain features) to enable accessibility and appropriate provisions for specified species to specified parts of the building envelope.

Case 2 relates to the same scale generic building scale design case in D6.1 which runs the Optimization Process on an ecological building envelope that can be replaced with a specific design case generated by the ontology-aided generative computational design process.

Primary volumes define the location of buildings, and overall biomass and soil volumes. Once *primary* volumes are located it is possible to detail them further by locating *secondary* and *tertiary* volumes, which entail more specific architectural, green and soil volumes. Since the purpose of geometric articulation is to shift from generic (cuboid) geometry to *urban landform* with distinct terrain features, a matching hierarchical order is established. *Primary* landform delivers a first overall level of geometric articulation to primary volumes, especially for architectural and soil volumes. *Secondar*y and *tertiary* landforms are subsequently generated to derive more detailed geometric articulation and geodiversity to enhance the possibility of meeting diverse ecological and architectural requirements.

2 ALGORITHMIC PROCESSES IN THE ONTOLOGY-AIDED GENERATIVE DESIGN PROCESS

This deliverable is characterised by a two-stage approach. Stage 1 describes the level that will be technically implemented at the end of the project. For Loop 2 and Loop 3 this entails the development of an Answer Set Programming (ASP) process. ASP is useful for knowledge representation and reasoning tasks, enabling designers to make well-informed choices, and facilitating the conversion of design requirements and constraints into computationally interpretable data. Stage 2 comprises a conceptual development for future advancement of the ontology-aided generative design process. This entails utilising an ASP algorithm for Loop 1 and a conceptual outline for extending Loop 2 and Loop 3 with a Genetic (GA) and a Machine Learning (ML) (K-means) algorithms. Stage 2 will not reach full technical resolution and implementation, because of computational / technical bottlenecks that require additional time for development.

The different algorithms that are technically or conceptually developed for the ontology-aided generative computational design process have different roles and related functionalities. These are related to the stages of facilitating the *translational process*, and the *generative* process for deriving spatial organisation variations (dataset *volumes*), and geometric articulation (dataset *landform*). In the following subsections we describe the tasks, the selected algorithms and workflows, and the related interfaces with the EIM Ontologies and the ECOLOPES Voxel Model for Loop 1, Loop 2, and Loop 3.

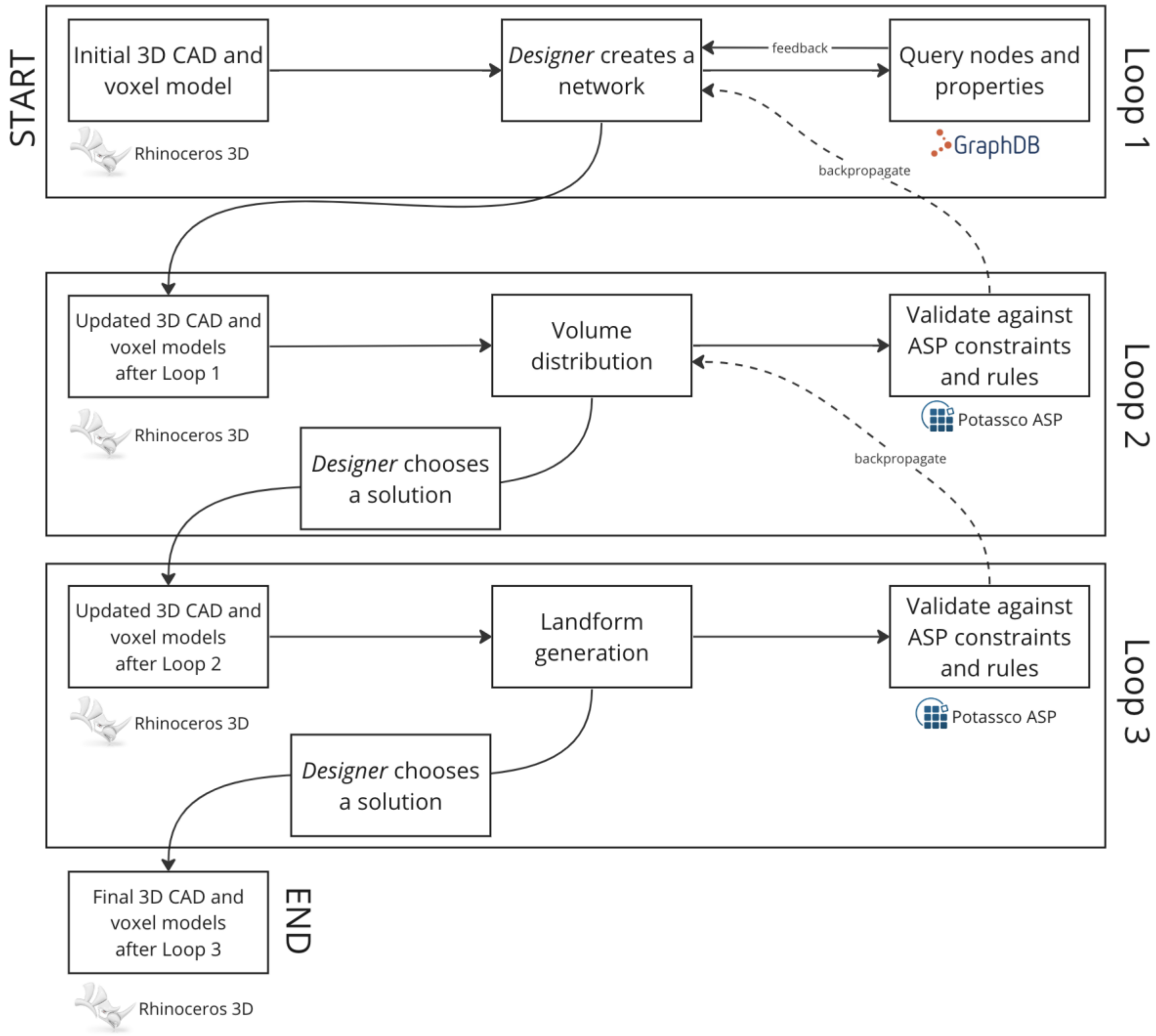


Fig. 3: The workflow describing the designer input and the interaction with the respective algorithms in different loops via GraphDB, and ASP constraints and rules.

Figure 3 displays the process steps starting from Loop 1 and ending with Loop 3. This involves the following:

1. Integration of Databases: The ECOLOPES Voxel Model incorporates different types of relational databases (RDBs) such as SQLite, and PostgreSQL. These databases are prototyped and tested to store and manage the voxel model data. The SQLAlchemy Python library is used to provide an SQL dialect agnostic solution for integrating the RDBs with the digital design process implemented in the Rhino 3D software.
2. Open-Source GIS Software: Open-source GIS processing software toolkits like QGIS and SAGA GIS are employed to generate geospatial analysis datasets. These datasets, representing environmental conditions such as solar exposure, topographic wetness, or wind exposure, can be converted into a voxel-based representation compatible with the ECOLOPES Voxel Model (*D5.3 ECOLOPES Voxel Model*).

3. Interaction with GraphDB: The ECOLOPES Voxel Model is integrated with GraphDB, a software solution that enables virtualization of data and integration with the EIM Ontology. The Ontop Virtualization technology, integrated into GraphDB, facilitates the interaction between the Voxel Model and the EIM Ontology. An OBDA/R2RML file defines the mapping between the RDB and the Knowledge Graph data structure, enabling the representation of voxel model data in an ontology-based format using RDF triples.
4. Coordinate Space Alignment: To ensure site-specific design proposals, the Voxel Model's coordinate space is aligned with the site boundaries and rotation. This alignment allows for accurate querying and utilisation of voxel model data within the generative computational design process. SQL functions and matrix operations are implemented within the RDB to transform large-scale voxel data into site-scale coordinate system space.
5. Designer Interactions: Architects and designers can interact with the ECOLOPES Voxel Model through the dedicated Grasshopper interface, which provides a visual programming environment within the Rhino 3D software. The Grasshopper interface allows designers to construct networks, validate network structures using GraphDB reasoning functionality, and explore voxel model datasets interactively.
6. Answer Set Programming (ASP): ASP is used as a declarative programming paradigm to represent and solve combinatorial problems within the ECOLOPES Voxel Model. ASP allows for logical reasoning and constraint satisfaction, enabling the model to generate design solutions that satisfy specified criteria and constraints.
7. Generative Process: The Voxel Model data, combined with ASP, is utilised in the generative computational design process. Designers can distribute volumes on the chosen site, with each volume assigned a predefined class. The ECOLOPES design process, powered by ASP, is executed based on the distributed volumes, and the Voxel Model data can be accessed through the GraphDB Ontop Virtualization interface.
8. Exporting Voxel Data: At the end of the generative process, the voxel-based representation of the geometry, along with the CAD-based representation, is saved for the Optimization Process as described in D6.1 Section 4.2. The voxel-based data is exported as a single SQLite database file containing multi-resolution data representing the results of the design process.

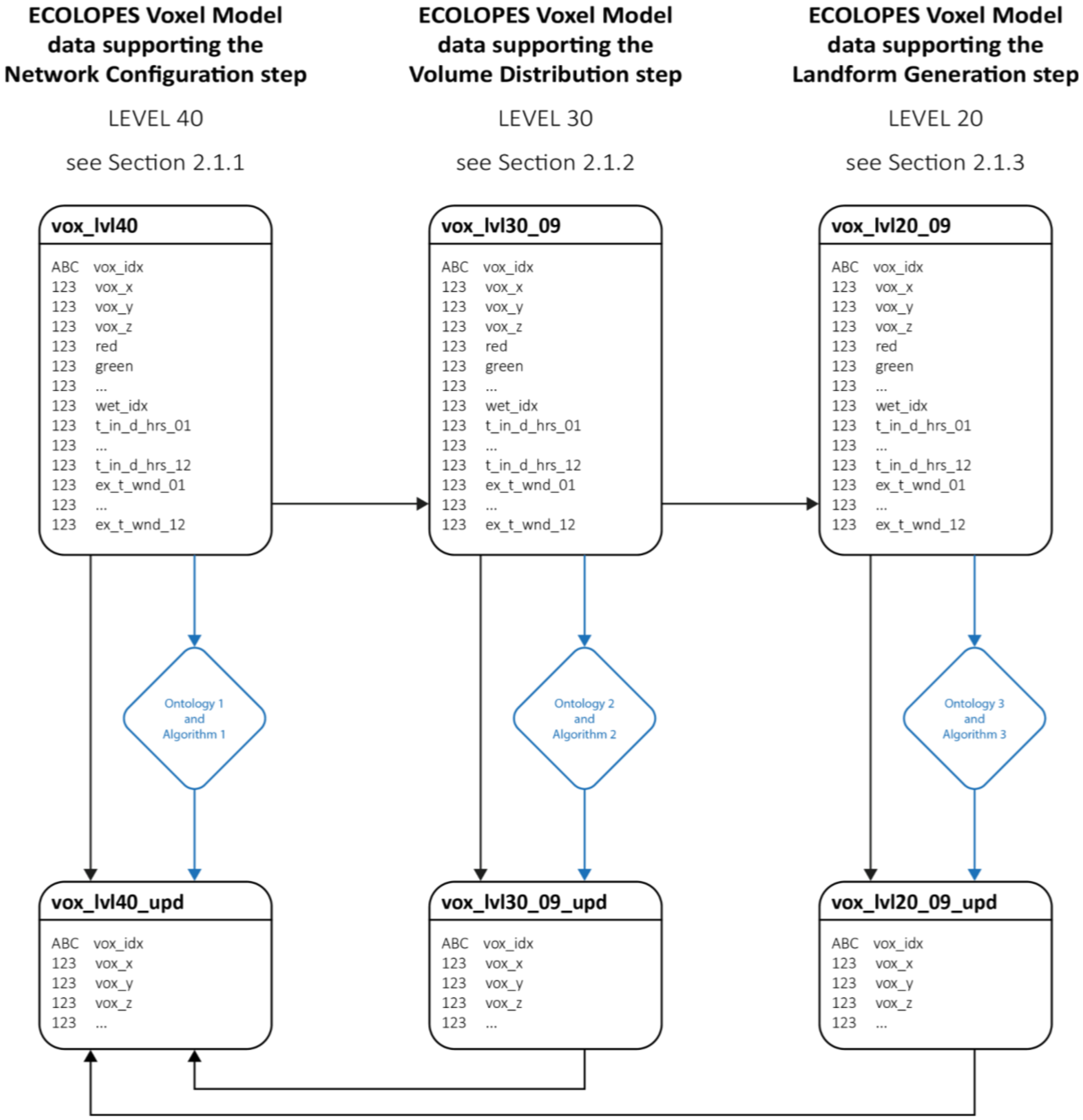


Fig. 4: Overview of the selected levels contained in the ECOLOPES Voxel Model and their relation to the computational procedures implemented in the three loops of the GCD process. Outcomes of each loop can be merged with the input data and written to a separate table (e.g., vox_lvl30_09_upd). This updated voxel-based representation can be merged with the large-scale data (vox_lvl40) and visualised in Rhinoceros. (D5.3 ECOLOPES Voxel Model)

2.1 Algorithms for the *Translational* Process: Loop 1

2.1.1 The Task

The first design stage is the *translational* process. It serves to set out the project-specific problem space for design. Requirements given by the design brief for a given project and site, and additional requirements are analysed, correlated, spatialised, and prepared. The *translational* process involves specific datasets prepared by the designer that serve as inputs into the design generation process via a knowledge graph that can be queried by the designer. This involves the preparation of datasets referred to as *maps* and *networks* (*D 5.1 Development Process for ECOLOPES Algorithms*, *D4.2 Interim EIM Ontology*). The dataset *networks* entails designer input in the form of User Networks (*D4.2 Interim EIM Ontology*) for initialising Loop 1. EIM Ontology 1 will aid the configuration of *Networks* (Ns) in the 3D CAD model and guide the generation of spatial organisation (dataset *volumes*) in Loop 2 and geometric articulation (dataset *landform*) in Loop 3 (*D4.2 Interim EIM Ontology*). In this context, algorithms are required that support analysis, correlation, spatialization, and preparation of the datasets that underlie the design generation process. This involves (1) enabling the designer to query and reason with EIM Ontology 1, (2) generating multiple design variations, and (3) facilitating data analysis.

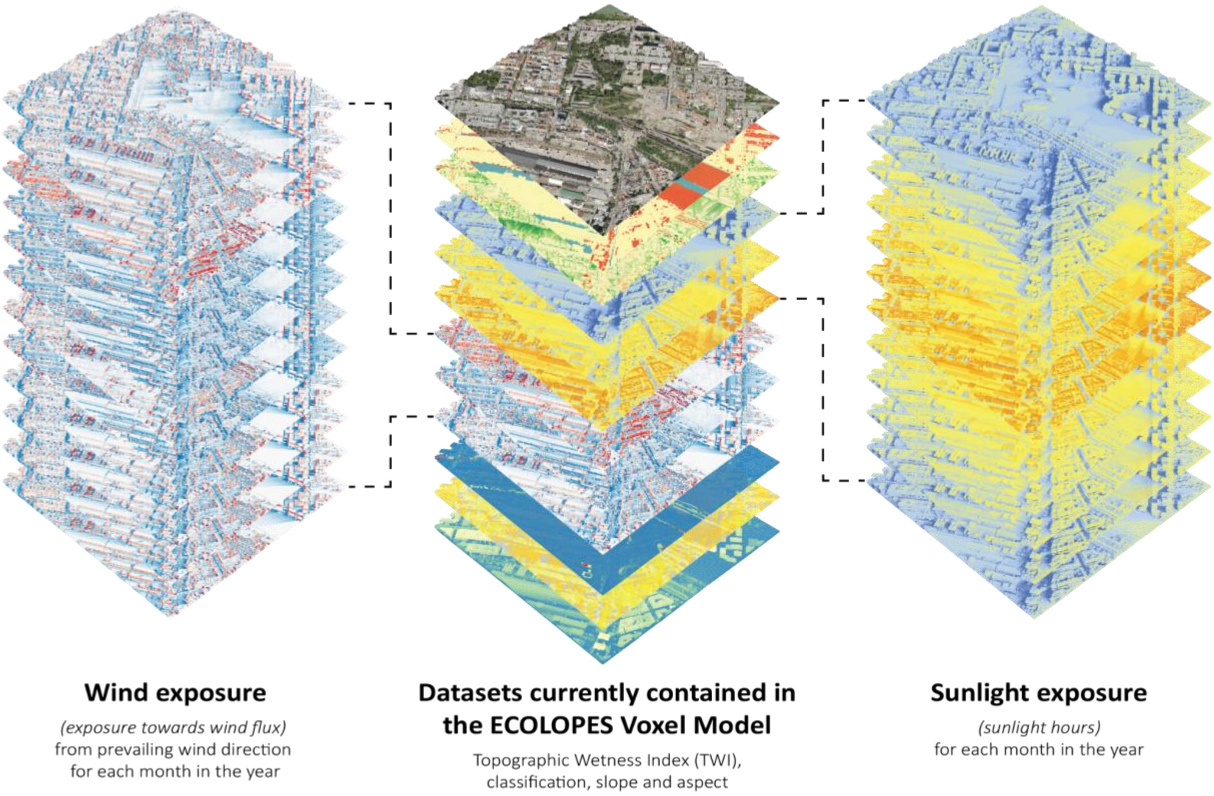


Fig. 5: Dataset maps: datasets contained in the ECOLOPES Voxel Model include geometric and classification data. This includes environmental performance data such as, for instance, topographic wetness index, as well as time series data, such as, for instance, insolation time and wind exposure. (D5.3 ECOLOPES Voxel Model)

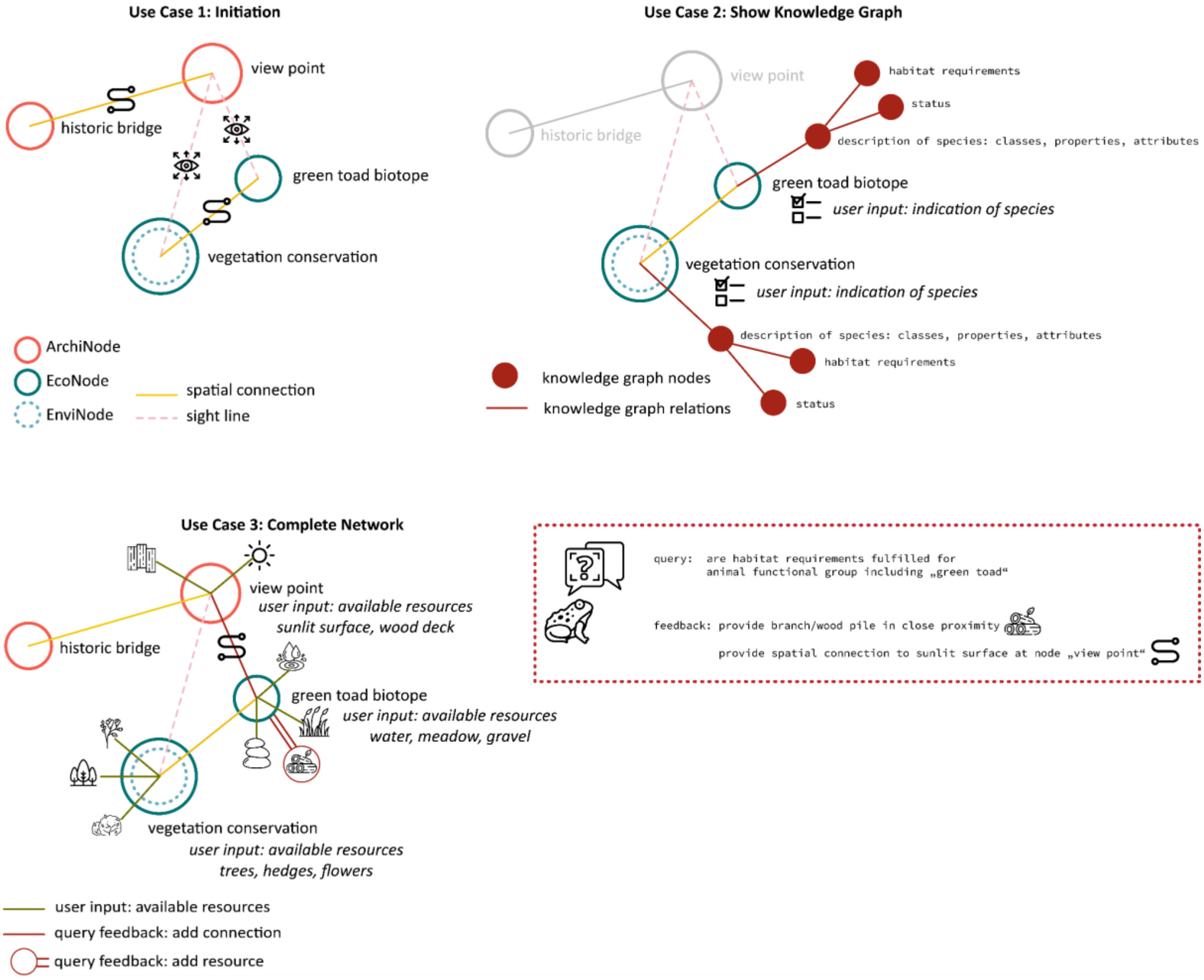


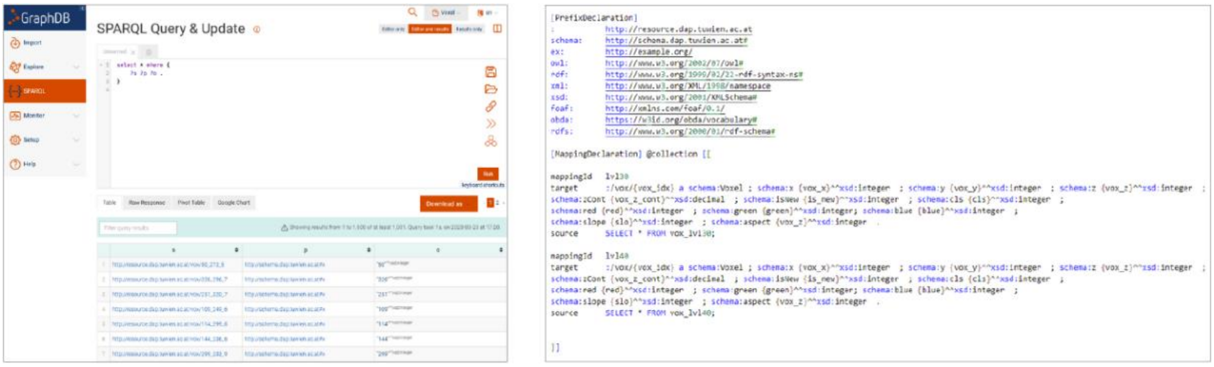
Fig 6: Illustration of designer configured networks for three different use cases. (D4.2 Interim EIM Ontology)

2.1.2 Selected Types of Algorithms and related Workflow

Loop 1 encompasses the *translational* process in ontology-aided generative computational design. Section 2.1 describes the task in Loop 1.

Stage 1 does not include additional algorithms for Loop 1, since this process can be facilitated without it. In stage 2 we outline extending Loop 1 in future with ASP, which will not be developed to the full required TRL. The ASP algorithm outlined in stage 2 will serve the purpose to convert design-related information into structured datasets for the translational process in Loop 1. ASP is useful for knowledge representation and reasoning tasks, enabling designers to make well-informed choices, and facilitating the conversion of design requirements and constraints into computationally interpretable data.

The stage 1 development entails that Loop 1 leverages GraphDB's SPARQL query endpoint to query and reason with the varied requirements and constraints (Fig. 7). This includes a combined query federation of different *datasets,* e.g., involving solar exposure and plants, returning a set of results that satisfy the conditions. For the cases where we don't need a recursive way of checking against the constraints in ASP using a set of rules that affect one-another, we solve such cases with GraphDB alone via SPARQL queries.



```
select * where {
    ?s ?p ?o .
}
```

```
[PrefixDeclaration]
:           http://resource.dap.tuwien.ac.at
schema:     http://schema.dap.tuwien.ac.at#
ex:         http://example.org/
owl:        http://www.w3.org/2002/07/owl#
rdf:        http://www.w3.org/1999/02/22-rdf-syntax-ns#
xml:        http://www.w3.org/XML/1998/namespace
xsd:        http://www.w3.org/2001/XMLSchema#
foaf:       http://xmlns.com/foaf/0.1/
obda:       https://w3id.org/obda/vocabulary#
rdfs:       http://www.w3.org/2000/01/rdf-schema#

[MappingDeclaration] @collection [[

mappingId   lvl30
target      :/vox/{vox_idx} a schema:Voxel ; schema:x {vox_x}^^xsd:integer  ; schema:y {vox_y}^^xsd:integer  ; schema:z {vox_z}^^xsd:integer  ;
schema:zCont {vox_z_cont}^^xsd:decimal  ; schema:isNew {is_new}^^xsd:integer  ; schema:cls {cls}^^xsd:integer  ;
schema:red {red}^^xsd:integer  ; schema:green {green}^^xsd:integer; schema:blue {blue}^^xsd:integer  ;
schema:slope {slo}^^xsd:integer  ; schema:aspect {vox_z}^^xsd:integer  .
source      SELECT * FROM vox_lvl30;

mappingId   lvl40
target      :/vox/{vox_idx} a schema:Voxel ; schema:x {vox_x}^^xsd:integer  ; schema:y {vox_y}^^xsd:integer  ; schema:z {vox_z}^^xsd:integer  ;
schema:zCont {vox_z_cont}^^xsd:decimal  ; schema:isNew {is_new}^^xsd:integer  ; schema:cls {cls}^^xsd:integer  ;
schema:red {red}^^xsd:integer  ; schema:green {green}^^xsd:integer; schema:blue {blue}^^xsd:integer  ;
schema:slope {slo}^^xsd:integer  ; schema:aspect {vox_z}^^xsd:integer  .
source      SELECT * FROM vox_lvl40;


]]
```

Fig. 7: Left: Screenshot of the GraphDB interface, showing how data contained in the ECOLOPES Voxel Model can be queried and represented in an ontology-based format (RDF triples) Right: Data saved in the RDB-based voxel model can be virtualized in GraphDB, by defining the mapping between the RDB and GDB data structure in an OBDA / R2RML file.

Stage 2 entails the conceptual development of an ASP algorithm, a declarative programming paradigm that enables logical reasoning and rule-based querying of EIM Ontology 1. ASP will enable the designer to query and reason with EIM Ontology 1 (knowledge graph) during the *translational* process. ASP enables designers to extract valuable insights and uncover relationships among different elements within the design problem space. ASP offers a logical framework for specifying constraints, rules, and conditions. In contrast to GraphDB, ASP can do reasoning with multiple constraints in a declarative way. Those constraints can be both local (e.g., provided by the user as a step in the translation process) and global (e.g., site requirements). In Loop 2 they can be generic rules of volume distribution based on soil, biomass, and architecture. ASP can augment and reason with both local and global constraints when returning an answer to the user that satisfies those. It might be that a constraint and a rule can have a 'chain effect' that it interacts with another one, e.g., addition or removal of a fact by a rule triggers another one. While GraphDB offers different OWL fragments to do reasoning with rules and constraints, it is not as flexible as ASP in defining the rules and constraints and providing explainable answers. Also, by using only SPARQL queries in GraphDB it is not feasible to capture different kinds of constraints, given that we do not need to specify such rules every time in the query, but instead we specify and store them as constraints that hold as 'global' constraints.

ASP can enable efficient and precise querying of EIM Ontology 1, facilitating the extraction of relevant data for subsequent design stages. The problem formulation stage involves defining the design context and objectives, as well as identifying the specific data requirements for the generative design process. With this foundation in place, design knowledge is encoded using logical rules and constraints within the ASP framework. This involves formalising concepts, relationships, and attributes relevant to the design problem, and encoding domain-specific rules and constraints that capture design considerations, preferences, and requirements. The next step involves query generation, where ASP rules and queries are developed to retrieve targeted data from EIM Ontology 1. Logical queries are constructed based on the defined design objectives and constraints, specifying the desired attributes and relationships to be retrieved. The formulated queries are then executed using an ASP solver, which employs reasoning capabilities to identify answer sets that satisfy the defined constraints and rules. From these answer sets, relevant data representing design elements, parameters, and contextual information is extracted. Following data retrieval, the extracted data undergoes filtering and refinement processes. This entails analysing and filtering out irrelevant or redundant information, as well as applying data refinement techniques such as cleaning and normalisation to ensure data consistency and reliability. The retrieved data is further validated against predefined constraints and quality criteria to maintain data integrity. Lastly, the retrieved data is transformed into a suitable representation for subsequent algorithmic processes. This transformation involves converting the data into a structured format, such as matrices or graphs, which facilitates efficient analysis and manipulation. This prepares the data for further stages in the generative design process.

To implement the ASP algorithm in Loop 1 it is useful for establishing a programming environment that supports logical reasoning capabilities. The formal representation of EIM Ontology 1, including concepts, relationships, and attributes, are defined using appropriate notations and frameworks. ASP rules and constraints can then be developed to encode the design knowledge and constraints specific to the design problem. The implementation would also necessitate constructing the query generation module, executing the queries using an ASP solver, and applying data filtering, refinement, and transformation techniques. It will be important to validate the implemented Algorithm 1 by executing test cases and comparing the results with expected outcomes to ensure the correctness and efficiency of the data retrieval and preparation process.

2.1.3 Interfaces with EIM Ontology 1 and ECOLOPES Voxel Model

The interface with EIM Ontology 1 in the ECOLOPES Computational Framework provides designers with the means to interact with the Knowledge Graph and access the design-related information contained within it. The use of EIM Ontologies plays a significant role in guiding the generative computational design process for designing ecological building envelopes. EIM Ontology 1 contains information about urban design principles, regulations, and constraints in Vienna, such as building heights, setback requirements, green spaces, and transportation infrastructure. Designers can access EIM Ontology 1 to retrieve relevant data and ensure compliance with the specific urban design guidelines of Vienna. For instance, a query in GraphDB can retrieve all plants that satisfy the sunlight exposure retained in voxel model - for further details and the SPARQL query refer to Fig. 21 in deliverable D.4.2. Such queries rely on join conditions, i.e., basic graph patterns in SPARQL, between data residing in different graphs or repositories, which are further expanded with FILTER queries to specify conditions.

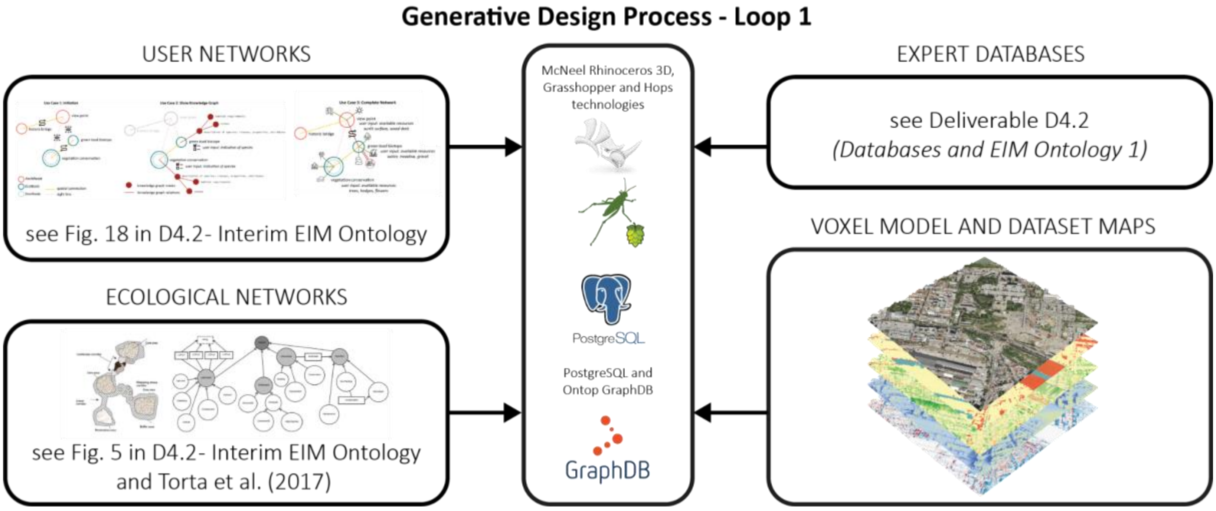


Fig. 8: Loop 1 in the generative design process enables combination of Dataset Networks, Dataset Maps, and data contained in the expert databases into 3D CAD based representation. Designer provides input by configuring User Networks in the McNeel Rhinoceros 3D interface. Dataset Networks consists of User Networks and Ecological Networks interactively queried from GraphDB, while the Dataset Maps is created by interactively querying the ECOLOPES Voxel Model.

The ECOLOPES Voxel Model integrates various datasets that are required or desired for the design process. By incorporating geospatial data such as topography, land use patterns, and existing infrastructure, the voxel model enables designers to visualise and manipulate the physical and environmental context of the project site. This empowers the designers to make informed decisions in the translational process, as well as in the subsequent stages of the generative process. (*D4.2 Interim EIM Ontology Section 4.1.5*)

Stage 2 of the deliverable entails the conceptual development of an ASP algorithm for Loop 1. The ASP algorithm can enhance the interactions and interfaces between the key components in Loop 1. EIM Ontology 1 is developed for the representation of Ecological Networks (ENs) as a Knowledge Graph. It integrates User Networks (UNs) defined by the designer according to the context, project, and user specific determinations and input. It reasons over the KG for inference of decision rules by using ASP in future. The interaction of EIM Ontology 1 and the ASP algorithm can enhance (1) the selection process and aid filtering the individuals (ontology instances/KG nodes) that will be included in the KG (i.e. selection from the regional plant pool according to conservation objectives), and (2) to advance informing the spatial distribution of individuals with non-spatial, spatial, or spatio-temporal EN relations and guide the configuration of 3D Networks (Ns) in CAD (*D4.2 Interim EIM Ontology Section 4.1.4*).

What we term Algorithm 1 in this context will include reasoning techniques including querying and constraint checking. In stage 2 we foresee enhancing reasoning with ASP rules. This rule-based algorithm ensures sound and complete answers to queries and constraints, thereby ensuring that specific relationships are put into the design context with requirements that are established in a graph, instead of a generic ecological query. The (2.5D/3D data) spatial or

(2.5D/3D and time-stamped data) spatio-temporal instances in the graph are then registered as nodes/voxels in CAD. EIM Ontology 1 will be used in Algorithm 1 as there are defined relationships such as "preys on", "threatened species", "invasive species" etc. and together with the data coming from databases are fed to Algorithm 1. The algorithm will help with both the "selection" and "distribution" process. (*D4.2 Interim EIM Ontology*)

At this stage of the *translational* process the Ontology is used for representation and reasoning of KGs, which integrates ENs and UNs, and in future as an ASP algorithm that can enable human controlled and automated reasoning to infer design instructions or decision rules for the iterative configuration of 3D Networks in the CAD environment (Ns of CAD Model 1) under predefined and emergent constraints. These constraints might be coming from the ontology (axioms, assertions, etc.), from designer defined inputs and general / meta-level design rules that apply to all design cases that are integrated in Algorithm 1 (*D4.2 Interim EIM Ontology*). EIM Ontology 1 is configured based on a set of competency questions, which will need to be revised and expanded over time related to the selection and distribution processes and the configuration of 3D Networks in CAD. This rule-based generative process using ASP can generate single or multiple solutions, which then can be evaluated by the designer manually and/or given as an input for graph optimization using machine learning to guide the selection of "best" 3D network alternatives in each iterative step in the *translational* process. We use a voxel-based system that allows retrieving and representing spatial nodes and turning instances of the ontology into voxel data points in 3D space in CAD.

By utilising this voxel-based representation, the design process can effectively incorporate spatial considerations, allowing for more comprehensive and informed decision-making. Additionally, the voxel-based system enables the capturing and preservation of spatial relationships between nodes, enhancing the accuracy and fidelity of the design representation. This representation facilitates a more holistic understanding of the design space, allowing designers to visualise and manipulate the elements in three-dimensional space. By converting instances of the ontology into voxel data points in 3D space within CAD, designers gain the capability to interact with the design at a granular level. They can manipulate and modify the voxel-based representation, exploring different design alternatives and evaluating their feasibility in real-time. Moreover, the integration of machine learning techniques in the graph optimization process further enhances the design selection process. By leveraging data and patterns, machine learning algorithms can provide valuable insights and recommendations to guide the designer in selecting network alternatives. This iterative feedback loop between the designer, Generative Process, and Machine Learning optimization ensures a continuous improvement and refinement of the design solution.

The integration of this interface is done using the Hops component, where we query and reason with the data from Ontology 1 stored in GDB. Typical queries include for instance:

- "What is the context of a particular node type?"
- "What kind of relations exist for this node type?"
- "Which kind of relations exist between node types?"

Answers are provided by the KG. In addition, the designer can ask questions that are specified in the design brief, and that have been formalised in the KG and can be queried.
Regarding Algorithm 1 this is used for the next step of reasoning with constraints and rules provided as input by the designer in the form of the dataset *networks*. Such constraints and rules are fed to the ASP program.

The interface between CAD Model 1, Algorithm 1, and EIM Ontology 1 in Loop 1 serves two main purposes: (1) it facilitates CAD Model 1 input, including voxel data used to initialise the translational process and reasoning over the Knowledge Graph of ENs, and (2) it enables designer feedback in each design iteration based on the 3D configuring Networks solutions, which integrate ENs and UNs and are derived from EIM Ontology 1-driven rule-based algorithmic procedures. The aim is to use a sequence diagram to illustrate the interactions and flow of messages between the designer, KG component, and the algorithm component. The diagram begins with the designer initiating the process by requesting information or performing an action related to the algorithm. The KG component, responsible for managing the ontology data, receives the request and processes it by querying the ontology and retrieving relevant data. Algorithm 1 is an ASP algorithm employed in the generative design process that represents complex constraints and provides a systematic approach to finding feasible design solutions within the specified design space. This allows for the exploration and generation of design solutions that meet constraints and requirements while leveraging the Knowledge Base and reasoning capabilities of EIM Ontology 1 (see *D4.2 Interim EIM Ontology Section 4.1.8*).

In the first loop of the ontology-aided design process the connection between the CAD Model 1 (CAD 1) and the ECOLOPES Voxel Model is facilitated through the McNeel Rhino 3D interface. In this phase of the process, the designer configures networks in the Rhino 3D software. The outcome of this process is a spatial configuration of the network nodes and their properties, expressed as native Rhino objects. Spatial configuration and internal structure of the network is validated by Ontology 1. The ECOLOPES Voxel Model features a Rhino 3D / Grasshopper interface that allows the designer to interact with the voxel model, querying available datasets that can be interactively visualised in the 3D viewport of the Rhino 3D software (see *D5.2 ECOLOPES Voxel Model*.)

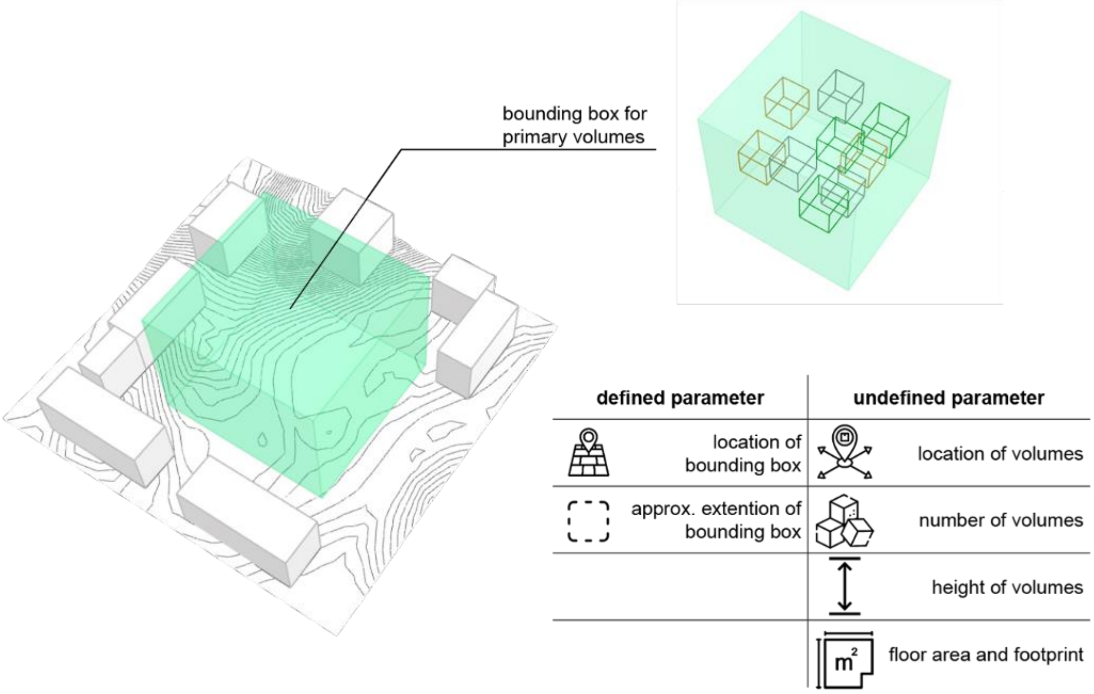
2.2 Algorithms for the *Generative* Process: Loop 2

2.2.1 The Task

Loop 2 facilitates the generation of the spatial organisation (dataset *volumes*) for each case-specific design output. First the design objectives, constraints, and criteria that guide the generative process are defined. This step also includes specifying performance metrics related to ecological and architectural criteria. These metrics are derived from the KPIs identified in D6.1. EIM Ontology 2 is developed to generate query results for Competency Questions related to the volume specification task according to specific criteria established in Loop 2, and to enable the implementation of rules inferred from the ontology to aid the iterative distribution of CAD Volumes in Loop 2. The selected type of algorithm then needs to generate a set of design solutions that satisfy the set criteria. This involves manipulating the defined parameters and constraints to generate a range of design alternatives.

2.2.2 Selected Types of Algorithms and related Workflow

The algorithms for Loop 2 facilitate Stage 1 of the generative computational design process, by generating variants of spatial organisation through volume distribution for specific design cases. Stage 1 in Loop 2 entails development of an Answer Set Programming (ASP) algorithm. Stage 2 comprises a conceptual development for future advancement of the ontology-aided generative design process. This entails extending Loop 2 with project-specific Genetic (GA) and Machine Learning (K-means) algorithms (see Appendix 1 and Appendix 2). Stage 2 will not reach full technical resolution and implementation.



defined parameter	undefined parameter
location of bounding box	location of volumes
approx. extention of bounding box	number of volumes
	height of volumes
	floor area and footprint

Fig. 9: Spatial constraints and parameters for volume distribution in Loop 2.

The generative process is initiated in Loop 2 with the aim to generate variants of spatial organisation via the distribution of architectural, biomass and soil volumes (dataset *volumes*). The inputs include geometric constraints, volumetric constraints, and the datasets maps and networks (Fig. 9).

In Loop 2 algorithms enable the generation of variants of spatial organisation by systematically varying parameters and constraints that influence volume distribution. To facilitate this task an ASP algorithm was selected for stage 1. Data can be accessed from the GraphDB's SPARQL endpoint to be queried and forwarded to the ASP algorithm to start the process of reasoning. Different types of volumes (architectural, biomass, and soil volumes) are distributed in this process, and checked if their distribution satisfies the criteria encoded in ASP. The data from EIM Ontology 2 that is derived from its SPARQL endpoint is fed to the algorithm that generates variations of spatial organisation via volume distribution. The ASP algorithm generates a set of instantiations of volumes, visualised in the CAD environment, that satisfy the given constraints. The generated design variations are then evaluated and ranked based on predefined metrics derived from the KPIs identified in D6.1, enabling designers to compare and select the most promising options. Through an iterative and interactive process, designers can refine the generated spatial organisation variants. The final output of the algorithms is spatial organisation through volume distribution.

For stage two we seek to develop on a conceptual level the utilisation of a GA and a ML (K-means algorithm). The current initial state of development of the GA algorithm is documented in appendix 1. The current state of development of the ML (K-means) algorithm is documented in appendix 2.

2.2.3 Interfaces with EIM Ontology 2 and ECOLOPES Voxel Model

In EIM Ontology 2 we have properties such as “volume” that describe each volume regarding whether it occupies one of the following values: air, architecture, soil, or biomass. The data from EIM Ontology 2 that is derived from its SPARQL endpoint is fed to Algorithm 2 that generates volume distribution. In case the constraints are not satisfied by ASP it is necessary to either repair the distribution of volumes, or to re-generate the volumes from scratch. Repairing the distribution of volumes in a minimal way is not always possible or can lead to ambiguous solutions, e.g., remove/add volumeX or remove/add volumeY, where a designer needs to choose between the two, while only knowing the impact of this decision further down the line. (see *D4.2 Interim EIM Ontology Section 4.2.1*)

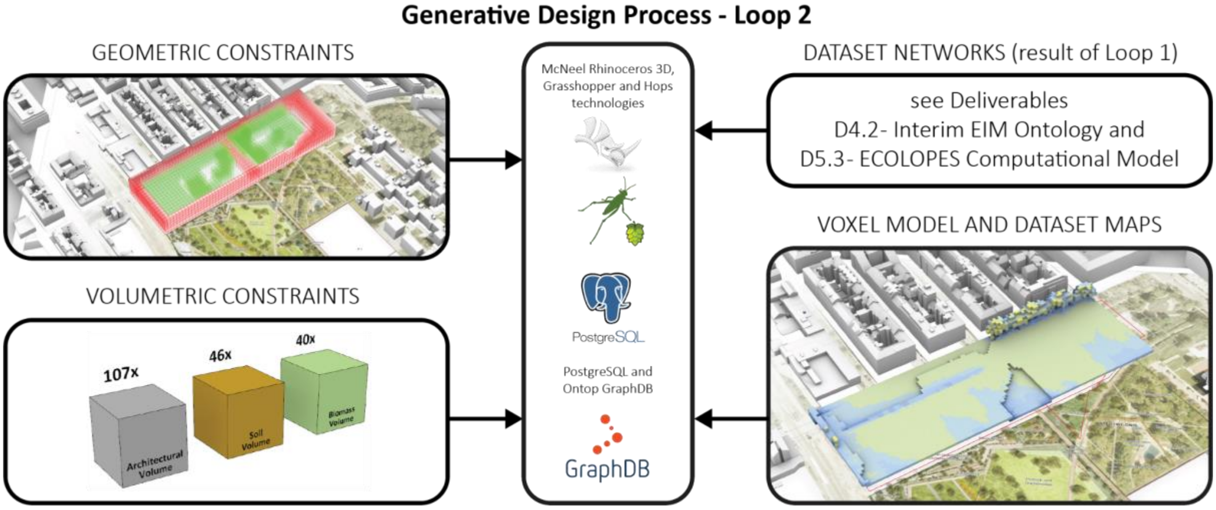


Fig. 10: In Loop 2 the generative design process is initiated to enable spatial organisation by way of distributing architectural, biomass and soil volumes. The inputs for Loop 2 are geometric constraints (e.g., project-specific site borders), volumetric constraints (e.g., as

specified by site-specific planning regulations), dataset maps (project-specific datasets contained in the ECOLOPES Voxel Model), and the designer-defined dataset networks.

Once the ASP algorithm generates a set of instantiations of volumes that satisfy the given constraints, these results are passed on to the CAD interface for visualisation and further design refinement. To achieve this, an intermediate component called the Hops component is employed. The Hops component is responsible for reading the results in JSON format, which represent the instantiated volumes, and subsequently rendering them within the CAD interface. By utilising the Hops component to bridge the gap between the output of the ASP algorithm and the CAD interface, designers can visualise the generated volumes and assess their feasibility. This interface enables designers to interact with the volumes, make modifications, and refine the design. (see *D4.2 Interim EIM Ontology*) The ASP algorithm and EIM Ontology 2 have direct access to data stored in the voxel model by the utilisation of SQL virtualisation method. Moreover, voxel data available in the levels introduced for the operation of EIM Ontology 2 (vox_lvl30_3 etc.) can be utilised in the CAD environment. The interface developed for the visualisation and interaction with the voxel model as a part of the task T5.1 (*D5.2 ECOLOPES Voxel Model*) enables designers to inspect the information utilised by EIM Ontology 2 and the ASP in Loop 2. This data can be visualised in the Rhinoceros interface and the results of the volume distribution can be graphically compared with the underlying voxel data that informs the distribution process. (*D4.2 Interim EIM Ontology*)

The interface with the ECOLOPES Voxel Model involves the integration of relational databases like SQLite, GraphDB, and PostgreSQL for efficient storage and management of voxel model data. Open-source GIS software such as QGIS and SAGA GIS generates geospatial analysis datasets, which can be converted into voxel-based representations. The voxel model also integrates with GraphDB, allowing data virtualization and interaction with the EIM Ontology. To ensure site-specific design proposals, coordinate space alignment is performed, enabling accurate querying and utilisation of voxel model data. Architects and designers can interact with the voxel model through the Grasshopper interface. The voxel model data is leveraged in the generative computational design process. At the end of the generative process, the voxel-based geometry is exported along with the CAD-based representation. ASP enhances the interface by enabling logical reasoning and decision-making capabilities.

2.3 Algorithms for the *Generative* Process: Loop 3

2.3.1 The Task

Loop 3 facilitates the generation of geometric articulation (dataset *landform*) for each case-specific design output. First the design objectives and constraints that guide the generative process are defined. In subsequent development the computed KPIs will be part of this initialisation of the generative process.

Loop 3 includes specifying performance metrics related to ecological and architectural criteria, again this will in the next steps include the computed KPIs.

EIM Ontology 3 is developed to generate query results for Competency Questions related to the geometry articulation task according to specific criteria established in Loop 3, and to enable the implementation of rules inferred from the ontology to aid the iterative generation of CAD geometry in Loop 3. The selected type of algorithm then needs to generate a set of design solutions that satisfy the set criteria. This involves manipulating the defined parameters and constraints to generate a range of design alternatives.

2.3.2 Selected Types of Algorithms and related Workflow

The algorithms for Loop 3 facilitate stage 2 of the generative computational design process, by way of generating variants of geometric articulation for selected volume distributions derived in Loop 2. Stage 1 in Loop 3 entails development of an Answer Set Programming (ASP) algorithm. Stage 2 comprises a conceptual development for future advancement of the ontology-aided generative design process. This entails extending Loop 3 with a Genetic (GA) and a Machine Learning (K-means) algorithms. Stage 2 will not reach full technical resolution and implementation, yet pave the way for future advancement of the ontology-aided generative computational design process.

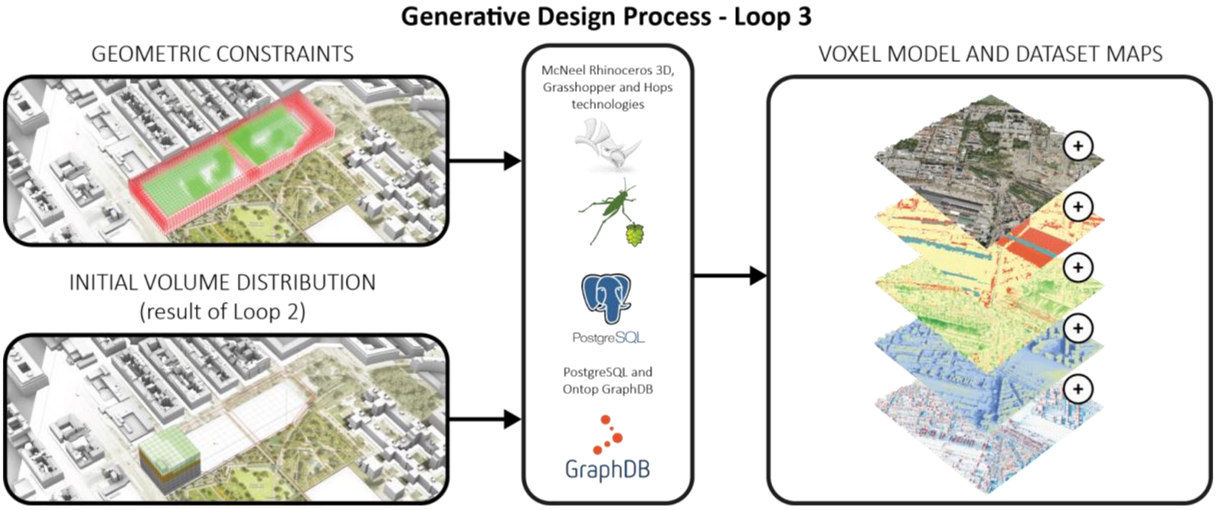


Fig. 11: In Loop 3 the generative design process is initiated to enable detailed geometric articulation for selected spatial organisation. Initial volume distribution created in the previous loop is supplemented by the definition of geometric constraints that are used as inputs to this process. As a result, updated spatial representation of the design process results is created and introduced into the ECOLOPES voxel model.

The generative process is finalised in Loop 3 by generating variants of geometric articulation (dataset *landform*) for selected spatial organisation outputs of Loop 2. Stage 1 entails the technical development of an ASP algorithm to enable the generation of variants of geometric articulation by systematically varying parameters and constraints that influence geometric articulation (e.g., building angle). Loop 3 data can be accessed from the GraphDB's SPARQL endpoint to be queried and forwarded to the ASP algorithm to start the process of reasoning. Different types of terrain or landform features are articulated specific to selected volume clusters representing architectural and soil volumes, and checked if their articulation satisfies the criteria encoded in ASP. The data from EIM Ontology 3 that is derived from its SPARQL endpoint is fed to the algorithm that generates variations of geometric articulation. The ASP algorithm generates a set of instantiations of geometries, visualised in the CAD environment, that satisfy the given constraints. The generated design variations are then evaluated and ranked based on predefined metrics, enabling designers to compare and select the most promising options. Through an iterative and interactive process, designers can refine the generated geometric articulation variants. The final output of the algorithms is geometric articulation associated with specific spatial organisation variants, i.e., volume distribution.

For stage two we seek to develop on a conceptual level the utilisation of a GA and a ML (K-means algorithm). The current initial state of development of the GA algorithm is documented in appendix 1. The current state of development of the ML (K-means) algorithm is documented in appendix 2.

2.3.3 Interfaces with EIM Ontology 2 and ECOLOPES Voxel Model

The interface with the ECOLOPES Voxel Model involves the integration of relational databases (see 2.2.3 and *D5.3 ECOLOPES Voxel Model*). The voxel model integrates with GraphDB, allowing data virtualization and interaction with the EIM Ontology via a SPARQL endpoint. Architects and designers can interact with the voxel model through the Grasshopper interface. At the end of the generative process, the voxel-based geometry is exported along with the CAD-based representation. ASP enhances the interface by enabling logical reasoning and decision-making capabilities regarding the spatial organisation, i.e., volume distribution. Different types of volumes (architectural, biomass, and soil volumes) are distributed in this process. Subsequently, these volumes are checked to ascertain that they satisfy the criteria encoded in ASP. This approach enables making determinations about permissible and non-permissible proximities of volumes according to specified criteria and rules.

3 VALIDATION

Technical validation will take place within different WPs where specific components are validated (Table 2). In this section we describe the technical validation of the components of the ontology-aided generative computational design process. The validation includes the EIM Ontology (*D4.2 Interim EIM Ontology*), the ECOLOPES Voxel Model (*D5.3 ECOLOPES Voxel Model*) and the ECOLOPES Computational Model.

Table 2: Overview of components to be validated (summarised from the GA workshop in Genoa held at M24) (D7.1 Report on the Methodology for ECOLOPES Multifunctionality Evaluation). The table shows the validation of the ontology-aided computational design process within the overall context of validation of the design approach, processes, and components.

Components	**Parameters**	**WP**	**How**
Ecological model/regional model	1. Regional connectivity 2. Functional groups 3. AFG and PFG biomass distribution	WP4	1. Statistical correlation of real-world data with simulated results 2. Correlation between diversity indices at a species level vs FGs level. 3. a) Plausibility of KGF outcomes; b) statistical correlation of real-world data with simulated results
Ontology aided generative computational design process	1. Ontological output 2. Design output (ECOLOPES Voxel Model and design algorithms)	WP4, WP5	Computational validation based on the Vienna Case Study. 1. Statistical analysis of answers generated by ontology using precision and recall method (see D4.2 Interim EIM Ontology). 2. Comparative case-based analysis of the ECOLOPES Voxel Model (see D5.2 ECOLOPES Voxel Model); Validation of the ECOLOPES Computational Model (see D5.3 ECOLOPES Computational Model). An overall validation of the ontology-aided generative computational design process will be also implemented (see *D5.4 ECOLOPES Computational Model Validation*)
Optimization and decision-making	KPIs	WP6	Computational validation of decision-making algorithms (e.g., TOPSIS, AHP) constructed in grasshopper using external Python libraries.
Simulation environment (KPIs)	KPIs-related parameters	WP6-WP7	Computational validation of OTC (and related parameters: air temperature, relative humidity, mean radiant temperature, wind speed) assessment component
ECOLOPES mock-ups	Soil and plant development, animal colonisation, and microbiota	WP7	Monitoring and sampling on ECOLOPES mock-ups (Building Blocks)
ECOLOPES design outcome/process	KPIs	WP7	Expert interviews / user validation
Social outcome (human perception and well-being)	Validate indirect and direct measures of nature related well-being (e.g., PANAS, PRS, cognitive tests) and measures of satisfaction of and perceptions from the *ecolopes*.	WP7	Lab experiments in virtual reality allowing immersion in environments with different types of *ecolopes*.

3.1 Validation of the Components of the Ontology-aided Generative Computational Design Process

3.1.1 Validation of the EIM Ontologies

The EIM Ontologies and the ontology-aided generative computational design process is an AI powered system that combines Logic Programming (LP) e.g. Answer Set Programming (ASP) for rules and constraints, Dataflow Programming (DFP) (Grasshopper), machine reasoning, i.e., ontology-based reasoning (OBR), i.e., TBox only (subsumption of classes) or TBox + ABox consistency checks (Protégé reasoner, e.g. HermiT), SPARQL-endpoint reasoning (RDFS or OWL profiles in GraphDB) and Machine Learning (ML). (*D4.2 Interim EIM Ontology*)

The EIM Ontologies are located between the Knowledge Base and ECOLOPES Computational Model. An interim KB currently contains the KGF results, a structured analysis of Ecological Models run on multiple input geometries (D.3.3.); as well as architectural input and regional data. From an information flow perspective, this can be represented in the following way, although feedback, interactions, and interfaces alter this simplified schema:

→ *Ecological Model* → ***EIM Ontologies*** → *design generation environment* → *optimization environment*→

EIM Ontology 1 effectively represents Ecological Networks (ENs) as a knowledge graph. The latter can be reasoned and integrates User Networks (UNs) to generate query results for Competency Questions related to the selection and distribution tasks according to specific criteria established in Loop 1. Furthermore, it enables the implementation of rules inferred from the ontology to aid the iterative configuration of CAD Networks (Ns) in the *translational process*. (*D4.2 Interim EIM Ontology*)

EIM Ontology 1 is a knowledge graph that serves to convert design requirements and constraints into computationally interpretable data. It includes various design-related information, such as project-specific requirements, site characteristics, environmental factors, and additional design constraints. EIM Ontology 1 provides a structured representation of this data, allowing designers to access and query relevant information to aid in the design generation process. By using this ontology, designers can effectively navigate and utilise domain-specific knowledge that enables informed decision-making throughout the design workflow. (*D4.2 Interim EIM Ontology*)

EIM Ontology 2 serves the generative process and aids the generation of spatial organisation via volume distribution (dataset *volumes*). EIM Ontology 2 builds on EIM Ontology 1 and generates query results for Competency Questions related to the volume specification task according to specific criteria established in Loop 2, and to enable the implementation of rules inferred from the ontology to aid the iterative distribution of CAD Volumes.

EIM Ontology 3 builds on EIM Ontology 1 and EIM Ontology 2 and is developed to generate query results for Competency Questions related to the specific geometric articulation (dataset *landform*) of selected volume distributions resulting from Loop 2. This is done according to criteria established in Loop 3, enabling the implementation of rules inferred from the ontology to aid the iterative generation of CAD geometry. This ontology describes and represents a building or feature in an *abstract form*. The abstract representation of the building is used for description and for reasoning.

For the ontology evaluations we will initially focus on consistency checks, Competency Questions, completeness criteria, and best practice conformance. In the context of the Vienna Case Study, we will likely also undertake measure against a golden benchmark and user study evaluation.

The Knowledge Graph consists of instance data (ABox) and terminological assertions (TBox) - i.e., axioms that can be imposed as restrictions on ABox (for more details refer to D4.2). We compute consistency checks to see if there are any anomalies in our KG, i.e., see if there are instances in ABox that satisfy the schema and constraints in the TBox. It can be the case due to bad modelling practices to render the ontology inconsistent, i.e. there will be no instance in ABox that can satisfy the constraints in TBox. Or, even in rather extreme cases TBox can be inconsistent with itself in isolation. These consistency checks (ABox+TBox) come for free as they are embedded in the Protégé tool that we are developing our ontology in and can be run as needed.

Competency Questions are described in detail in deliverable D4.2 and they can be used to check whether for a given query there is always a result returned. For competency queries we have distinguished between ASK and SPARQL queries that can be posed over a KG. SPARQL is a standardised language for querying knowledge graphs and has its “look and feel” like SQL. ASK queries are a specialisation of SPARQL queries - with the same query body but a different query head - in the sense that instead of returning answers, they return *true* or *false* depending on whether there are answers or not returned by the query. This can be sufficient for some use cases in which it is not required to know the answers but to the extent if there are answers at all. As an example, we provide the CQ from D4.2 that returns ‘threatened species, and here you can see the difference between the two.

```
SELECT * WHERE { ?s a :Species ; :status :threatened }
ASK WHERE { ?s a :Species ; :status :threatened }
```

Validation is described in D4.2. For each CQ a corresponding ASK and SELECT is created, which are evaluated against GraphDB’s SPARQL endpoint. Such requests can be automated with curl requests that can be imported as Postman collections so that they can be maintained, shared, and run periodically.

Regarding completeness criteria we use the notion of Relative Completeness (Balaraman et al.), which means that we check for each entity (e.g., species) how complete it is with respect to other entities of the same type (species). To illustrate with the previous example: we can check if all the species have the `:status` property or not, given that such a property is very important for species. As a baseline, we can take all species of the same type, e.g., for class `:Animal` we compute all the properties and attributes that all entities have and based on selection of TOP 5 properties and attributes, we see if other entities of the same class type have those or not, measuring the relative completeness of the entity. Using this notion of relative completeness, we compute the percentage of the entity, e.g. the entity :A is 60%=3/5 because it does not have properties X and Y that predominantly exist in the similar entities (same class type), but it has others in TOP 5: Z, V, W. Based on this feedback, we can refine further our KG and add properties X and Y for entity A if we can increase completeness by incorporating a further dataset.

We plan to compute the relative completeness measure for all entities, as they can be automated using SPARQL queries, see Relative Completeness Indicator (Recoin) for Wikidata.

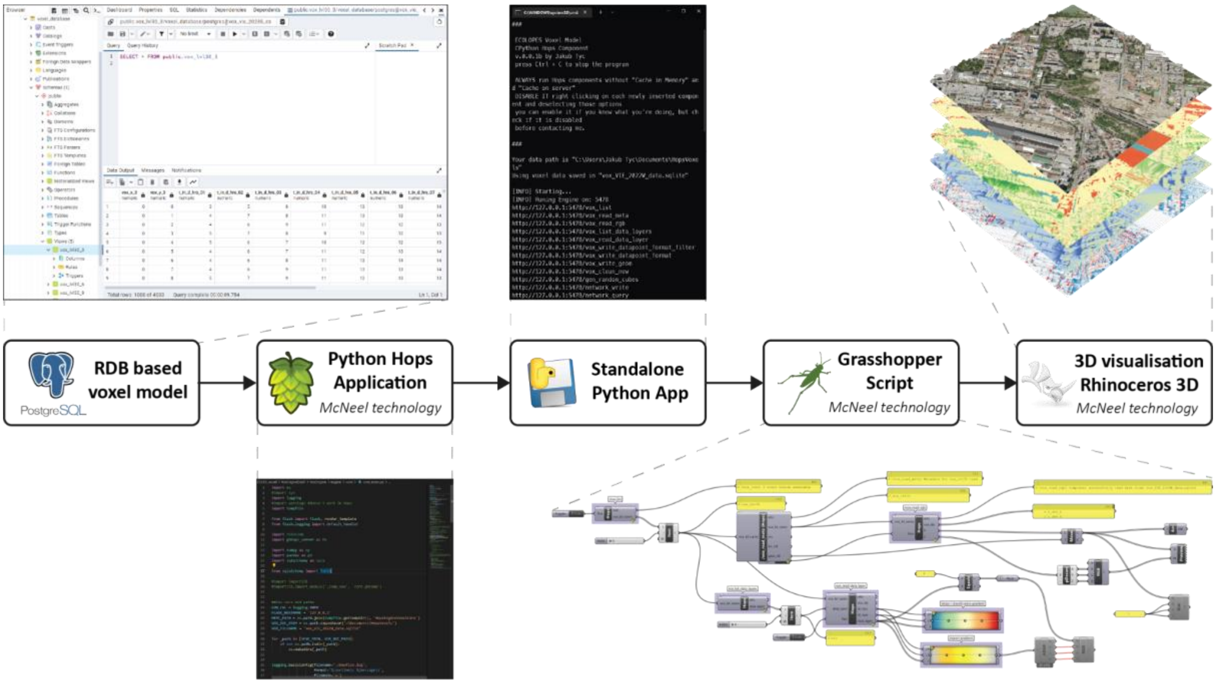
Regarding the final point, best practices conformance we have already created our ontologies using a URI scheme, reusing taxonomies and ontologies whenever possible (e.g., geonames), and checking against a service that can detect and evaluate the ontology (see https://themis.linkeddata.es/).

3.1.2 Validation of the ECOLOPES Voxel Model

The Voxel Model receives data from different sources including relevant databases, the Ecological Model, the Knowledge Generation framework, and if required from various simulations executed in Geographic Information Systems (GIS) software. Relevant data can be indicated and / or called via the EIM Ontologies. Data contained in the Voxel Model can then be utilised in the data-driven generative computational design process through which design outputs are created that consist of (1) geometry contained within the CAD model, (2) design specific data contained in the voxel model, and (3) ontological output. The resulting data package can then be used within the optimization process to derive design outputs with optimised architectural and ecological performances. In the following subsections we deliver a conceptual and technical characterization of the Ecolopes Voxel Model.

The ECOLOPES Voxel Model uses a range of technologies to link the voxel data encoded in an RDB-based voxel model with the Rhinoceros / Grasshopper interface. Figure 12 shows how the chosen software technologies are used in the ECOLOPES Voxel Model implementation. This implementation builds on the technologies readily available within the McNeel Rhinoceros software ecosystem. Rhinoceros and Grasshopper are one of the most widely used tools in architectural design. Originally, McNeel introduced GHPython components into the Grasshopper environment, based on the IronPython (*IronPython*, 2017). To overcome some of the limitations posed by the IronPython, we used the Grasshopper Hops components, which adds external functions to Grasshopper through Rhino.Compute. Hops integrates a modern Python interpreter (CPython 3.9) with the Rhinoceros/ Grasshopper environment through a REST API based interface. ECOLOPES Voxel Model Grasshopper definitions are written as Hops components to establish an interface with the RDB. SQLAlchemy Python library (SQLAlchemy, 2018/2023) is used to provide an SQL-dialect agnostic solution for integrating RDBs with the digital design process implemented in the Rhinoceros software. For the RDB-based ECLOPES Voxel Model, different types of RDBs, including SQLite, MariaDB and PostgreSQL, have been prototyped and tested. Python technology was chosen, among others, due to its wide compatibility. Python version 3.9 is compatible with McNeel libraries. The Python Hops application has been packaged into a single executable file for internal distribution. The presented application has been successfully tested on both Windows and

MacOS platforms, including the ARM based M1 architecture. Data contained in the voxel model has been created with a range of open-source geospatial analysis tools, such as QGIS (Open-Source Geospatial Foundation Project 2020), Whitebox Tools (Lindsay 2016) and SAGA GIS (Conrad et al. 2015).



```
###

 ECOLOPES Voxel Model
 CPython Hops Component
 v.0.0.1b by Jakub Tyc
 press Ctrl + C to stop the program

 ALWAYS run Hops components without "Cache in Memory" an
d "Cache on server"
 DISABLE IT right clicking on each newly inserted compon
ent and deselecting those options
 you can enable it if you know what you're doing, but ch
eck if it is disabled
 before contacting me.

###

Your data path is "C:\Users\Jakub Tyc\Documents\HopsVoxe
ls"
Using voxel data saved in "vox_VIE_2022W_data.sqlite"

[INFO] Starting...
[INFO] Running Engine on: 5478
http://127.0.0.1:5478/vox_list
http://127.0.0.1:5478/vox_read_meta
http://127.0.0.1:5478/vox_read_rgb
http://127.0.0.1:5478/vox_list_data_layers
http://127.0.0.1:5478/vox_read_data_layer
http://127.0.0.1:5478/vox_write_datapoint_format_filter
http://127.0.0.1:5478/vox_write_datapoint_format
http://127.0.0.1:5478/vox_write_geom
http://127.0.0.1:5478/vox_clean_new
http://127.0.0.1:5478/gen_random_cubes
http://127.0.0.1:5478/network_write
http://127.0.0.1:5478/network_query
```

Fig. 12: Technologies utilised to implement the ECOLOPES Voxel Model were linked in a sequence. RDB-based voxel data can be queried through the McNeel Python Hops application packaged into a single executable file. This Python application exposes voxel data in the McNeel Rhinoceros/ Grasshopper environment for user interaction.

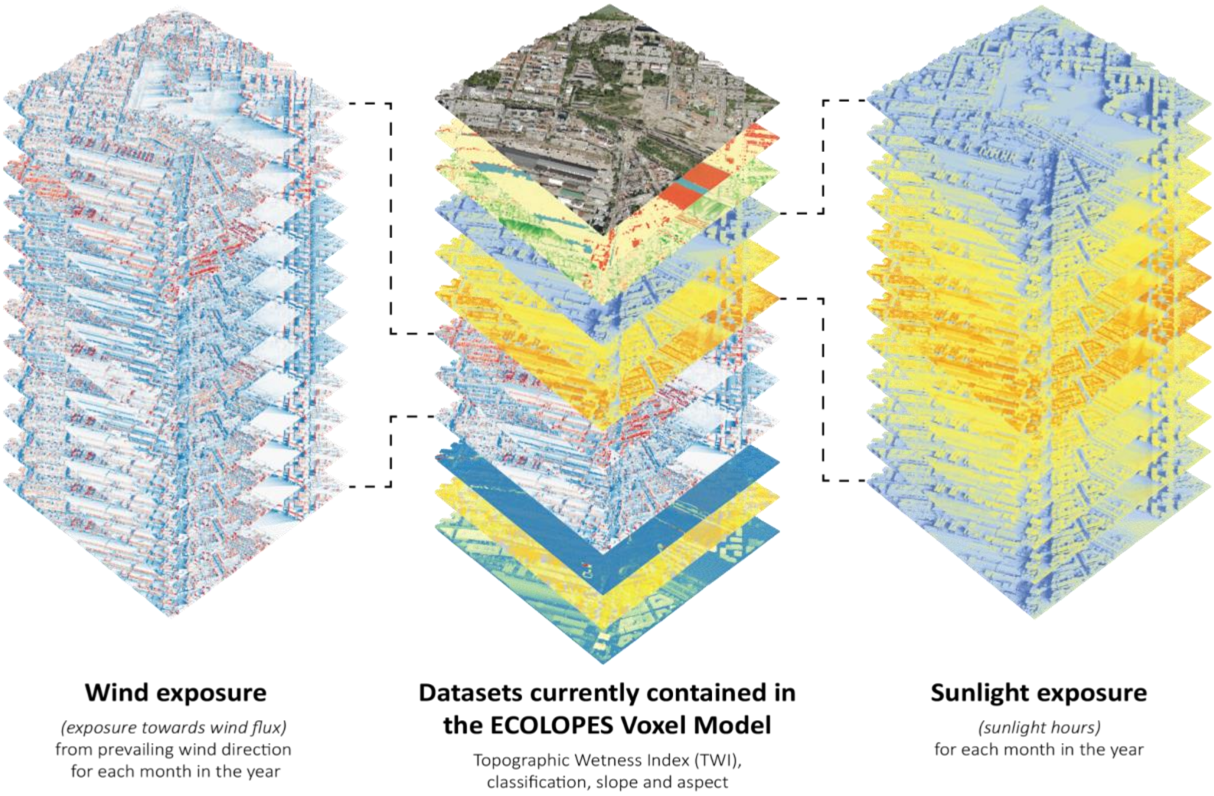
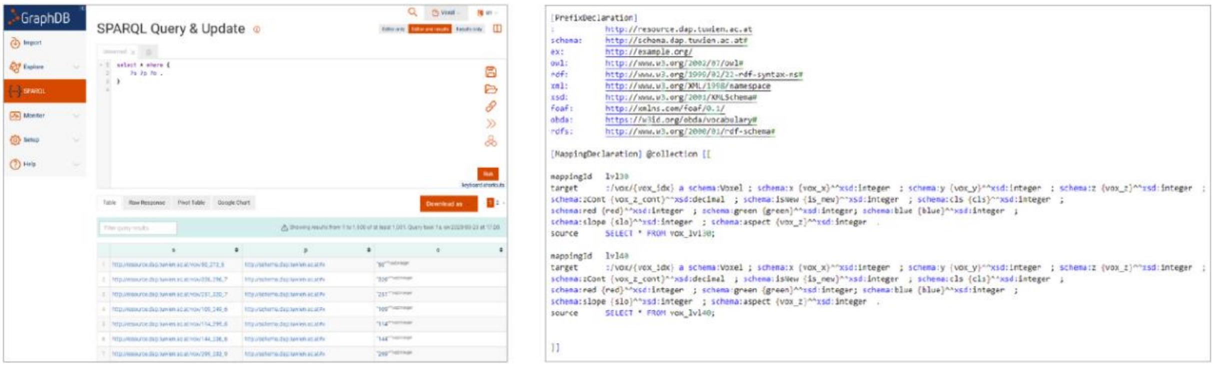


Fig. 13: Datasets contained in the ECOLOPES Voxel Model include geometric and classification data. This includes environmental performance data such as, for instance, topographic wetness index, as well as time series data describing insolation time and wind exposure.



```
select * where {
    ?s ?p ?o .
}
```

```
[PrefixDeclaration]
:           http://resource.dap.tuwien.ac.at
schema:     http://schema.dap.tuwien.ac.at#
ex:         http://example.org/
owl:        http://www.w3.org/2002/07/owl#
rdf:        http://www.w3.org/1999/02/22-rdf-syntax-ns#
xml:        http://www.w3.org/XML/1998/namespace
xsd:        http://www.w3.org/2001/XMLSchema#
foaf:       http://xmlns.com/foaf/0.1/
obda:       https://w3id.org/obda/vocabulary#
rdfs:       http://www.w3.org/2000/01/rdf-schema#

[MappingDeclaration] @collection [[

mappingId   lvl30
target      :/vox/{vox_idx} a schema:Voxel ; schema:x {vox_x}^^xsd:integer  ; schema:y {vox_y}^^xsd:integer  ; schema:z {vox_z}^^xsd:integer  ;
schema:zCont {vox_z_cont}^^xsd:decimal  ; schema:isNew {is_new}^^xsd:integer  ; schema:cls {cls}^^xsd:integer  ;
schema:red {red}^^xsd:integer  ; schema:green {green}^^xsd:integer; schema:blue {blue}^^xsd:integer  ;
schema:slope {slo}^^xsd:integer  ; schema:aspect {vox_z}^^xsd:integer  .
source      SELECT * FROM vox_lvl30;

mappingId   lvl40
target      :/vox/{vox_idx} a schema:Voxel ; schema:x {vox_x}^^xsd:integer  ; schema:y {vox_y}^^xsd:integer  ; schema:z {vox_z}^^xsd:integer  ;
schema:zCont {vox_z_cont}^^xsd:decimal  ; schema:isNew {is_new}^^xsd:integer  ; schema:cls {cls}^^xsd:integer  ;
schema:red {red}^^xsd:integer  ; schema:green {green}^^xsd:integer; schema:blue {blue}^^xsd:integer  ;
schema:slope {slo}^^xsd:integer  ; schema:aspect {vox_z}^^xsd:integer  .
source      SELECT * FROM vox_lvl40;


]]
```

Fig.14: Left: Screenshot of the GraphDB interface, showing how data contained in the ECOLOPES Voxel Model can be queried and represented in an ontology-based format (RDF triples) Right: Data saved in the RDB-based voxel model can be virtualized in GraphDB, by defining the mapping between the RDB and GDB data structure in an OBDA / R2RML file.

The functionality of the ECOLOPES Voxel Model was tested internally by the development team throughout the stages of the development of the Voxel Model, including the alpha version to ensure that the required TRL was reached. The internal validation is based on data availability and current development of other components, such as EIM Ontologies (*D4.2*

Interim EIM Ontologies) and ECOLOPES Computational Model (*D5.4 ECOLOPES Computational Model*).

The datasets contained in the ECOLOPES Voxel Model have been validated. Typical data validation tests, including data types, formats and consistency checks have been executed. Secondly, the process of conversion of raw input datasets into ECOLOPES Voxel Model datasets has been validated. The tabular representation of the raw data and ECOLOPES Voxel Model has been compared to identify possible errors in translation. These two representations of the ECOLOPES Voxel Model datasets have been manually inspected and consistency checks that validate total row count and data types have been executed. This was followed by the visual inspection of the graphical representation of the datasets. Raw input data has been translated into a 2.5D representation compatible with widely used GIS software and visualised in the QGIS interface. This data visualisation has been compared with the 3D representation of the same data encoded in the ECOLOPES Voxel Model, generated in Rhinoceros 3D software. This allowed us to validate visually the consistency of the datasets contained in the ECOLOPES Voxel Model. In the future it is expected that new datasets will be introduced into the ECOLOPES Voxel Model. Analogous process of validation will be executed to check the consistency of the datasets contained in the ECOLOPES Voxel Model.

Secondly, the ECOLOPES Voxel Model components developed in the process have been validated in a short test case. This test case, presented in Figure 15, was used to validate the basic set of components required to read data from the ECOLOPES Voxel Model in the Rhinoceros and Grasshopper environment.

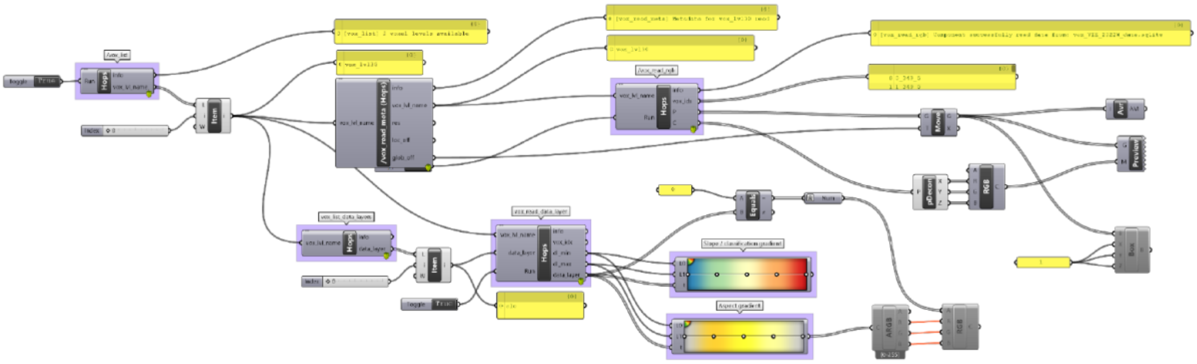


Fig. 15: Example of Grasshopper Hops components implemented to enable the interaction between the designer and the ECOLOPES Voxel Model through the McNeel Grasshopper interface.

The ECOLOPES Voxel Model components are developed iteratively, and each finished iteration is packaged as a standalone Python application. Currently only an .exe file for Microsoft Windows platform is produced, but initial tests to include Linux / MacOS platforms and containerized, cloud-based developments have been successfully completed. Each new iteration of the packaged application is manually validated against the test case file. In future, as new functionality will be implemented, additional test cases will be introduced into the process.

Finally, the Vienna Case Study will provide an additional level of validation that will address both internal functionalities and the overall functionality of the envisioned computational design process. Individual components implemented as a part of the ECOLOPES Voxel Model, EIM Ontologies and the ECOLOPES Computational Model will be validated, based on the interactions with the designers executing the Vienna Case Study. Moreover, the overall approach and the interactions between the parts of the design process will be validated through this case study.

3.1.3 Validation of the ECOLOPES Computational Model

Regarding the ECOLOPES Computational Model, the primary approach that will be technically implemented is known as Answer Set Programming (ASP). Lifschitz explained that "the idea of answer set programming is to represent a given computational problem by a logic program whose answer sets correspond to solutions, and then use an answer set solver … to find an answer set for this program". (Lifschitz, 2002). Mueller elaborated further that "answer set programming is an approach to knowledge representation and reasoning. Knowledge is represented as answer set programs, and reasoning is performed by answer set solvers." (Mueller, 2015) (*D5.3 ECOLOPES Computational Model*)

Our team recognises that the ontology-aided generative computational design process would in principle benefit from a combination of different types of algorithms with different specific functionalities. However, purpose-configuring a multitude of algorithms with different functionalities and ensuring proper functional interaction is a complex undertaking that exceeds what is possible in the ECOLOPES research project. To address this question, we pursue a two-stage process. (*D5.3 ECOLOPES Computational Model*)

Stage 1 entails algorithms that will be technically implemented by the end of the project at the required TRL. Stage 1 has no algorithmic process in Loop 1 but employs ASP in Loop 2 and Loop 3. Stage 2 comprises a conceptual development that will not reach technical implementation at the required TRL. This includes conceptualising ASP for use in Loop 1 and extending Loop 2 and Loop 3 with a Genetic Algorithm (GA) and a Machine Learning algorithm (K-means). While stage 2 will not reach full technical resolution and implementation it will provide a clearly defined approach for future development of the ontology-aided generative computational design process. (*D5.3 ECOLOPES Computational Model*)

In the context of ontology evaluation, we discussed different evaluation criteria which are applicable in the context of algorithms. These include:

- Measure (e.g., F-score) against a golden benchmark
- User study evaluation

In this context, algorithms are evaluated both separately and in terms of their interactions between Loop 1 - Loop 2 and Loop 2 - Loop 3.

Regarding measuring a F-score, we need a golden dataset that is annotated by an expert user that given a specific input, it also provides the actual answers that should be returned by the algorithm. Based on the golden dataset, we can compute the measure of F1-score that computes the precision (accuracy) and recall (completeness). The creation of such an annotated golden dataset is yet to be created.

The user study evaluation will be a survey given to the expert users to determine if the results returned make sense based on a predetermined set of tasks to be done by the user. This will be intertwined along with validation of the Vienna Case Study.

3.2 Validation of the Interaction between the Components

In this section we describe the technical validation of the interactions between the components of the ontology-aided generative computational design process. These include interactions between the EIM Ontology (*D4.2 Interim EIM Ontology*), the ECOLOPES Voxel Model (*D5.3 ECOLOPES Voxel Model*) and the ECOLOPES Computational Model. The interactions between the components are key to facilitating the translational process (Loop 1) and the generative process (Loop 2, Loop3).

3.2.1 EIM Ontology and ECOLOPES Voxel Model

Currently the EIM Ontologies are undergoing intensive development and in the upcoming months both the structure of the EIM Ontologies and the functionalities required for the interaction with other components of the ECOLOPES Computational Design workflow will be further developed. The ECOLOPES Voxel Model has reached an advanced level of development (*D5.3 ECOLOPES Voxel Model*). In the upcoming months, the interactions between EIM Ontologies and ECOLOPES Voxel Model will be validated and required adaptations of the existing computational components will be made to facilitate the seamless integration between EIM Ontologies and ECOLOPES Voxel Model.

Validation of the interoperability of datasets contained in the EIM Ontologies will be conducted in the following months as the development of EIM Ontologies advances. In this process, typical data validation tests, including data types, formats and consistency checks will be executed. Raw data derived from queries executed against the deployed GraphDB instance (containing EIM Ontologies) and the deployed PostgreSQL instance (containing ECOLOPES Voxel Model) will be validated to make sure that no errors are introduced into the data in the bi-directional translation process between the EIM Ontologies and ECOLOPES Voxel Model. Likewise, the outcomes of this process will be validated visually by the designers. Data returned by the implemented components will be visualised in the Rhinoceros interface and evaluated by the designers.

Secondly, interactions between the computational components developed for ECOLOPES Voxel Model and EIM Ontologies will be validated in short test cases. Initial approach to initiate a validation approach that utilises test cases can be seen in Figure 16. In this example, an interactive connection between the GraphDB environment that contains EIM Ontologies and the ECOLOPES Voxel Model has been established. Initial validation was conducted by a simple test case, allowing the designer to query locations suitable for plants requiring high sunlight exposure. Computational components developed in this process are utilising analogous methods to the ECOLOPES Voxel Model components. New functionalities are introduced iteratively. After each iteration a new standalone executable file is produced and validated against existing test cases.

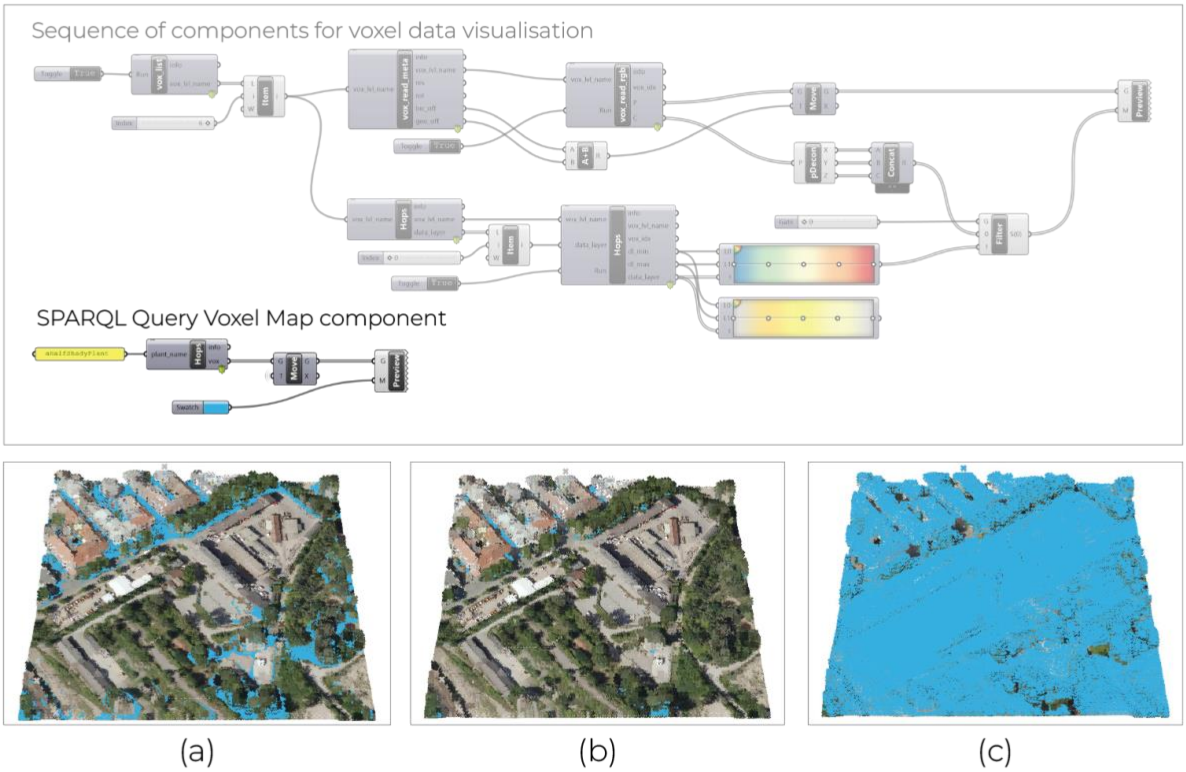


Fig. 16: Integration between the ECOLOPES Voxel Model and an exemplary dataset stored in the GraphDB. Query and reasoning functionalities provided by the SPARQL endpoint can be implemented within the computational setup of the ECOLOPES Voxel Model. Systematic, voxel-based data structuring enables interoperability between the two components, implemented by Grasshopper and Hops (for a more detailed explanation see D5.3 ECOLOPES Voxel Model).

Higher-level validation will be conducted in the Vienna Case Study, where the interactions between EIM Ontologies and ECOLOPES Voxel Model will be validated based on the interactions provided by the designers working on the Vienna Case Study. Individual functionalities of the components constituting the EIM Ontologies and ECOLOPES Voxel Model will be adapted to reflect the results of the validation to assure the applicability of the computational approach provided by the EIM Ontologies and ECOLOPES Voxel Model in the context of a design process.

3.2.2 EIM Ontology and ECOLOPES Computational Model

The EIM Ontologies (*D4.2 - Interim EIM Ontologies*) are being developed and further enriched with datasets that are deemed relevant for the domain. The integration with the Computational Model needs to be validated to ensure that the results are sound and can be used in the subsequent optimization environment and process (WP6). In terms of data-level integration there will be no need for an integrated test between Ontologies and Computational Model given that the data is used in isolation for each part. Regarding functional integration a set of test cases will be used to validate whether the functionality is correct in terms of integration. The designer input will be useful in the validation to decide whether the integration is correct based on the visualisations produced in Rhino. As a final step, we will undertake validation in the context of the Vienna Case Study, where in this use case as the validation progresses, we can further adjust and see which parts need change or data refinement.

3.2.3 ECOLOPES Voxel Model and ECOLOPES Computational Model

At the time of writing, ECOLOPES Computational Model components are being actively developed and it is anticipated that in the upcoming months numerous additional functionalities will be introduced. At the same time the ECOLOPES Voxel Model has reached an advanced level of development (*D5.2 ECOLOPES Voxel Model*). Interactions between ECOLOPES Voxel Model and ECOLOPES Computational Model will be validated in the next steps, following the introduction of the functionalities implemented as a part of the ECOLOPES Computational Model.

Extensive validation of datasets utilised in the ECOLOPES Computational Model is not required, since this model operates primarily on the datasets contained in the EIM Ontologies and in the ECOLOPES Voxel Model. Components of the ECOLOPES Computational Model are utilised in three loops and each loop has different data requirements. Translation of the data into required representation is facilitated by the components implemented within the ECOLOPES Voxel Model and EIM Ontologies. For this reason, additional low-level validation at the level of data is not expected in this process.

Functional validation of the interactions between ECOLOPES Voxel Model and ECOLOPES Computational Model will be facilitated analogously to the interactions between EIM Ontologies and ECOLOPES Voxel Model. Test cases will be identified, and the iterative development of the components will be validated against the identified test cases. Visual representation of the interactions between ECOLOPES Voxel Model and ECOLOPES Computational Model will be validated by the designers in the process of continuous development.

The Vienna Case Study is introduced to provide higher-level validation for the interactions between ECOLOPES Voxel Model and ECOLOPES Computational Model. The designers that will implement the Vienna Case Study will be evaluating individual functionalities of the components implemented within the process. Interactions between the ECOLOPES Voxel Model and ECOLOPES Computational Model will be iteratively validated and required adaptations will be introduced throughout the course of the Vienna Case Study.

3.3 Validation of the Design Output: The Vienna Case Study

The Ecolopes research project includes individual case studies for the cities of Vienna, Munich, Genoa, and Haifa. A consistent logic is applied to specific aspects across the case studies (D7.1).

In the Vienna Case Study, it is necessary to test and validate the ontology-aided generative computational design workflow. In this section we describe preparations for validation of design output of the components and the workflow of the ontology-aided generative computational process (design generation environment) in the context of the Vienna Case Study. For the case study we have selected a location on which currently a real-life development project is taking place, namely the "Nordbahnhof Freie Mitte" development plan. The case study is currently in preparation and will run from October 2023 to the end of January 2024 and will involve researchers from WP4.7 and WP5.

The case study will serve to test and validate the ontology-aided generative computational design process in terms of the components, component interaction, and design output. Criteria for site selection included suitability of site characteristics for the intended design experiment and specified design cases, as well as data availability. The selected site is characterised by a central large green area with a variety of green space designations and well documented existing local ecosystems that offer considerable opportunities for the design of ecological building envelopes.

Fig. 17: Location of the Nordbahnhof Freie Mitte development site in the context of Vienna. (Source: Google Earth)

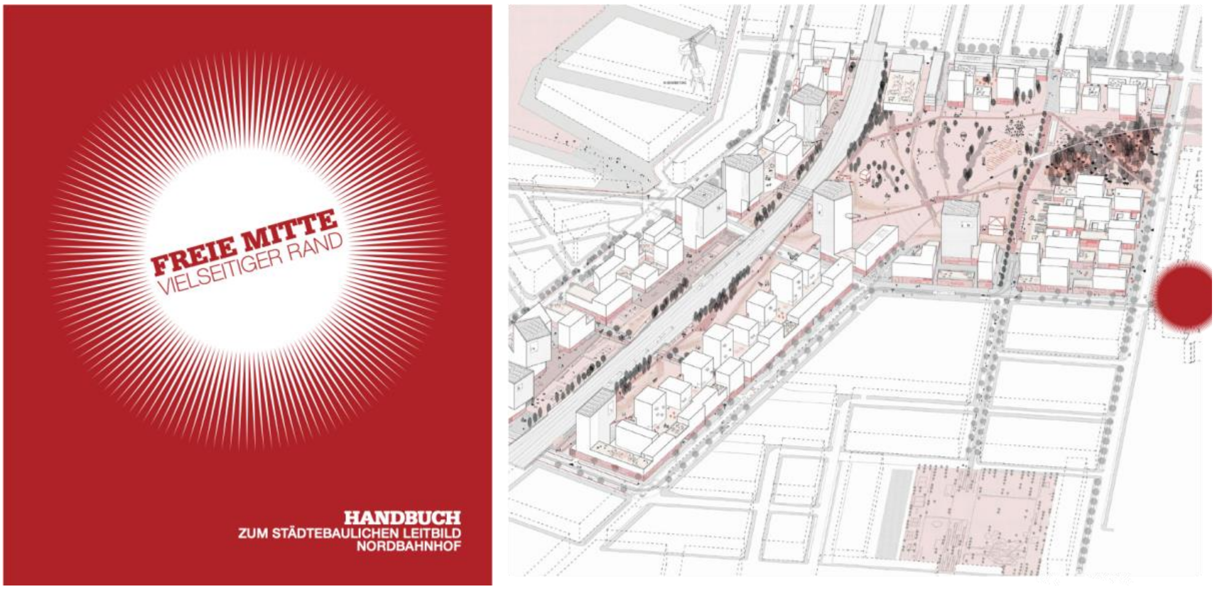


Fig. 18: Document of the municipal development of the development site Nordbahnhof Freie Mitte (left) and axonometric view of the intended programmatic and volumetric composition of the masterplan. (Vlay, 2015)

Two design cases were specified that are common design cases in architectural practice.

Design Case 1 addresses the design of a master plan for the development of a given site. In such cases the number and distribution of building volumes, including footprint, floor area ratio, maximum volume, and maximum height, are not yet defined. In the context of this research this entails that spatial organisation is generated through the distribution of architectural, biomass and soil volumes, which we term for case 1 *primary volumes*, as well as geometric articulation of site and buildings leading to what we term for case 1 *primary landform*. Landform can therefore be coherently designed across the entire site, with all volumes adhering closely to the landform scheme. For design case 1 we selected a plot from the overall masterplan that is large enough to accommodate an ensemble of buildings and landscape design of the plot.

Design Case 2 addresses the design of an individual building for which all constraints, such as footprint, floor area ratio, maximum volume, and maximum height, etc. are already established by a municipal master plan. Since the generic maximum allowed primary volume is already given by the masterplan, the task is to partition the primary volume into *secondary* and *tertiary* architectural, biomass and soil volumes. To enable different species to inhabit the envelope it is useful to develop the building geometry as a *secondary* and *tertiary landform* (hierarchical nesting of terrain features) to enable accessibility and appropriate provisions for specified species to specified parts of the building envelope. For design case 2 we selected a specified area for one building that is defined by the current master plan in terms of allocated building footprint, floor area ratio, maximum volume, and maximum height, etc.

Primary volumes define the location of buildings, and overall biomass and soil volumes. Once *primary* volumes are located it is possible to detail them further by locating *secondary* and *tertiary* volumes, which entail more specific architectural, green and soil volumes. Since the purpose of geometric articulation is to shift from generic (cuboid) geometry to *urban landform* with distinct terrain features, a matching hierarchical order is established. *Primary* landform delivers a first overall level of geometric articulation to primary volumes, especially for architectural and soil volumes. *Secondar*y and *tertiary* landforms are subsequently generated to derive more detailed geometric articulation and geodiversity to enhance the possibility of meeting diverse ecological and architectural requirements.

Validation of the design outcome will be based on fulfilment of architectural and ecological criteria set by the design brief, including specified KPIs (these will be selected to match with selected KPIs in the overall ECOLOPES research project). This will also include set criteria for compensation for the loss of unsealed areas due to the building footprint(s) by built surfaces covered with soil of specified depth, as well as the reuse of soil that needed to be excavated for construction purposes and for underground spaces. Moreover, this includes criteria pertaining to water management, i.e., water distribution for irrigation purposes and on-site rainwater drainage.

In addition to the fulfilment of architectural and ecological criteria we will establish benchmarks for proportional relations of architectural, biomass and soil volumes that exceed current state-of-the-art designs. The development of such benchmarks will follow the example listed in section 5 regarding the development of design benchmarks in master-level design studios.

In the Vienna Case Study, we will place focus on validating the output of the three loops that make up the ontology-aided generative computational design process.

Loop 1 facilitates the configuration of the dataset *networks* in a voxelized 3D space, materialised in the Rhinoceros CAD environment. It involves EIM Ontology 1 (KG), the ECOLOPES Voxel Model, and the CAD environment. Validation of the outputs resulting from the processes proposed in the Loop 1 can be approached from the technical and domain-specific perspective. Currently, the components implemented as a part of Loop 1 are at different stages of development. The ECOLOPES Voxel Model has reached an advanced level of development where most of the required functionalities are implemented. EIM Ontology 1 has been largely conceptualised and initial tests related to dataset interoperability have been executed. Components of the ECOLOPES Computational Model considered for the Loop 1 have also been conceptualised. It has been decided that reasoning capabilities available in the computational framework used to implement EIM Ontology (GraphDB) are sufficient to provide algorithmic support for the design processes proposed for the Loop 1. At the time of the start of the case study the anticipated state of the EIM Ontology 1 and related algorithmic procedures used for reasoning (SPARQL queries) will be further advanced. From the technical perspective, previously described components will be validated regarding the interoperability of the components and the functionality of the interfaces. From the domain-specific perspective, the ECOLOPES Voxel Model, EIM Ontology 1 and the ECOLOPES Computational Model will be validated through the interactions with the designers conducting the Vienna Case Study. This activity will provide feedback on the overall functionality of the individual components as well as the functionality of the interfaces between the components. Regarding the input data validation, ecological data from the database used for ecological modelling (TRY traits database) has been pre-examined as a part of the WP4 activities. Initial comparison between the data retrieved from the TRY database and a local species list retrieved from the environment map of the City of Vienna “Stadt Wien - Umweltgut” has been conducted. In the following steps, further validation of the interdisciplinary datasets will be conducted. Regarding the output data, both the technical and domain-specific validation will be conducted. Technical validation will consist of typical data type and consistency checks. Domain-specific validation will be conducted incorporating disciplinary perspectives representative for the disciplines involved in the functionalities of the Loop 1 components.

A key question in the context of a site and design brief specific case study is whether and to which extent specific process steps are generally applicable and to which extent outputs are generalisable. For Loop 1 the deployment of GIS-based simulations provides a generally applicable method for data generation (datasets *maps*). Each generated dataset is geo-location and frequently time specific. The designer configured datasets *networks* (i.e., stakeholder networks) are, however, not only specific to a given site, but also informed by the design brief for a given project. Their configuration involves querying a KG (EIM Ontology 1) and is therefore reliant on the content of the KG. To be applicable to a broad range of sites the KG needs to be extended over time.

Loop 2 facilitates generating spatial organisation via the distribution of architectural, biomass, and soil volumes in a voxelized 3D space, materialised in the Rhinoceros CAD environment. This involves EIM Ontology 2, ASP, and CAD Model 2. Both the technical and domain-specific validation will be conducted in the context of functionalities implemented in Loop 2. Given the different levels of advancement of different components, extensive validation could not have been executed at the current point in time. The ECOLOPES Voxel Model has reached an advanced level of implementation while the components of the EIM Ontology 2 and the ECOLOPES Computational Model have been conceptualised. Currently, Loop 2 extends the scope of the proposed algorithmic components by including the Answer Set Programming (ASP) element. On the technical level, interoperability between the ECOLOPES Voxel Model, EIM Ontology 2 and the chosen ASP solver (Potassco ASP) has been initially validated. Since the remaining interfaces are analogous to the implementation proposed in the Loop 1, detailed validation of all components will be conducted as a part of the Vienna Case Study. At the same time, domain-specific validation of both the datasets and the components of Loop 2 will be conducted as the Vienna Case Study progresses.

A key question in the context of a site and design brief specific case study is whether and to which extent specific process steps are generally applicable and to which extent outputs are generalisable. For Loop 2 the deployment of EIM Ontology, ASP, and ECOLOPES Voxel Model requirements, constraints and site-specific variants of spatial organisation are created. The output of Loop 2 are variants of spatial organisation, that is, different distributions of architectural, biomass, and soil volumes that are geo-location and time specific. The process is configured to be generally applicable for all sites and design briefs. The design outputs are site and design brief specific. Benchmarks for design output evaluation and ranking can either be general (i.e., comparison with current state-of-the-art green architectures irrespective of location), or can be location specific (i.e., comparison with local state-of-the-art green architectures).

Loop 3 facilitates the generation of geometric articulation of selected spatial arrangements derived in Loop 2 in a voxelized 3D space, materialised in the Rhinoceros 3D CAD environment. It involves EIM Ontology 3, ASP, and CAD Model 3. In analogy to the previous loops, the components of Loop 3 are validated both from the technical and domain-specific perspective. Development of those components is largely dependent on the progress of the computational processes constituting the Loops 1 and 2. It is anticipated that the interfaces implemented for the interaction between EIM Ontology and the Potassco ASP solver will be applied as a part of the functionalities implemented within the Loop 3. The Vienna Case Study is introduced into the process to provide the context in which the algorithmic procedures constituting the Loop 3 of the ECOLOPES Computational Model will be validated. In this context, both the technical and domain-specific constraints of the datasets and computational components will be validated as the Vienna Case Study progresses.

A key question in the context of a site and design brief specific case study is whether and to which extent specific process steps are generally applicable and to which extent outputs are generalisable. For Loop 3 the deployment of EIM Ontology, ASP, and ECOLOPES Voxel Model requirements, as well as selected spatial configuration variants in CAD, constraints and site-specific variants of spatial organisation are created. The output of Loop 3 are variants of geometric articulations for selected volume distributions, that is, *landform* consisting of terrain features that are geo-location and time specific. The process is configured to be generally applicable for all sites and design briefs. The design outputs are site and design brief specific. Benchmarks for design output evaluation and ranking can either be general (i.e. broad comparative analysis based comparison with build form, i.e. landform architecture, or natural landscape instances), or can be location specific (i.e. comparative analysis based comparison with local landform buildings or local natural landscape instances).

3.4 Validation of the Robustness of the Approach for Architectural Practice

Given the overall aim of the ECOLOPES research project to develop a design approach and computational design workflow for use in architectural practice, it is necessary to validate the robustness and usefulness of the approach in a simulated practice context. In WP5 we validate the robustness of the ontology-aided generative computational design process for use in architectural practice. We base our approach on the understanding that an architect with a first degree (BA) in architecture should be able with a reasonable amount of additional training to instrumentalise the conceptual, methodological, and computational aspects of the ontology-aided generative computational design process. Therefore, we utilise master-level design studios and master thesis projects at TU Wien as testbeds for this purpose. This part of the validation examines (1) the type of training that is necessary to enable master-level students (see also *D7.1 report on the methodology for multifunctionality evaluation,* Section 5) to work with the ECOLOPES approach, and (2) evaluates learning outcomes based on design outcomes of ECOLOPES projects undertaken by the students. In the following subsections we describe how master-level design studios and master thesis projects at TU Wien served this purpose.

Master-level design studios at TU Wien serve the purpose of establishing whether architects with a first degree (BA) can comprehend and work with the conceptual approach, as well as the related methods and tools. To ensure practice relevance of the projects we introduced and pursue two distinct design cases that frequently occur in practice and for which the ontology-aided generative computational design process needs to generate relevant results. Here we examine (1) the type of training that is necessary to enable master-level students to work with the ECOLOPES approach, and (2) evaluates learning outcomes based on design outcomes of ECOLOPES projects undertaken by the students. Four master-level studios have been concluded and an intensive summer studio is currently underway. The first two master-level studios focused on the design of a Kindergarten *ecolope* in a peripheral area of the city in Wien Liesing neighbouring a Natura 2000 site. This site is characterised by data richness regarding local species pools. The second site that is used for the third and fourth is identical with the site for the Vienna Case Study, the Nordbahnhof - Freie Mitte development site. Two further studios are planned for 2024-25 that will focus on the same site.

Table 2: Overview of the six master-level Ecolopes studios, including sites, focus and stages of development, and primary research and design approach. The studios are organised in pairs, running the identical program back-to-back. Focus and stages of development are shifted after each completed pair of studios. Studios 1 and 2 initiate the translational process development. Across all six studios the translational process is developed in three phases, placing emphasis on the high level of designer involvement in preparing the input for the generative process. Studios 3 and 4 initiate the development of the generative process regarding spatial organisation (Loop 2 - dataset volumes). Studios 5 and 6 will initiate the development of the generative process regarding geometric articulation (Loop 3 - dataset landform).

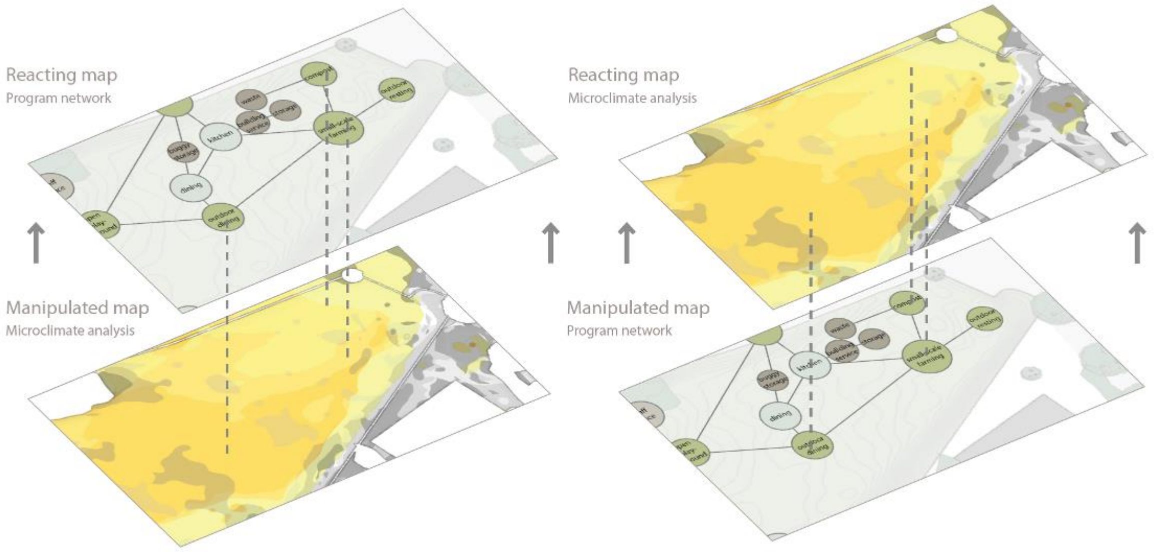
Ecolopes Studios	Program	Phase 1 Development	Phase 2 Development	Phase 3 Development	Research & Design Approach
Studio 1 Winter semester 2021-22	Kindergarten Liesing	Translational Process Loop 1 Datasets *Maps & Networks*	–	–	Research by Design
Studio 2 Summer semester 2022	Kindergarten Liesing	Translational Process Loop 1 Datasets *Maps & Networks*	–	–	Research by Design
Studio 3 Winter semester 2022-23	Nordbahnhof Freie Mitte Design Case 1 & Design Case 2	Generative Process Loop 2 Dataset *Volumes*	Translational Process Loop 1 Datasets *Maps & Networks*	–	Research by Design Evidence-based Design
Studio 4 Summer semester 2023	Nordbahnhof Freie Mitte Design Case 1 & Design Case 2	Generative Process Loop 2 Dataset *Volumes*	Translational Process Loop 1 Datasets *Maps & Networks*	–	Research by Design Evidence-based Design
Studio 5 Summer semester 2024	Nordbahnhof Freie Mitte Design Case 1 & Design Case 2	Generative Process Loop 2 Dataset *Volumes*	Generative Process Loop 2 Dataset *Volumes*	Translational Process Loop 1 Datasets *Maps & Networks*	Research by Design Evidence-based Design
Studio 6 Winter semester 2024-25	Nordbahnhof Freie Mitte Design Case 1 & Design Case 2	Generative Process Loop 2 Dataset *Volumes*	Generative Process Loop 2 Dataset *Volumes*	Translational Process Loop 1 Datasets *Maps & Networks*	Research by Design Evidence-based Design

For the studios we purpose-configured a teaching plan that was updated and developed from semester to semester. At TU Wien a one semester-long design studio typically consists of weekly half-day sessions distributed over 15 weeks. We configured a teaching plan consisting of lectures, seminars, and workshops, accompanied by tutorial sessions focusing on the students' individual design projects.

To ground the studios scientifically and methodologically we selected three key approaches that facilitate the work, including research-through-design (Frayling, 1993; Rogers & Yee, 2015) methodology (Lenzholzer et al, 2017), evidence-based design (Stichler, 2010), and data-driven design (Deutsch, 2015), with an explicitly interdisciplinary take on the latter (Hensel & Bier, 2022). Lenholzer et al. distinguished between four types of research-through-design: (1) (post-)positivism, (2) constructivism, (3) transformative, and (4) pragmatism (Lenholzer et al., 2013; Lenzholzer et al, 2017). For the Ecolopes studios we mainly draw upon the post-positivist and the pragmatist approach. The post-positivist approach is characterised by questions concerning physical and functional matter, prescriptive, objective, deductive, and quantitative design knowledge (aimed at verifying hypotheses and design guidelines). This approach deploys design hypothesis testing, 'before and after design' experiments, following a strict protocol. Research evaluation criteria are quantitative, objective, and generalisable. The pragmatist approach is characterised by problem-solving real-world questions, practice-orientation, inclusion of various types of design knowledge. It deploys mixed methods that depend on the research questions, and research evaluation criteria that depend on the selected research questions and methods. (Lenholzer et al., 2013; Lenzholzer et al, 2017) In order to ground the research-through-design approach in scientific evidence we complement it with an evidence-based design (EBD) approach. Sackett et al. defined evidence-based practice for any discipline as "the conscientious, explicit, and judicious use of current best evidence in decision making". (Sacket et al, 1996, p. 71) Stichler defined evidence-based design as "the optimal use of existing research evidence to guide design decisions" (Stichler, 2010). Furthermore, we introduced an interdisciplinary approach to data-driven design (Hensel & Bier, 2022; Sunguroğlu Hensel et al, 2022) to enable a multi-domain approach to data-driven design computing.

A further key aspect was the selection of software tools. Students were required to have adequate working knowledge in Rhinoceros and Grasshopper to participate in the studio. In this context students need to be introduced to some fundamentals in utilising data-sources, including the use of databases and the generation of required data through simulations. Regarding the latter, students are introduced to Geographic Information Systems (GIS), as well as to some fundamentals of data structuring.

To facilitate students with the necessary knowledge and skills for the *translational* process, the evidence-based design approach was coupled with multi-domain data driven design. Targeted simulations in GIS enables students to derive geo-spatial datasets (dataset *maps*). Moreover, the evidence-based approach coupled with ecologist expert input enables students to develop stakeholder networks (dataset *networks*) in the CAD environment (Rhinoceros and Grasshopper).



The microclimate is analyzed and informs the program network accordingly:

- In the solar and wind exposed areas, functions that can allow for exposure to the outside should be placed
- In the solar exposed but wind protected areas, functions such as farming should be placed
- In the slightly more shaded and wind protected areas, functions such as compost should be placed

	Solar exposed	Shaded	Sequential shading	Wind exposed	Wind protected
Small-scale farming area	x		x	x	
Outdoor dining area		x			x
Compost area		x			x
Program elements distribution					
Microclimatic conditions					

The program network is placed and informs the microclimate map accordingly:

- The small-scale farming area requires the highly solar exposed microclimate, but also the need for sequential shading. Therefor a shading element is required in the microclimate map.
- The outdoor dining area requires a more solar and wind protected microclimate
- The compost area requires extra shading

Fig. 19: Example of student work focused on the translational process, correlating maps with networks to derive input for the generative process (Ecolopes Studio Kindergarten Liesing, winter semester 2021-22, students: Juliana Schuch & Filip Larsson).

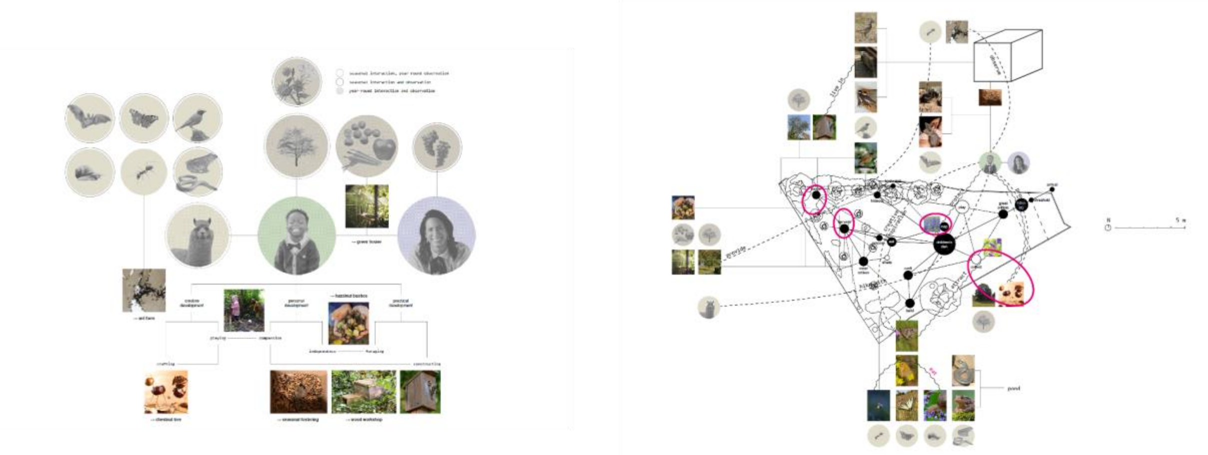


Fig. 20: Example of student work focused on the translational process, configuring networks of stakeholder relations and interactions (left) and placing stakeholder related provision networks on site (Ecolopes Studio Kindergarten Liesing, winter semester 2021-22, student: Victoria Nemeth).

To facilitate students with the necessary knowledge and methods for the *generative* process, it was necessary to introduce purpose and concepts concerning design variety generation (Rittel, 1970), as well as analysing, benchmarks, and ranking multiple design outputs. This was provided through lectures, seminars, and discussions. Furthermore, design outputs (spatial organisation, geometric articulation) needed to be generated, evaluated, and further developed based on research-through-design, that is project-based design, in the studio. Most students did not reach the point of learning and utilising more advanced software tools to facilitate a generative computational design process. However, some students with more advanced software skills did employ some existing algorithmic processes for this purpose. In follow-up studios this part of the *generative* process will be more foregrounded.

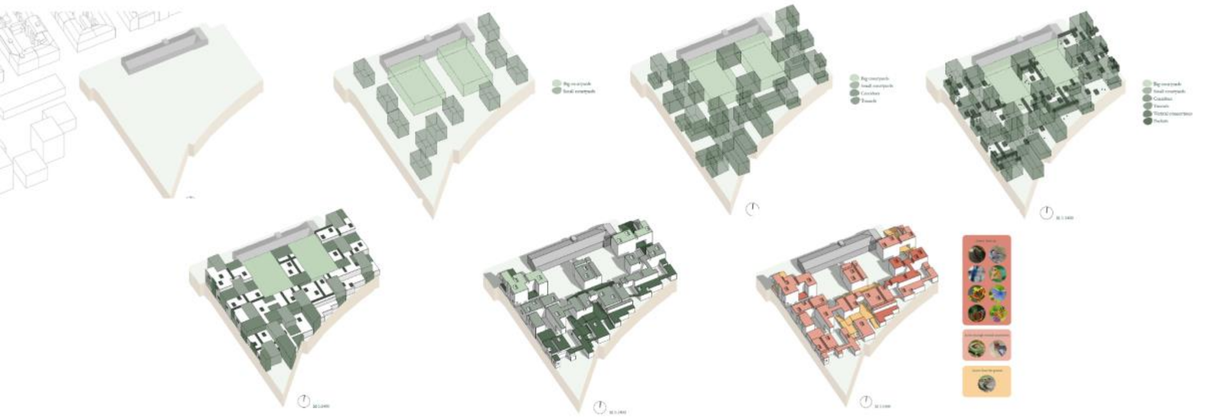


Fig. 21: Example of student work focused on step-by-step process for spatial organisation through distribution of architectural, biomass and soil volumes for design case 1 (Ecolopes Studio Nordbahnhof Freie Mitte, winter semester 2022-23, students: Vera Neulinger & Ela Trojar).

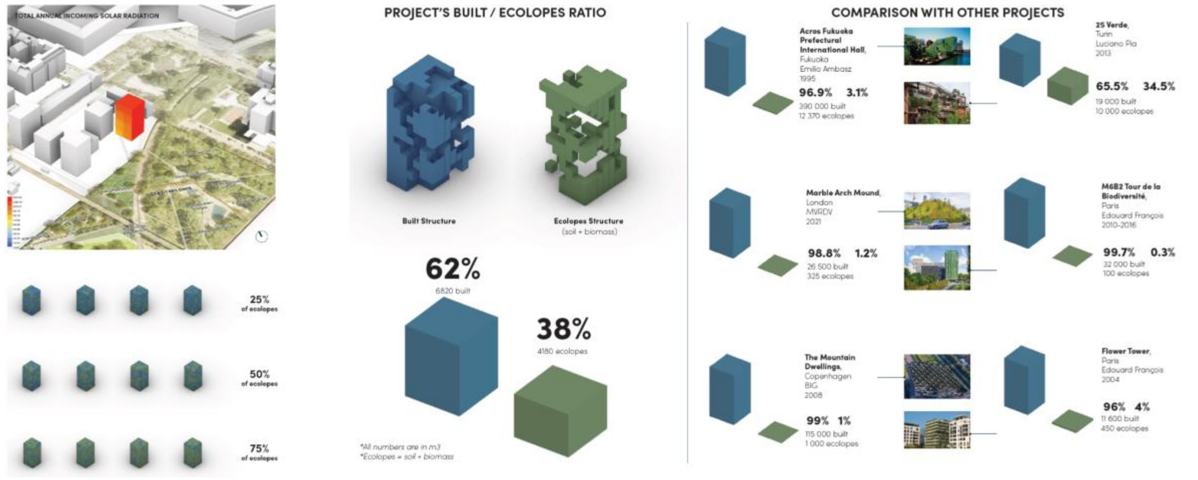


Fig. 22: Example of student work focused on spatial organisation through distribution of architectural, biomass and soil volumes for design case 2. This study included comparative analysis of volume ratios of current state-of-the-art green architectures to derive benchmarks for the design generation (Ecolopes Studio Nordbahnhof - Freie Mitte, winter semester 2022-23, students: Julie Doyen & Blandine Seguin).

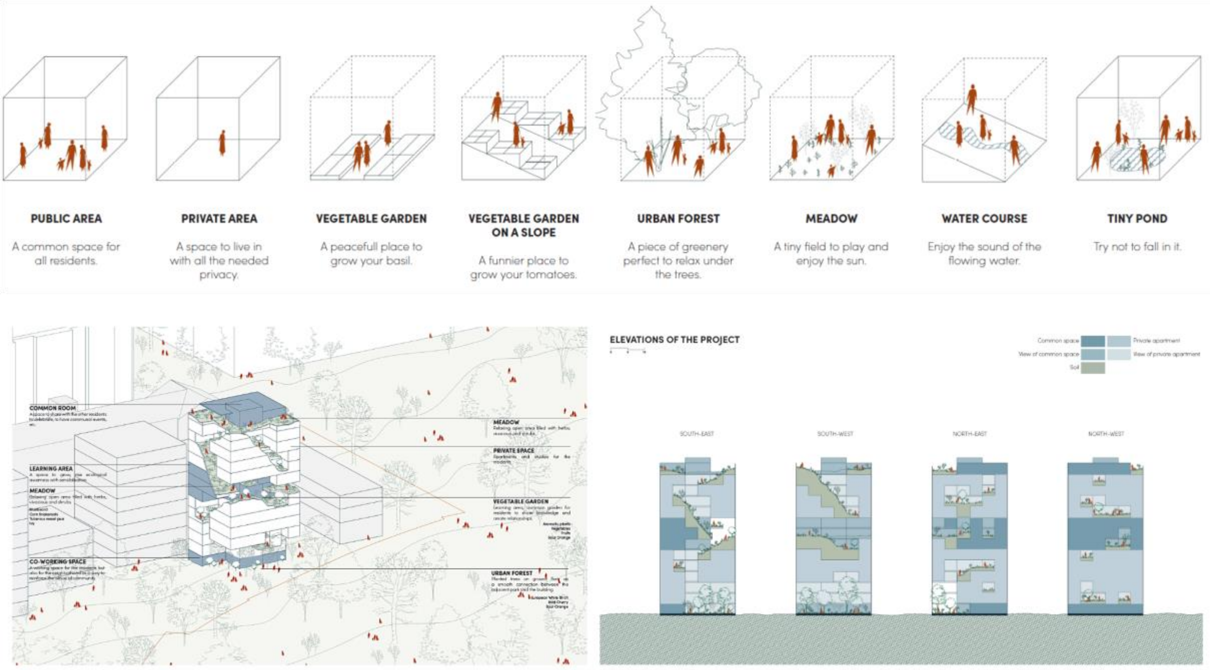
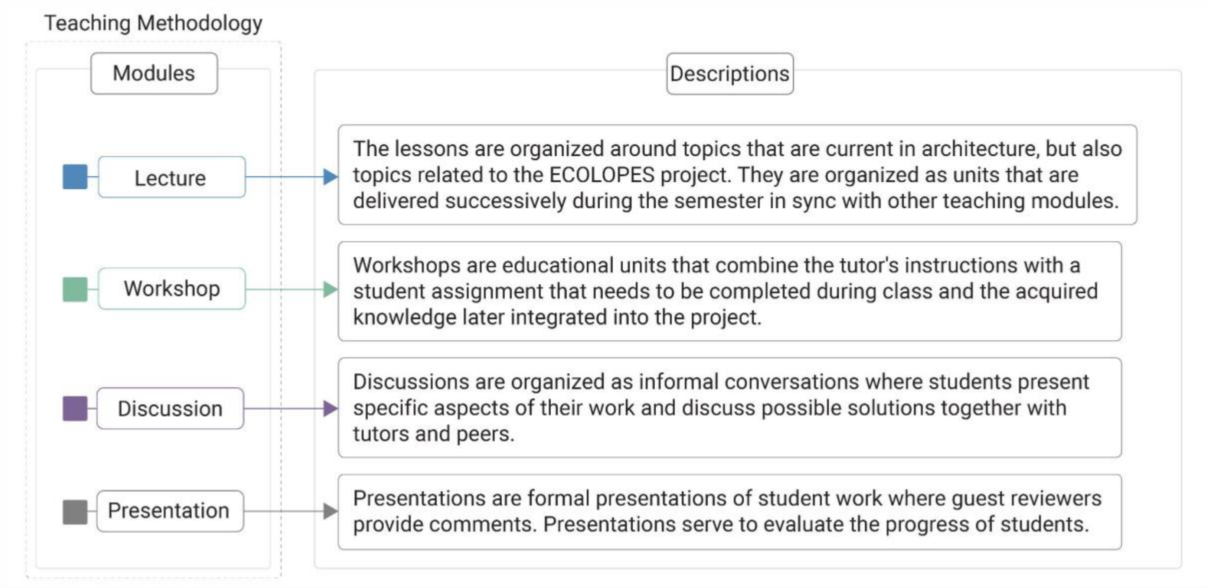


Fig. 23: Design based on the volume distribution shown in Figure 20 (Ecolopes Studio Nordbahnhof Freie Mitte, winter semester 2022-23, students: Julie Doyen & Blandine Seguin).

Since most computational components are still under development, the students were not yet introduced to the EIM Ontologies, use of the ECOLOPES Voxel Model and ecolopes specific algorithmic processes. Nevertheless, students were taught, explored, and helped further develop the conceptual approach that underlies the ontology-aided generative computational design approach. Our team documented the studio work and is in the process of preparing two books, to be published by TU Wien, on the projects for the two different sites. We evaluated each student's work in terms of evidence of comprehension of the approach (also in the context of grading the work), as well as possible contributions to the further development of the ECOLOPES approach. In forthcoming studios, we aim to introduce student questionnaires to obtain detailed student feedback, pending on approval by the TU Wien ethics committee, to be used for validating the teaching approach.

Figures 24 to 22 summarily display the structure and content of the teaching plan for one semester. Figure 24 shows the selected teaching activities for the winter semester 2022-23. This includes lectures, workshops, discussions, and presentations of studio work. Figure 25 shows how the teaching content is organised as a series of different teaching activities. Figure 26 shows how the teaching activities and topics are laid out as a semester plan. Figure 27 shows a revised semester plan that is informed by the evaluation of learning process and outcomes.



Teaching Methodology

Modules	Descriptions
🟦 Lecture	The lessons are organized around topics that are current in architecture, but also topics related to the ECOLOPES project. They are organized as units that are delivered successively during the semester in sync with other teaching modules.
🟩 Workshop	Workshops are educational units that combine the tutor's instructions with a student assignment that needs to be completed during class and the acquired knowledge later integrated into the project.
🟪 Discussion	Discussions are organized as informal conversations where students present specific aspects of their work and discuss possible solutions together with tutors and peers.
⬛ Presentation	Presentations are formal presentations of student work where guest reviewers provide comments. Presentations serve to evaluate the progress of students.

Fig. 24: Teaching activities selected for the ECOLOPES Design Studio, including lectures, workshops, discussions, and presentations of student work (presented by Tina Selami and Asst. Prof. Dr. Milica Vujovic at INTECOL2022 Congress in Geneva, Switzerland, 28.08.-02.09. 2022).

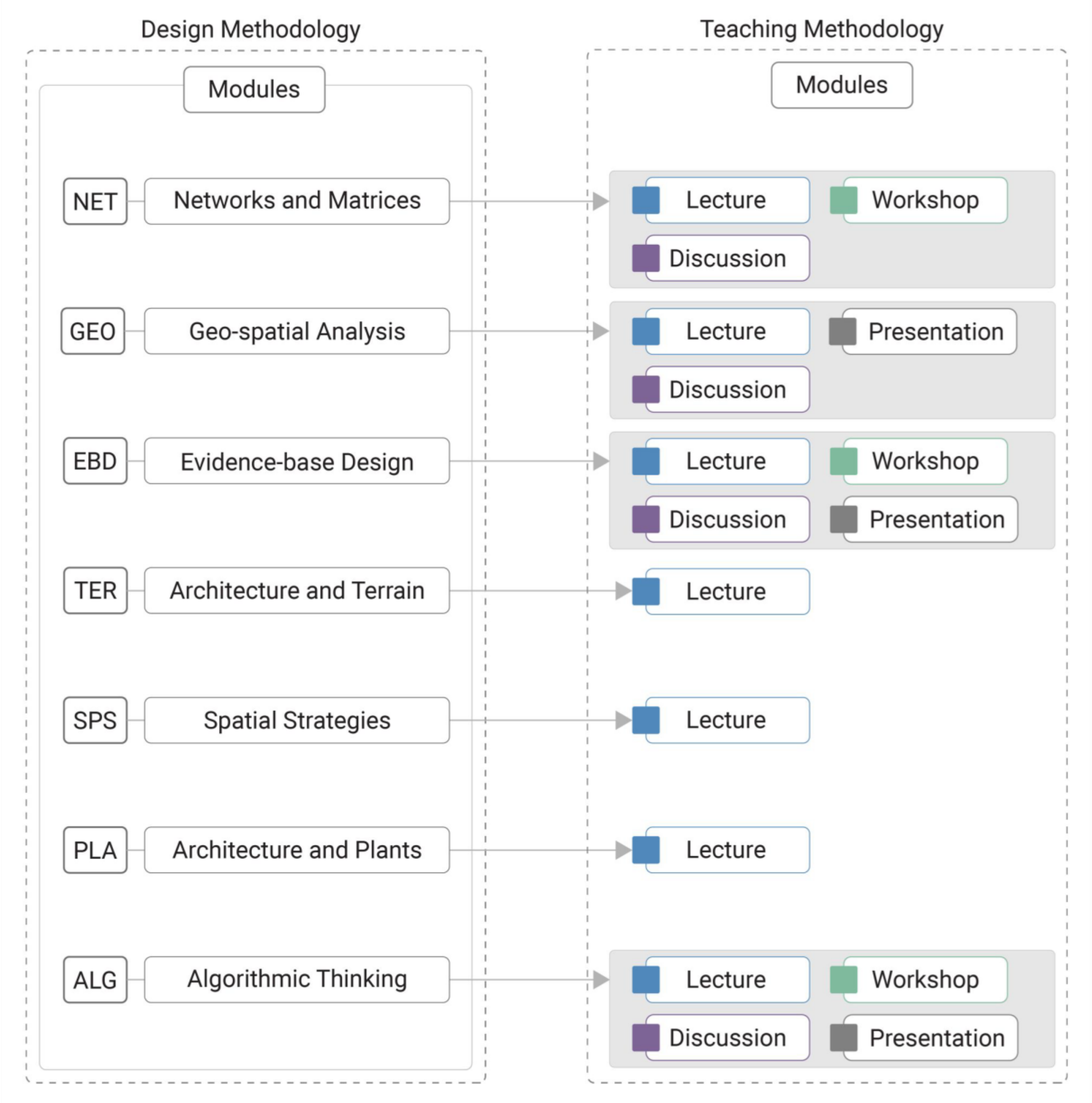


Fig. 25: Teaching topics (left column) and allocated types of teaching activities selected for the ECOLOPES Design Studio (presented by Tina Selami and Asst. Prof. Dr. Milica Vujovic at INTECOL2022 Congress in Geneva, Switzerland, 28.08.-02.09. 2022).

Fig. 26: Semester schedule from the ECOLOPES Design Studio (winter semester 2022-23) showing how teaching methodology aligns with design methodology (presented by Tina Selami and Asst. Prof. Dr. Milica Vujovic at INTECOL2022 Congress in Geneva, Switzerland, 28.08.-02.09. 2022).

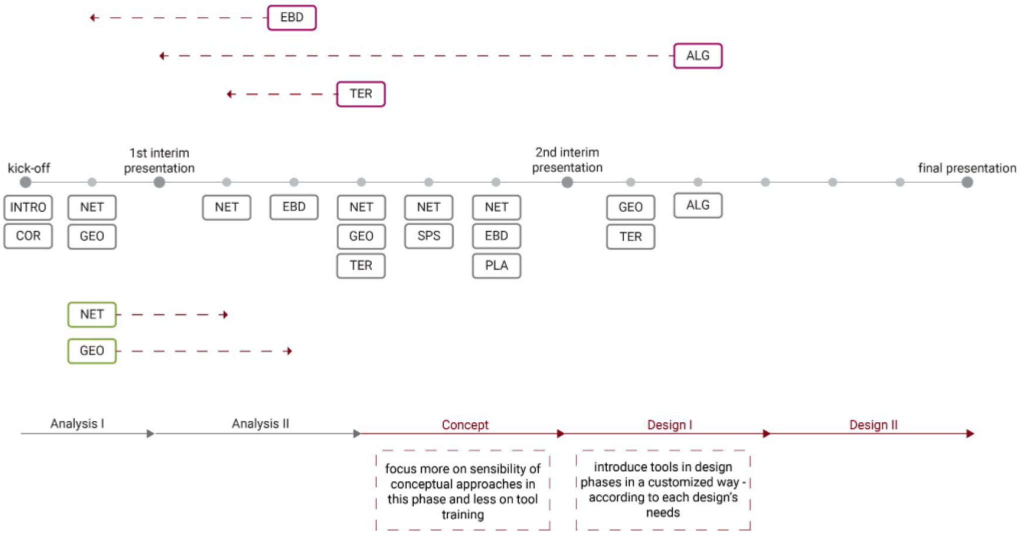


Fig. 27: Revised timeline of the semester schedule for the following semester. Revisions are based on evaluation of the learning process informed by discussions with students, as well as on evaluation of learning outcomes by the teaching team (presented by Tina Selami and Asst. Prof. Dr. Milica Vujovic at INTECOL2022 Congress in Geneva, Switzerland, 28.08.-02.09. 2022).

Furthermore, TU Wien's research department for Digital Architecture and Planning (Prof. Hensel) and the research department for Three-dimensional Design and Model Making (Prof. Kern) offered an Ecolopes master thesis project focused on a Sculpture Museum for the Wienerberg site in Vienna that was asked to integrate and / or foreground the ECOLOPES approach. Two master thesis projects have been completed in 2023. This includes the "nARTure - Sculpture Museum Wienerberg" project by Livia Dirnböck (see Appendix 3) and the "Museum Metamorphosis" project by Agnes Henzinger. The first project has already been published by TU Wien. The second project is currently in preparation for publication. Further calls for Ecolopes master thesis projects are currently in preparation.

Thus far, only two master thesis projects have been completed. However, their difference in terms of conceptual approach to the Ecolopes topic is notable. The first master thesis foregrounds the program of the sculpture museum, while intensively integrating the Ecolopes approach. The second project uses the Ecolopes approach as an opportunity to fundamentally rethink the way in which a museum can be thought of based on an Ecolopes perspective. This suggests that the Ecolopes approach can be robust enough to underpin significantly different approaches to architectural design, ranging from directly applied to fundamentally transformative perspectives. This is a useful insight when evaluating the robustness of ECOLOOPES in a practice context, in which different practices have different approaches to planning and design.

4 FURTHER DEVELOPMENT STEPS

In this section, we address open questions pertaining to the advancement of the algorithms utilised in the ECOLOPES Computational Model. As described above we pursue a two-stage development of the ECOLOPES Computational Model, i.e., the selected algorithms that underlie and facilitate the ECOLOPES Computational Model. Stage 1 describes the level that will be technically implemented at the end of the project. This stage entails no additional algorithmic process in Loop 1. In stage 1 an Answer Set Programming (ASP) algorithm will be implemented for Loop 2 and for Loop 3. Stage 2 of the deliverable comprises a conceptual development focused on utilising an ASP algorithm also for Loop 1, as well as a conceptual outline for extending Loop 2 and Loop 3 with a Genetic Algorithm (GA) and a Machine Learning (ML) algorithm (K-means). Stage 2 will not reach full technical resolution and implementation yet provides a prepared approach for future development of the ontology-aided generative computational design process.

4.1 Open Questions and Next Steps

As outlined above, stage 1 of the development process of the ECOLOPES Computational Model entails the technical development and implementation of ASP algorithms for the generative aspects of the ontology-aided generative computational process, namely Loop 2 (spatial organisation) and Loop 3 (geometric articulation). Open Questions and next steps include:

1. For Loop 2 - Spatial Organisation (dataset *volumes*): The extension of Moore system to the system with diagonals (Orciuoli et al, 2017), i.e., for each volume, not only addressing up, below, left, or right, but also diagonals and including those in the ASP constraints and rules.
2. For Loop 3 - Geometric Articulation (dataset *landform*): To what extent do we need to abstract the representation of a building so that we can reason effectively with ASP?

Stage 2 of the development process of the ECOLOPES Computational Model entails the conceptual development of an ASP algorithm for the *translational* process (Loop 1) and GA and ML algorithms for the *generative* process (Loop 2 and Loop 3). This stage will not reach full technical development and implementation. Instead, this stage will clearly point towards future development steps. Open Questions and next steps include:

1. What are suitable strategies for integrating ASP with GA and ML (K-means) algorithms to leverage their complementary strengths and improve overall design optimisation?
2. How can the outcomes of ASP reasoning be utilised as constraints or objectives in the Genetic Algorithm, enabling the GA to generate design solutions that align with logical rules derived from the EIM Ontology and knowledge graph?
3. How to incorporate domain-specific knowledge and constraints into the fitness evaluation function of the GA to ensure ecologically informed and feasible design solutions?
4. How can ML (K-Means) algorithms be optimised to handle high-dimensional and heterogeneous voxel model data efficiently, while considering various distance metrics and clustering evaluation techniques?
5. What techniques can be employed to integrate the results of K-Means clustering into the ASP reasoning process, allowing the ASP algorithm to reason over identified clusters and their implications on the design constraints and objectives?

The next step in advancing the interface between the EIM Ontology include:

1. Developing a robust and scalable framework for mapping and integrating voxel model data into the EIM Ontology, considering the differences in data structures, granularity, and representation approaches. This involves designing efficient algorithms and methods for transforming voxel-based representations into ontology-based formats, ensuring semantic interoperability and data consistency.
2. Extending the EIM Ontology to incorporate domain-specific concepts and relationships related to the voxel model, such as environmental conditions, building performance metrics, material properties, and design constraints. This step involves collaborating with domain experts to identify relevant ontology extensions and ensuring the ontology adequately captures the necessary knowledge for voxel model analysis and decision-making processes.

3. Enhancing the interface's querying and reasoning capabilities through ASP techniques. This involves developing ASP-based modules that enable complex reasoning tasks, such as spatial reasoning, constraint satisfaction, and optimisation, allowing users to explore and analyse voxel model data in a more nuanced manner.

The Vienna Case Study, which will be conducted from October 2023 to the end of January 2024. Subsequently, it will be necessary to evaluate the soundness of the design output, and the extent of generalisability of the design process and design outputs.

Validation of the components developed as part of EIM Ontology, ECOLOPES Voxel Model and the ECOLOPES Computational Model will be executed in parallel to the development of the individual components. This validation will be running along with the Vienna Case Study and the integration between the different components will be tested utilising data created as a part of this design experiment.

4.2 Intended Development Stage at the End of the Project

As outlined above, we pursue a two-stage development process. Stage 1 describes the level that will be technically implemented at the end of the project (TRL 4). This stage has no additional algorithmic process in Loop 1. For both Loop 2 and for Loop 3 an ASP algorithm will be implemented and developed to meet TRL 4 requirements.

Stage 2 comprises a conceptual development focused on utilising an ASP algorithm for Loop 1, as well as a conceptual outline for extending Loop 2 and Loop 3 with a GA and a ML algorithm (see Appendix 1 and Appendix 2). Stage 2 will not reach full technical resolution at TRL 4. However, it will provide a prepared approach for future development of the ontology-aided generative computational design process.

4.3 Technology Readiness Level

The research outcomes presented in this report are based on software implementation of currently alpha versions of parts of the ECOLOPES Computational Model that were tested internally by the development team. The researchers that were involved in the development are continuously evaluating the implemented functionalities.

ECOLOPES Computational Model components that are required to reach TRL 4 are the ASP algorithms for design generation in Loop 2 (spatial organisation) and Loop 3 (geometric articulation). The ASP algorithm for Loop 1 and the GA and ML algorithms for Loop 2 and Loop 3 will only be conceptually developed and to a lesser extent technically developed and are not expected to reach TRL 4.

To check the effectiveness of algorithms and the required TRL it is necessary to ensure that the set of solutions returned are *sound* and, to a large degree, *complete*. Hence, we are going to compute the F-measure comparing the returned set from the algorithms in different loops against a golden dataset that was annotated by the designer experts describing the expected solutions for a particular input.

According to the TRL self-assessment tool implemented as a part of the BRIDGE2HE H2020 project (TRL Assessment | NCP Portal Management | Horizon Europe NCP Portal, 2022), the pursued level of technological advancement is representative of TRL 4.

4.4 Adherence to FAIR Principles

To adhere to the FAIR principle and promote research reproducibility, datasets produced during this study will be published in one of the most recognizable open access data repositories. According to the practices observed in the field, the Zenodo repository (European Organization For Nuclear Research & OpenAIRE, 2013) has been identified as a repository that promotes discoverability of datasets published in the field of architectural design. We will publish the ECOLOPES Computational Model in the ECOLOPES GitLab repository which will be made public. This will enable tracking of changes between versions and feedback by the community to indicate "Issues" that need to be resolved. The effort related to ensuring data interoperability has been initiated as a part of the data exchange functionality required for the integration of the ECOLOPES Computational Model data with the key components of the ontology-aided generative computational design process, that is the design generation environment.

5 PUBLICATION PLAN

We recently submitted a scientific article for peer-review to Frontiers of Architectural Research journal that focuses on the conceptual framework for an ontology-aided generative computational design process for ecological building envelopes. In the article we describe the conceptual approach and the development of the related components of the ontology-aided generative computational design process (EIM Ontologies, ECOLOPES Voxel Model, ECOLOPES Computational Model).

A second scientific article will focus specifically on the development and utilisation of the ECOLOPES Computational Model and algorithmic processes in the context of an ontology-aided generative computational design process for ecological building envelopes.

A third scientific article will focus on the technical elaboration of the ECOLOPES Computational Model / Algorithmic Processes from a computer science perspective.

A fourth scientific article will focus on the validation of the ECOLOPES ontology-aided generative computational design process for ecological building envelopes that will report the results of the Vienna Case Study and include other validation approaches and aspects regarding the ECOLOPES Computational Model.

REFERENCES

Alahuhta, J., Ala-Hulkko, T., Tukiainen, H., Purola, L., Akujärvi, A., Lampinen, R. and Hjort, J. (2018). The role of geodiversity in providing ecosystem services at broad scales. *Ecological Indicators*, *91*, 47-56. https://doi.org/10.1016/j.ecolind.2018.03.068

Balaraman, V., Razniewski, S., & Nutt, W. (2018). Recoin: Relative Completeness in Wikidata. In P.-A. Champin, F. Gandon, M. Lalmas, & P. G. Ipeirotis (Eds.), Companion of the The Web Conference 2018 on The Web Conference 2018, {WWW} 2018, Lyon, France, April 23-27, 2018 (pp. 1787-1792). ACM.

Brazier, V., Bruneau, P.M.C., Gordon, J.E., and Rennie, A.F. (2012). Making Space for Nature in a Changing Climate: The Role of Geodiversity in Biodiversity Conservation. *Scottish Geographical Journal*, *128*(3-4), 211-233. https://doi.org/10.1080/14702541.2012.737015

Frayling, C. (1993) Research in Art and Design. *Royal College of Art Research Papers*, *1*(1), 1-5.

Hensel, M., & Bier, H.H. (Eds.) (2022) Interdisciplinary Data-integrated Approaches. *Spool* 9(1). https://doi.org/10.47982/spool.2022.1.00

Jasiewicz, J., & Stepinski, T.F. (2013) Geomorphons - a pattern recognition approach to classification and mapping of landforms. *Geomorphology, 182*, 147-156. https://doi.org/10.1016/j.geomorph.2012.11.005

Lenzholzer, S., Duchart, I., & Koh, J. (2013) 'Research-through-designing' in landscape architecture. *Landscape and Urban Planning*, *113*, 120-127. https://doi.org/10.1016/j.landurbplan.2013.02.003

Lifschitz, V. (2002) Answer set programming and plan generation. *Artificial Intelligence*, *138*(1–2), 39-54. https://doi.org/10.1016/S0004-3702(02)00186-8

Loussaief, S., & Abdelkrim, A. (2018). Convolutional neural network hyper-parameters optimization based on genetic algorithms. *International Journal of Advanced Computer Science and Applications*, *9*(10). https://doi.org/10.14569/IJACSA.2018.091031

Makki, M., Showkatbakhsh, M., Tabony, A., & Weinstock, M. (2019). Evolutionary algorithms for generating urban morphology: Variations and multiple objectives. *International Journal of Architectural Computing*, *17*(1), 5-35. https://doi.org/10.1177/1478077118777

Mueller, E.T. (2015) Commonsense Reasoning (2nd ed.). Morgan Kaufmann.

Orciuoli, F., Parente, M. (2017) An ontology-driven context-aware recommender system for indoor shopping based on cellular automata. *Journal of Ambient Intelligence and Humanized Computing*, *8*, 937–955. https://doi.org/10.1007/s12652-016-0411-2

Rogers, P.A., & Yee, J. (2015) *The Routledge Companion to Design Research*. Routledge.

Sackett, D. L., Rosenberg, W. M., Gray, J. A., Haynes, R. B., & Richardson, W. S. (1996) Evidence-based medicine: What it is and what it isn't. *British Medical Journal*, *312*(7023), 71–72. https://doi.org/10.1136/bmj.312.7023.71

Stichler, J.F. (2010) Weighing the Evidence. *HERD: Health Environments Research & Design Journal*, *3*(4), 3-7. https://doi.org/10.1177/19375867100030

Sunguroğlu Hensel, D., Tyc, J., & Hensel, M. (2022) Data-driven Design for Architecture and Environment Integration: Convergence of data-integrated workflows for understanding and designing environments. *Spool*, *9*(1), 19-34. https://doi.org/10.47982/spool.2022.1.02

Tukiainen, H., Kiuttu, M., Kalliola, R., Alahuhta, J., and Hjort, J. (2019). Landforms contribute to plant biodiversity at alpha, beta, and gamma levels. *Journal of Biogeography*, *46*(8), 1699-1710. https://doi.org/10.1111/jbi.13569

Tukiainen, H., Maliniemi, T., Alahuta, J., Hjort, J., Lindholm, M., Salminen, H., Snåre, H., Toivanen, M., Vilmi, A., and Heino, J. (2022). Quantifying alpha, beta and gamma geodiversity. *Progress in Physical Geography: Earth and Environment*, *47*(1), 140-151. https://doi.org/10.1177/03091333221114714

Vernham, G., Bailey, J.J., Chase, J.M., Hjort, J., Field, R., and Schrodt, F. (2023). Understanding trait diversity: the role of geodiversity. *Trends in Ecology & Evolution*, *38*(8), 736-748. https://doi.org/10.1016/j.tree.2023.02.010

Vlay, B., Streeruwitz, L., Käfer, A., Horvath, K., Wagner, S., Grasz, W., Bava, H., Schomakers, K., Stadler, A., Madreiter, A., Silvestri, B., Geier, S., Homeier, I., Hartmann, S., & Raimund, H. (2015). Freie Mitte—Vielseitiger Rand. Handbuch zum städtebaulichen Leitbild Nordbahnhof. *Magistrat der stadt Wien. Magistratsabteilung 21 – Stadtteilplanung und Flächennutzung.* https://www.wien.gv.at/stadtentwicklung/projekte/nordbahnhof/grundlagen/leitbild-2014/pdf/handbuch-gesamt.pdf

Weisser, W., Hensel, M., Barath, S., Grobman, Y.J., Hauck, T.E., Joschinski, J., Ludwig, F., Mimet, A., Perini, K., Roccotiello, E., Schloter, M., Shwartz, A., Sunguroğlu Hensel, D., Vogler, V. (2022) Creating ecologically sound buildings by integrating ecology, architecture, and computational design. *People & Nature*, 5(1), 4-20. https://doi.org/10.1002/pan3.10411

APPENDIX 1: INITIAL GENERATIVE ALGORITHM CODE

In appendix 1 we include an initial general version of code for the type of GA we envision for the stage 2 development, which will not reach full technical implementation at the required TRL.

Stage 2 of the development focuses on a conceptual level on the utilisation of a GA to enhance Loop 2 and Loop 3 of the ontology-aided computational generative design process. GAs are based on principles of evolutionary computation to iteratively generate and refine design solutions (Makki et al, 2019). GAs operate on a population of candidate solutions represented as individual outputs. The GA initialises a population of diverse and randomly generated individuals, representing an initial set of potential design solutions for spatial organisation, in this case volume distributions. The optimisation process takes place through a series of iterative generations. In each generation, a selection process is performed, where individuals with higher fitness scores, indicating better design performance, are favoured for reproduction. The reproduction phase involves the application of genetic operators, such as crossover and mutation. Crossover involves the exchange of genetic information between selected individuals to create offspring with a combination of their parent's characteristics (Loussaief and Abdelkrim, 2018). Mutation introduces random changes to individual "chromosomes" to maintain diversity and prevent premature convergence to suboptimal solutions. Mutation enables exploration of uncharted regions of the design space, potentially uncovering novel solutions. The iterative nature of the Genetic Algorithm makes it possible to continually evolve the population over multiple generations. This evolutionary process encourages eventual convergence towards design solutions that exhibit desirable attributes.

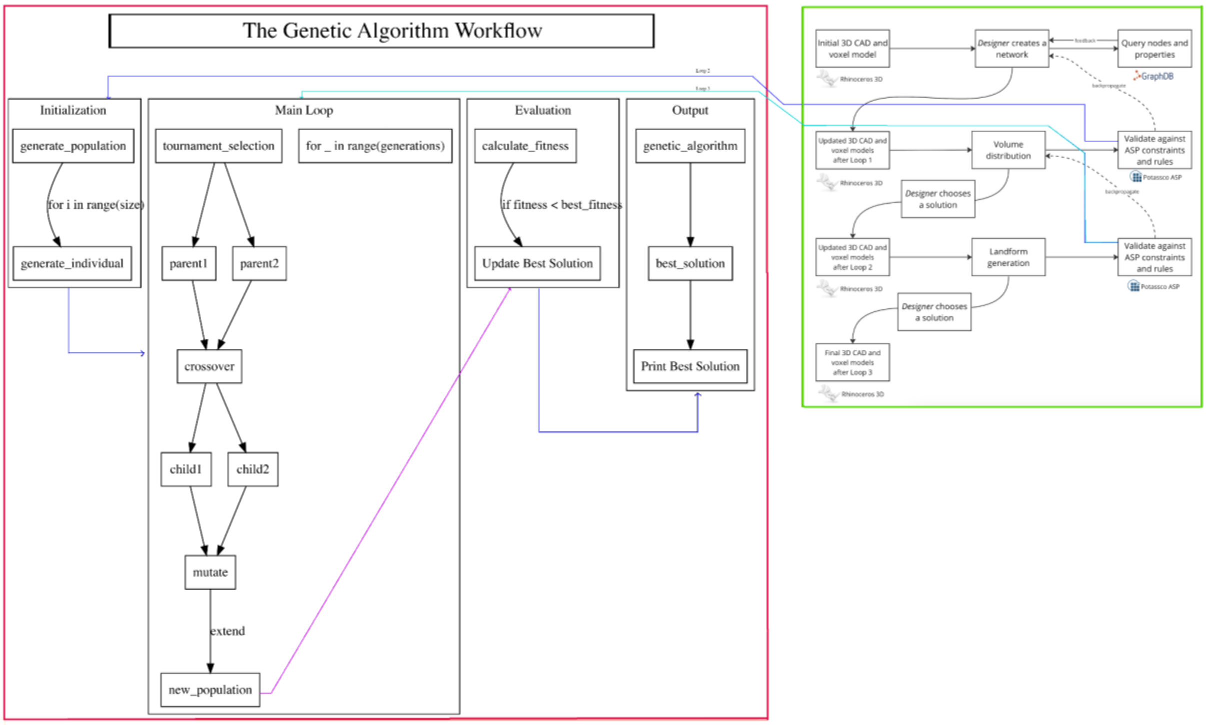


Fig 12: The workflow describing the designer input and the interaction with the respective algorithms in different loops via GraphDB, ASP constraints and rules and Genetic Algorithm.

Description of the technical link between ASP constraints and rules and the initialisation of the GA Workflow:

ASP deployed in Loop 2 and Loop 3 has a central role in defining logical constraints, spatial considerations, and rule-based criteria for developing design solutions. These constraints and rules take shape in response to project specific design objectives and ecological benchmarks, and architectural limitations contained in the EIM ontologies. In Loop 2, ASP has an important role in shaping constraints and rules derived from project specific design objectives, ecological criteria, and architectural constraints outlined in the EIM ontology. In Loop 2 we process the data from GraphDB that undergoes a step-by-step validation process against ASP constraints and rules before being transitioned into the GA initialization step. The data from GraphDB is typically represented as structured graph data. The data is stored in nodes and edges, where nodes represent entities (e.g., objects, concepts) and edges represent relationships between these entities. The data we acquire is encoded in RDF format. In Loop 3, a similar technical connection between ASP and GA occurs with a focus on geometric articulation. Starting from Loop 3, at a step where data is validated against ASP constraints and rules which involves having already generated landform data, this data flows directly into the main GA loop instead of GA first step initialization phase.

The first step is to retrieve relevant data from GraphDB. This data typically includes information about architectural elements, ecological criteria, design objectives, and any other project-specific data that is created via OWL. ASP constraints and rules are based on project-specific requirements. These constraints and rules are expressed in a formal logic language compatible with ASP. The data retrieved from GraphDB is then subjected to the ASP validation process. This process involves running the ASP solver with the formulated constraints and rules and the retrieved data as input. The ASP solver performs logical reasoning to determine if the data complies with the defined constraints and rules. The ASP solver generates output that includes answer sets. These answer sets represent valid configurations or solutions that satisfy the constraints and rules. If the data from GraphDB is consistent with the ASP constraints and rules, one or more answer sets will be generated. If conflicts are identified between the data and ASP constraints/rules, further data refinement may be necessary. This could involve adjusting the data to meet the constraints or revising the constraints themselves.

Once the data has successfully passed the ASP validation process, it is transitioned via Python language libraries to the GA initialization step in a format that the GA Algorithm can work with. The validated data is encoded into a format suitable for the Genetic Algorithm. This format could be a binary encoding or any other representation that maps the data to genetic parameters used by the GA. In the GA initialization step, we have created a function which initialised a population of design candidates. This population represents potential solutions to the design problem. The Genetic Algorithm is configured with parameters such as population size, mutation rate, and the number of generations. These parameters control how the GA will evolve the initial population over successive generations.

The provided code represents the development stage of GA designed for the project specification. The GA aims to solve the problem by using a set of parameters that determine the assignment of data points to different classes. The GA code begins by importing the necessary libraries for data processing, handling, visualisation, and GA tasks. These libraries include NumPy for numerical operations, pandas for data handling, Matplotlib and Seaborn for data visualisation, and scikit-learn for data splitting and preprocessing.

The GA code sets several constants to define the problem and configure the genetic algorithm. The generate_individual function is defined to create an initial individual (a possible solution) for the genetic algorithm. It generates random values to assign data points to different classes. The generate_population function creates a population of random solutions by calling the generate_individual function multiple times. The calculate_fitness function computes the fitness of an individual within the population. It evaluates how well the individual's assignment of data points matches the target class counts. The goal is to minimise this fitness value. The tournament_selection function implements tournament selection, a mechanism for selecting individuals from the population based on their fitness. It randomly samples a subset of individuals (tournament size k) and selects the one with the lowest fitness. The crossover function performs a crossover between two parents to create a child. It selects a random crossover point and combines the genetic information of the parents to produce a new solution.

The mutate function introduces random mutations to an individual with a specified mutation rate. It iterates through the individual and assigns random class values to some data points. The main genetic_func manages the genetic algorithm. It initialises a population, evolves it over multiple generations, and tracks the best solution found. In each generation, it selects parent individuals through tournament selection, performs crossover to create new individuals, and applies mutation. In the main part of the GA code, parameters such as population size and mutation rate are defined.

The technical validation process takes place throughout the step-by-step development of the GA code to ensure functionality and effectiveness in training, testing, and validating the algorithm. In the training phase the GA learns and adapts to the underlying patterns and characteristics of the dataset. The training phase is validated by assessing GA's convergence by computing L1 and L2 regularisation (Type 1 and Type 2). `(l1_error_regular= np.mean(np.abs(predicted_val-ground_truth)))` and `(l2_error = np.mean((predicted_val - ground_truth) **2).` These types of errors are the validation criteria applied.

In the Testing phase we focus on evaluation of the GA's performance under controlled conditions. We use Python language libraries to check if the machine has learned or not. The testing step works well with the training data. In the testing phase, validation is achieved by evaluating the GA's predictive accuracy through a comparison of its output with the ground truth data, using necessary metrics. `F1_score_measuring = accuracy_score(predictedval-groundtruth);precision=precision_score(predictedval-groundtruth);recall=recall_score(predictedval-groundtruth`.Comparing the expected output with ground truth is the criteria for the testing validation.

In the validation phase the GA's performance is rigorously assessed against predefined criteria. Here, the GA's performance undergoes a rigorous assessment against predefined criteria. The focus lies on confirming the correctness of the training phase. This validation process entails a thorough comparison of the GA's output with the designers' expectations, made possible by Python language libraries that enable accurate comparisons. We use 10% of the dataset for validation `(validation_ratio = 0.1)`. For the validating process we use metrics `(from sklearn.metrics import accuracy_score, precision_score, recall_score, f1_score)` that include accuracy, precision, recall, F1-score. The aim is to quantitatively assess the GA's performance and verify that it meets the defined project objectives.

The code listed below will be further developed in custom visualisation and analysing the output. The visualisation steps will be `convergence plots` which show how the efficiency or quality of the process improves over generations. Track key process parameters, such as cycle time or defect rate, against the number of iterations, `population density` will be In the context of ecological modelling, use population diversity visualisations to illustrate how different species' populations change over time, `performance metrics plot` which plot performance metrics like sensitivity and specificity over iterations. Monitor how the GA improves accuracy; and `analyzing the output` will be such steps like `statistics` that will show GA-driven recommendations,and `comparison step` which will compare all the related solution and choose the best output, `predictive solutions` which will analyse GA-generated solutions that predict failures in the model, these solutions will involve monitoring the model overtime to catch any faults.

The initial version of code for the GA is configured as described below:

```
# Here we import the necessary libraries

# Here we import the necessary library for generating random numbers

import random

# Here we import the necessary library for data processing

import numpy as np


# Here we import the necessary library for data handling
import pandas as pd


# Here we import the necessary library for data visualisation
import matplotlib.pyplot as plt
```

```
# Here we import the necessary library for enhanced data visualisation
import seaborn as sns

# Here we import the necessary library for data splitting
from sklearn.model_selection import train_test_split

# Here we import the necessary library for data preprocessing
from sklearn.preprocessing import StandardScaler

# Here we import the necessary metrics
from sklearn.metrics import confusion_matrix, accuracy_score,
classification_report

# Constants for the problem definition and genetic algorithm configuration
# This is the size of the x-axis of the 3D matrix
X_SIZE = 27

# This is the size of the y-axis of the 3D matrix
Y_SIZE = 9

# This is the size of the z-axis of the 3D matrix
Z_SIZE = 3

# This is the number of classes in the problem
NUM_CLASSES = 4

# This is the number of human samples in the dataset
HUMAN_COUNT = 107

# This is the number of animal samples in the dataset
ANIMAL_COUNT = 46

# This is the number of plant samples in the dataset
PLANTS_COUNT = 40

# This is the number of microbiota samples in the dataset
MICROBIOTA_COUNT = 3

# This is the names of the classes in which we define the names of the classes
that we want to classify our data into
class_names = ['human', 'animal', 'plants', 'microbiota']

# This is a function in which we generate an initial individual (possible
solution)
def generate_individual():
```

```
#This is a ternary operator that returns the random values for the classes that we want to classify our data into
return [random.randint(0, NUM_CLASSES - 1) for _ in range(X_SIZE * Y_SIZE * Z_SIZE)]

# This is a function that generates a population of random solutions to the problem
def generate_population(size):

#Here we return the random values with a for loop using the range function
return [generate_individual() for _ in range(size)]

#This is a function that calculates the fitness of the individual in the population
def calculate_fitness(individual):

#Here we assign the class counts to the individual in the population using for loop and range function
class_counts = [individual.count(i) for i in range(NUM_CLASSES)]

#Here we assign the fitness using for loop and range function by taking the sum of the absolute difference between the class counts and the target counts
fitness = sum(abs(class_counts[i] - target_counts[i]) for i in range(NUM_CLASSES))

# Here we return the fitness
return fitness

# This is a function in which we select an individual from the population using tournament selection
def tournament_selection(population, k=5):

# Here k is the tournament size we assign it to selected
selected = random.sample(population, k)

#Here we return the minimum value of the selected individuals using the key function and the calculate fitness function
return min(selected, key=calculate_fitness)

# This is a function in which we perform crossover between two parents to create a child
def crossover(parent1, parent2):

#Here we assign the crossover point to the random value of the length of the parent1 using the randint function from the random module
crossover_point = random.randint(0, len(parent1) - 1)
```

```
#Here we assign the child to the parent1 and parent2 using the crossover point
child = parent1[:crossover_point] + parent2[crossover_point:]

#Here we return the child
return child

#Here we define the mutate function with the individual and mutation rate as parameters
def mutate(individual, mutation_rate):

#Here we iterate through the individual using for loop and range function to mutate the individual
for i in range(len(individual)):

#Here we assign the individual to the random value of the NUM_CLASSES using the randint function from the random module
individual[i] = random.randint(0, NUM_CLASSES - 1)

#This is a function in which we define the genetic algorithm with the population size, generations and mutation rate as parameters
def genetic_algorithm(population_size, generations, mutation_rate):

#Here we assign the population to the generate population function with the population size as a parameter
population = generate_population(population_size)

# Here we assign the best solution to None
best_solution = None

# Here we assign the best fitness to infinity
best_fitness = float('inf')

#Here we iterate through the generations and evolve the population each time with for loop
for _ in range(generations):

# Here we assign the new population to an empty list
new_population = []

# Here we use for loop to iterate through the generations
for _ in range(population_size // 2):

# Here we assign the parent1 to the tournament_selection function
parent1 = tournament_selection(population)

# Here we assign the parent2 to the tournament_selection function
```

```
parent2 = tournament_selection(population)

# Here we assign the child1 to the crossover function with the parent1 and parent2 as parameters
child1 = crossover(parent1, parent2)

# Here we assign the child2 to the crossover function with the parent2 and parent1 as parameters
child2 = crossover(parent2, parent1)

#Here we mutate the child1 with the mutation rate as a parameter
mutate(child1, mutation_rate)

#Here we mutate the child2 with the mutation rate as a parameter
mutate(child2, mutation_rate)

#Here we extend the new population with the child1 and child2 using the extend function
new_population.extend([child1, child2])

# Here we assign the population to the new population
population = new_population

# Here we use for loop to iterate through the population
for individual in population:

# Here we assign the fitness to the calculate fitness function with the individual as a parameter
fitness = calculate_fitness(individual)

# Here we use if statement to check if the fitness is less than the best fitness
if fitness < best_fitness:

# Here we assign the best solution to the individual
best_solution = individual

# Here we assign the best solution to fitness
best_fitness = fitness

# Here we return the best solution
return best_solution

# This is the Main function, here we run the program to test the genetic algorithm
if __name__ == '__main__':
```

```
# Here we assign the population size to 50
population_size = 50

# Here we assign the mutation rate to 0.1
mutation_rate = 0.1

# Here we assign the target counts to the human count, animal count, plants count and microbiota count and best solution to the genetic algorithm function with the population size, generations and mutation rate as parameters
target_counts = [HUMAN_COUNT, ANIMAL_COUNT, PLANTS_COUNT, MICROBIOTA_COUNT]
best_solution = genetic_algorithm(population_size, generations, mutation_rate)

# Here we print the best solution
print("Best solution:", best_solution)
```

APPENDIX 2: ML CODE

In appendix 2 we include an initial version of code for the type of ML we envision for the stage 2 development, which will not reach full technical implementation at the required TRL.

The employment of an ML (K-means) algorithm serves to further enhance Loop 2 (spatial organisation) and Loop 3 (geometric articulation) of the ontology-aided generative computational design process. This algorithm utilises the output generated by the GA (see Appendix 1), which consists of a set of design solutions that have undergone optimisation based on the defined fitness function and design objectives. The ML algorithm aims at spatializing the design data, allowing for the generation of cluster assignments that group similar design elements together. The ML algorithm can generate cluster assignments based on the voxel model data. This clustering serves to identify distinct spatial configurations and patterns within the design output. By leveraging the K-means algorithm, designers can gain insights into the spatial organisation of the design and identify coherent groupings of design elements. The ML (K-means) algorithm enables the designers to explore and understand the spatial relationships and clustering tendencies in the design data. The aim is the formation of cohesive and well-defined clusters based on the underlying patterns in the design data. The integration of the K-Means algorithm within the EIM Ontology framework opens up possibilities for knowledge discovery and exploration.

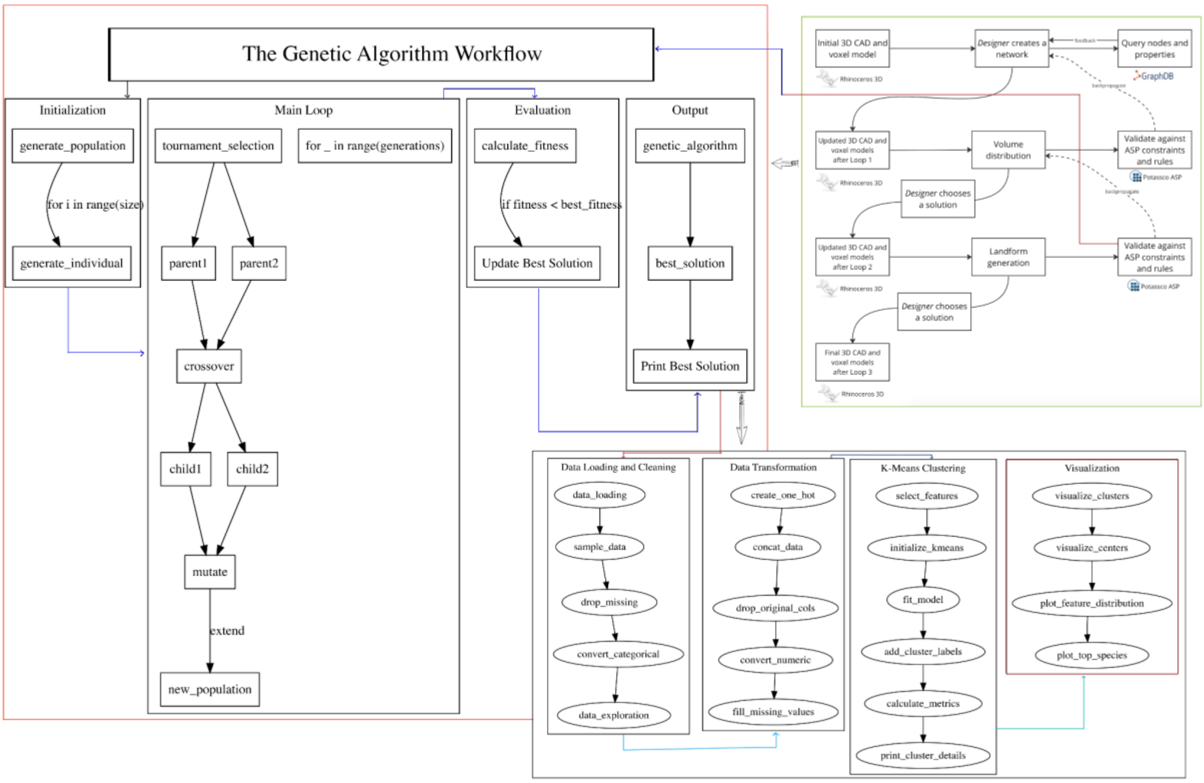


Fig 13: Workflow describing the designer input and the interaction with the respective algorithms in different loops via GraphDB, ASP constraints and rules, and Genetic Algorithm with K-Means Machine Learning Algorithm.

Description of the technical link between the ML output and the initialisation of the ML (K-means) workflow:

The technical link between K-means and the GA facilitates a seamless transition from data clustering and validation to optimization and design solution generation. To link between GA and K-Means clustering, Python libraries are used to streamline the transfer of data outputs from the GA optimization process into the subsequent K-Means clustering analysis. The relevant data is exported from the GA optimization phase and it is saved to a `CSV` file. Python libraries such as “`import GA_output`” and “`from output import data.csv`” are utilised. By employing these libraries, it is ensured that the data generated through the GA optimization is readily accessible for further analysis within the K-Means framework. With the data transferred from GA to K-Means, the machine learning analysis continues with data transformation and diagnostic steps. This involves exploring and understanding the data to make informed decisions during the clustering process. The crucial step in this phase is data description and exploration. To facilitate this, various Python functions, including the 'transpose' function, which allows us to examine the data from multiple perspectives are used.

K-means is employed to group data points into clusters based on their similarity or proximity in feature space in response to project-specific design objectives, ecological benchmarks, and architectural limitations in the EIM ontologies. K-means, deployed in Loop 2 and Loop 3, has a central role in clustering algorithm plays a crucial role in the workflow; a technical connection between K-Means and GA occurs with a focus on geometric articulation, contributing to the achievement of specific project objectives related to data analysis, pattern recognition, and classification of the design solutions. In Loop 2, K-Means is vital in clustering based on their feature space similarity. This clustering aligns with the project-specific design objectives, ecological benchmarks, and architectural constraints defined in the EIM ontologies.

In Both Loop 2 and Loop 3, the initial phase involves retrieving pertinent data from the GA algorithm. This data typically includes information about architectural elements, ecological criteria, design objectives, and any other project-specific data created via ASP data flowed through GA, where it is processed. We are using the data from the output of the GA algorithm which transitioned into the K-means initialization step using Python Language data transfer libraries such as `ga_output_data = pd.read_csv('ga_output.csv')`. The data extracted from the GA predominantly originates from its initial stage, where new design solutions are generated, such as `new_design = generate_population (param1, param2)`. Each solution often represents a set of parameters or assignments derived from the GA optimization process. The data from GA output is typically defined as structured `CSV` data and saved in a format that Python can easily read. The data is newly generated populated data, which is the best output for the design solution. Starting from Loop 3, at a particular stage where data is being obtained, the main step is `tournament = compete_population (child, child2)` for geometric articulation or further optimization with the K-Means algorithm.

The provided K-Means code represents the development stage of ML designed for the project specification. The K-Means aims to solve the problem by using a set of parameters and learning techniques like gaussian_kernel (x, y, sigma=1.0) that determine the assignment of data points to different classes. The K-Means code begins by importing the necessary libraries such as from sklearn metrics. pairwise import pairwise_kernels, for data processing, handling, visualisation, and K-Means tasks. These libraries include sklearn for finding the nearest centroids, Matplotlib and Seaborn for data visualisation, and scikit-learn for data splitting and pre-processing. The K-Means code defines several constants to configure the K-Means algorithm and establish the problem's parameters. The `init_method == "kmeans++"` function initialises centroids using the `K-Means++` method, ensuring reproducibility in the assignment of data points to different classes. The KMeans function creates classes and clusters of random solutions by invoking the `fit` function multiple times. The `k.fit function` calculates the fitness of an individual within the population, assessing the alignment of the individual's data point assignments with the target class counts. The objective is to maximise this fitness value. The K-Means function implements K-Means clustering, a mechanism for partitioning data from the population based on their similarity. The `kernel` in K-Means works efficiently to sample a subset of individuals `(kernel size k)` and selects the one with the minimum distance.

The `gaussian_kernel` function computes the Gaussian kernel similarity between two data points x and y. It's used to measure the similarity between data points in the kernel space. Cluster `assignments (labels)` are initially assigned randomly to each data point. While iteration cycles for a maximum of `max_iters` iterations or until convergence is reached. In each iteration, the cluster centroids are updated. For each cluster `i`, the new centroid is computed as the mean of the data points assigned to that cluster. The kernel matrix is computed, where each element `(i, j)` represents the similarity between data points `i` and `j` using the Gaussian kernel. Each data point is assigned to the cluster with the highest similarity, as computed from the kernel matrix. The algorithm checks whether the cluster assignments have changed. If not, it breaks out of the loop as convergence is reached.

The intended technical validation of the K-Means code involves in the first step data preprocessing and exploration. In this phase, the code imports essential libraries, loads data from a CSV file `('eco.csv')` into a pandas `import pandas as pd` DataFrame, and performs preliminary data cleaning by removing rows with missing values. It converts categorical variables to numerical codes and performs one-hot encoding `df_encoded = pd.get_dummies(df, param1, param2)` for certain columns related to weights and species. Additionally, it handles missing values in specific columns by imputing them with the column mean and deals with geospatial data by obtaining latitude and longitude information using the geopy library. The next step focuses on K-means clustering. It selects the 'features' `feature_selector = SelectKBest(score_func= chi-squared= 4, k=4)` column for clustering, specifies the number of clusters, and initializes the KMeans model. The model is fitted to the data `model.fit(X,y)`, and cluster labels are added to the original dataset. The code calculates the best score and provides insights into the clusters. Following this, the code presents visualizations of the clustering results. It includes scatterplots `plt.scatter(x, y, c='blue', marker='o', label='Data Points')` displaying data points with cluster assignments, a scatterplot of cluster centers, and various bar plots to visualize the distribution of features and species. Finally, the code showcases the training history `history = model.fit(X, y, epochs=50, verbose=1)` of a machine learning model which is `model.compile_k-means(optimizer = 'sgd', loss = 'mean_squared_error', metrics = ['mean_absolute_error'])` plotting accuracy and loss metrics over epochs.

The initial version of the ML code is configured as follows and will serve as a basis for further project-specific development:

```
# Here we import the necessary libraries
# Here we import the pandas library for data analysis tools
import pandas as pd

# Here we import the numpy library for numerical analysis tools
import numpy as np

# Here we import the KMeans library for clustering
from sklearn.cluster import KMeans

# Here we import the silhouette_score library for cluster evaluation
from sklearn.metrics import silhouette_score

# Here we import the matplotlib library for data visualisation
import matplotlib.pyplot as plt

# Here we import the seaborn library for data visualisation
import seaborn as sns

# Here we import the warnings library to ignore warnings
import warnings
warnings.filterwarnings('ignore')

# Here we import the os library to interact with the operating system
import os

# Here we import the sys library to interact with the Python interpreter
import sys

# Here we load the related data from the csv file into a pandas dataframe
data = pd.read_csv('eco.csv')

# Here we print the sample of the input data
print("Sample of the input data:")
```

```
# Here we display the first 5 rows of the data
print(data.head(5))

# Here we display the last 5 rows of the data
print(data.tail(5))

# Here we perform data cleaning here we drop any rows with missing values
data = data.dropna()

# Here we reset the index of the dataframe
data = data.reset_index(drop=True)

# Here we convert the 'features' column to a categorical variable
data['features'] = data['features'].astype('category')

# Here we convert the categorical variable to numerical codeS
data['features'] = data['features'].cat.codes

# Here we display data exploration
print("\nData Exploration:")

# Here we display the data types of each column
print(data.info())

# Here we display some summary statistics for each column
print(data.describe())

# create one-hot encoded columns for weights and species
one_hot_weights = pd.get_dummies(data['feature'], prefix='weights')
one_hot_species = pd.get_dummies(data['species'], prefix='species')

# Here we concatenate the original data with the one-hot encoded columns
data = pd.concat([data, one_hot_weights, one_hot_species], axis=1)

# Here we drop the original weights and species columnS
data = data.drop(['feature', 'species'], axis=1)

# Here we print the first few rows of the modified dataframe
print(data.head())

# Here we convert the 'features' column to a categorical variable
data['Value.01_vol_class']    =    pd.to_numeric(data['Value.01_vol_class'],
errors='coerce')
```

```
# Here we fill any missing values with the mean of the column
data['Value.01_vol_class'].fillna(data['Value.01_vol_class'].mean(),
inplace=True)

# Here we assign the data to the read csv function with the data as a parameter
and the delimiter to the tab
data['Value.box_x_min'] = pd.to_numeric(data['Value.box_x_min'],
errors='coerce')

# Here we fill any missing values with the mean of the column
data['Value.box_x_min'].fillna(data['Value.box_x_min'].mean(),
inplace=True)

# Here we convert the 'features' column to a categorical variable
data['Value.box_x_max'] = pd.to_numeric(data['Value.box_x_max'],
errors='coerce')

# Here we fill any missing values with the mean of the column
data['Value.box_x_max'].fillna(data['Value.box_x_max'].mean(),
inplace=True)

# Here we assign the data to pd to numeric function with the data as a
parameter and the errors to coerce to the tab
data['Value.box_y_min'] = pd.to_numeric(data['Value.box_y_min'],
errors='coerce')

# Here we fill any missing values with the mean of the column
data['Value.box_y_min'].fillna(data['Value.box_y_min'].mean(),
inplace=True)

# Here we assign the data to pd to numeric function with the data as a
parameter and the errors to coerce to the tab
data['Value.box_y_max'] = pd.to_numeric(data['Value.box_y_max'],
errors='coerce')

# Here we fill any missing values with the mean of the column
data['Value.box_y_max'].fillna(data['Value.box_y_max'].mean(),
inplace=True)

# Here we assign the data to pd to numeric function with the data as a
parameter and the errors to coerce to the tab
data['Value.box_z_min'] = pd.to_numeric(data['Value.box_z_min'],
errors='coerce')

# Here we fill any missing values with the mean of the column
```

```
data['Value.box_z_min'].fillna(data['Value.box_z_min'].mean(),
inplace=True)

# Here we assign the data to pd to numeric function with the data as a
parameter and the errors to coerce to the tab
data['Value.box_z_max'] = pd.to_numeric(data['Value.box_z_max'],
errors='coerce')

# Here we fill any missing values with the mean of the column
data['Value.box_z_max'].fillna(data['Value.box_z_max'].mean(),
inplace=True)

# Here we convert the 'features' column to a numeric variable
data['Value.box_volume'] = pd.to_numeric(data['Value.box_volume'],
errors='coerce')

# Here we convert the 'features' column to a numeric variable
data['02_weights'] = pd.to_numeric(data['02_weights'], errors='coerce')

# Here we fill any missing values with the mean of the column
data['02_weights'].fillna(data['02_weights'].mean(), inplace=True)

# Here we convert the 'features' column to a numeric variable
data['01_vol_class'] = pd.to_numeric(data['01_vol_class'], errors='coerce')

# Here we fill any missing values with the mean of the column
data['01_vol_class'].fillna(data['01_vol_class'].mean(), inplace=True)

# Set the top 10 locations related to spatial data
new_data_set['location'] = data_set['location'].value_counts().index[:10]

# Set the count of the top 10 locations related to spatial data
new_data_set['count'] = data_set['location'].value_counts().values[:10]

# Here we assign the geolocator to the nominatim function with the user agent
as a parameter
geolocator = Nominatim(user_agent='geoapiExercises')

# Here we set up rate limiting for geocoding requests
geocode = RateLimiter(geolocator.geocode, min_delay_seconds=0.5)

# Initialize dictionaries for latitude and longitude
lat = {}
long = {}
```

```
# Iterate through locations to get latitude and longitude
for i in new_data_set['location']:
      location = geocode(i)
      lat[i] = location.latitude
      long[i] = location.longitude

# Add latitude and longitude columns to the DataFrame
new_data_set['latitude'] = new_data_set['location'].map(lat)
new_data_set['longitude'] = new_data_set['location'].map(long)

# Create a map object and centre it to the a mean point
map   =   folium.Map(location=[10.0,   10.0],   tiles='CartoDB   dark_matter',
zoom_start=1.5)

# Add circle markers for each location on the map
for i in range(len(new_data_set)):
      folium.CircleMarker([new_data_set.iloc[i]['latitude'],
new_data_set.iloc[i]['longitude']],
radius=5, color='red', fill=True).add_to(map)

# Add circle markers with adjusted radius based on count
for _, r in new_data_set.iterrows():
      counts = r['count'] * 0.4 folium.CircleMarker([float(r['latitude']),
float(r['longitude'])],
radius=float(counts), color='lightcoral', fill=True).add_to(map)

# Add title to the map
map.get_root().html.add_child(folium.Element(title))

# Display the map
print(map)

# Here we select the 'features' column for clustering
X = data[['features']]

# Here we choose the number of clusters you want to identify
num_clusters = 4

# Here we initialise the KMeans model with the chosen number of clusters
kmeans = KMeans(n_clusters=num_clusters, random_state=42)

# Here we fit the model to the data
kmeans.fit(X)
```

```
# Here we add cluster labels to the original dataset
data['cluster'] = kmeans.labels_

# Here we calculate Silhouette score for the entire dataset
silhouette_avg = silhouette_score(X, kmeans.labels_)

# Here we calculate the inertia
inertia = kmeans.inertia_

# Here we print the number of clusters
print(f"\nNumber of clusters: {num_clusters}")

# Here we print the silhouette score
print(f"Silhouette Score: {silhouette_avg}")

# Here we print the inertia
print(f"Inertia (within-cluster sum of squares): {inertia}")

# Here we print cluster centres and sizes
cluster_centers = kmeans.cluster_centers_

# Here we print the cluster centres
cluster_sizes = np.bincount(kmeans.labels_)

# Here we print the cluster sizes and details
print("\nCluster Details:")

# Here we print the cluster details
for cluster_num, centre, size in zip(range(num_clusters), cluster_centers,
cluster_sizes):

# Here we print the cluster number, centre, and size
print(f"Cluster {cluster_num}: Center: {centre}, Size: {size}")

# Here we visualise the clusters, we set the figure size
plt.figure(figsize=(10, 6))

# Here we set the style
sns.set(style='whitegrid')

# Here we plot the clusters and parameters
```

```
sns.scatterplot(data=data,    x='index',    y='weights',    hue='cluster',
palette='tab10', s=80)

# Here we set the title
plt.title('K-Means Clustering of Features')

# Here we set the x-axis label
plt.xlabel('Index')

# Here we set the y-axis label
plt.ylabel('Features')

# Here we set the legend title
plt.legend(title='Cluster')

# Here we show the plot
plt.show()

# Here we set the figure size
plt.figure(figsize=(8, 6))

# Here we plot the cluster centres
plt.scatter(cluster_centers[:,   0],   [0]   *   num_clusters,   marker='X',
color='red', s=200, label='Cluster Centers')

# Here we set the title
plt.title('Cluster Centers')

# Here we set the x-axis label
plt.xlabel('Features')

# Here we set the legend title
plt.legend()

# Here we show the plot
plt.show()

# Here we use another plot in which we specify the features and size.
plt.rcParams['figure.figsize'] = (10, 5)

# Here we set the font size
plt.rcParams['font.size'] = 6

# Here, we plot the countplot parameters
```

```
sns.countplot(x='feature', data=data)

# Here we rotate the x-axis labels
plt.xticks(rotation=45)

# Here we set the title
plt.title('Distribution of feature')

# Here we use barplot for top 20 species
top_species = data['species'].value_counts().nlargest(20)

# Here we set the figure size
plt.rcParams['figure.figsize'] = (12, 6)

# Here we set the font size
plt.rcParams['font.size'] = 6

# Here we set the layout
plt.tight_layout()

# Here we plot the barplot parameters
sns.barplot(x=top_species.index, y=top_species.values)

# Here we rotate the x-axis labels
plt.xticks(rotation=45)

# Here we set the title
plt.title('Top 20 Species')

# Here we set the figure size
plt.figure(figsize=(10, 6))

# Here we set the style
sns.set(style='whitegrid')

# Here we plot the clusters
sns.scatterplot(data=data, x='index', y='weights', hue='cluster',
palette='tab10', s=80)

# Here we set the title
plt.title('K-Means Clustering of Features')

# Here we set the x-axis label
plt.xlabel('Index')
```

```
# Here we set the y-axis label
plt.ylabel('Features')

# Here we set the legend title
plt.legend(title='Cluster')

# Here, we display the plot
plt.show()

# Here we plot the cluster centres
plt.scatter(cluster_centers[:,   0],   [0]   *   num_clusters,   marker='X',
color='red', s=200, label='Cluster Centers')

# Here we set the figure size
plt.figure(figsize=(8, 6))

# Here we set the title
plt.title('Cluster Centers')

# Here we set the x-axis label
plt.xlabel('Features')

# Here we set the legend title
plt.legend()

# Here we show the plot
plt.show()

# Here we set the figure size
plt.rcParams['figure.figsize'] = [12, 8]

# Here we set the font size
plt.rcParams['font.size'] = 14

# Here we set the number of epochs
epochs = 750

# Here we plot the accuracy
plt.plot(history.history['accuracy'], label='Accuracy')

# Here we plot the validation accuracy
plt.plot(history.history['val_accuracy'], label='Validation Accuracy')
```

```
# Here we plot the loss
plt.plot(history.history['loss'], label='Loss')

# Here we plot the validation loss
plt.plot(history.history['val_loss'], label='Validation Loss')

# Here we set the legend
plt.legend()
```

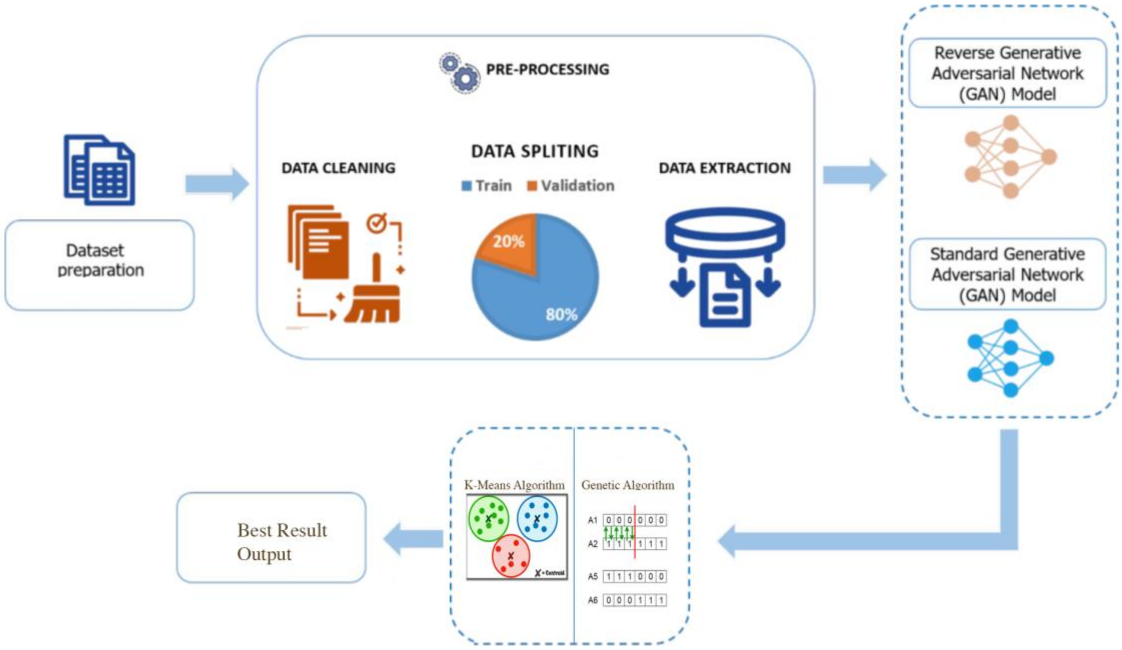


Fig 14: The overall Workflow of Genetic Algorithm with K-Means Machine Learning Algorithm.

Figure 14 illustrates the deployment of K-Means and the GA, integrated with the Generative Adversarial Network (GAN) and the Reverse Generative Adversarial Network (RGAN). This framework `labels_real = np.ones((batch_size, 1)); labels_fake = np.zeros((batch_size, 1))` is tailored for the creation, pre-processing, cleaning, and splitting of project-specific data. GAN `generator _ optimizer = tf. Keras. optimizers. Adam(learning _ rate = 0.0002)` plays a pivotal role in the creating of synthetic data, underpinned by a dynamic adversarial process. Within this process, the generative model learns from the input data and subsequently generates new data instances `d_loss_fake = discriminator.train_on_batch(generated_images, labels_fake).` These generated data instances closely resemble the characteristics of the original dataset, effectively enriching the available data resources. Whilst RGAN model `discriminator_optimizer. minimize (discriminator_loss)` is employed in the pre-processing phase to remove noise and outliers from the data. RGANs reversed `data = discriminator(generated_data)` are known for their ability to enhance data quality by generating cleaner versions of the input data. For data cleaning phase, the data was prepared for analysis. It includes steps such as removing duplicate records and correcting errors `data = data. drop_duplicates(); outliers = data[~data.isin(data.quantile([0.25, 0.75]).values.T)]`. The output of this phase is a clean and well-prepared dataset. The second step is data splitting `X_train, X_test, y_train, y_test = train_test_split(data, test_size=0.20, random_state=42)` which consist of two sets - the training set and the validation set. The training set is used to train the K-Means machine learning model, while the validation set is used to test the model's performance and ensure it's not overfitting. The percentages of data allocated to training and validation are 20% and 80%, respectively. As the model compilation model. `Compile (optimizer = 'adam', loss= 'categorical_crossentropy', metrics=['accuracy'])` and fitting `model.fit(X_train, y_train, epochs=50)` processes unfold, this culminates of in the presentation of the best possible output.

DAP Master Thesis Vol. 3

N**ART**URE

Sculpture Museum Wienerberg
An Ecolopes Project

Livia Dirnböck

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Prof. Dr. Michael U. Hensel

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N**AR**TURE

Sculpture Museum Wienerberg
An Ecolopes Project

Livia Dirnböck

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Foreword

Architecture is a definition of space and spaces have limits if they are to be perceived as such on a phenomenological level. This demarcation in its material manifestation implies the separation of an area from nature, an "inside" is created. There, comfort, security, and protection from climate and other species can be better adjusted and controlled for humans and for other forms of life domesticated by them than outside this border in the "outside". Architecture is therefore a protection against the conditions of nature, more dramatically expressed it serves to fight against them.

This topological description of architecture is certainly very schematic and certainly too rigid to do justice to the diverse design considerations concerning architectural enclosure. For example, the enclosure can house nature in the form of nesting sites or vegetation. Openings such as windows or doors perforate this border, at least temporarily. The resulting reduction of separation "inside" is a basic human need, which is why ever larger openings are established with increasing technical possibilities that create a strong connection to open spaces and the "outside". They are now a quality feature not only of residential architecture, but also of commercial buildings and public buildings such as museums. When we thus open the boundary as desired to create a stronger relationship of human with the "outside," are we also compelled to allow elements of nature to come in? Or do we do everything we can to ensure that this limit is only semi-permeable?

In the context of art, as is the context of the project presented here within, this question is particularly delicate. The context of exhibiting art requires a securely sheltered environment for conservation purposes. The artefacts are expected to no longer change because they have a cultural and economic

value. However, the opening of the enclosure implies a loss of control and thus a problem for the conservator and the work of art. Excluded from this argument are obviously works of art that consciously conceptually include change caused, for instance, by the impact of exposure to natural dynamics. If acceptance of the direct coexistence of nature and art and thus also acceptance of mutual change increases, museums could also open to the outside in terms of space and climate.
Until such point, architectures will have a discrete form that, as described, must separate itself from and exclude nature. Such temporary demarcations are expected of the visitor and may be deemed to be conducive to contemplation. Today, however, it has been realized on a broad level that demarcation is a problem for nature simply because of the quantity of construction that changes natural environments much to their detriment. It has also been comprehended that reducing interaction with nature implies reduction in human quality, wellbeing, and health. For this reason, the question arises as to what an architecture might look like that positively embraces nature by making its border permeable while creating a protected space for art?

This master thesis by Livia Dirnböck is the first in a series of thesis conducted at Vienna University of Technology. In the written part, work deals intensively with the place, the museum itself and the topic of "Ecolopes -ecological building envelopes", the theme of a European Commission funded research project. The project initially accepts the need for protected interior spaces, so that works of art that require conservation can continue to be exhibited. The negative impact of the architecture on the ecological context of the Wienerberg Park is reduced by a variety of measures and intensive provisions for other species are created. The author arranges the program in various separate volumes, thus creating the flexibility to respond to the existing context such as existing topography, plants, and pathways. At the same time, the arrangement of the volumes and a consistent, independent design language result in a coherent design. The central area between the closed elements is spatially particularly interesting. With a lot of sensibility, a place is established that is highly permeable, but at the same time defines a place. It opens upwards, offering views, but also acts as a base for works of art and visitors.

Particular attention is paid to the building enclosure, which offers comprehensive colonization possibilities for plants and animals. The elements of the architecture are elevated so that the foundation can be minimized, and a living space for various species is created between the surface of the earth and the parts above it. This area is supplied with light via reflection using the water surfaces and numerous openings in the architecture. The elevation and the choice of material also mean that the project can be easily dismantled, thereby remaining true to the credo of the Australian architect Glen Murcutt to "touch the earth lightly". Likewise, it is easy to imagine that if the architecture is no longer used in future, and provided that the technical elements are removed, it can remain in place to be further colonized by nature and to fully become part of the natural environment.

Working through the requirements of the "Ecolopes" program in a convincing manner as part of a diploma thesis is a considerable achievement. Yet, I am particularly pleased that despite these demanding requirements an enjoyable work was created that is also convincing in terms of design and function. The project is integrated into the existing park landscape, creates a high added value for visitors, and shows sculptural art in a special natural context.

Christian Kern, Univ.-Prof. Arch. Dipl. Ing.

IV

Abstract

The construction and building industries emit almost 40% of global C02 emissions[1]. This entails a great new challenge for architects worldwide. The ecolope's[2] research approach tries to counteract the increasing densification of cities thus preventing negative effects on the environment. Main focus is placed on the building envelope, which, in addition to the architectural tasks related to the design of a museum, should also provide habitat for different species and thereby address the needs of humans, animals, plants and microbiota.

The thesis proposes a speculative project situated in the nature reserve Wienerberg. The design of the project specifically addresses deficits in the area and provides architectural solutions. It is important to minimize interventions in the existing structures, taking local conditions and requirements into account. The projects spatial organisation is based on an analysis of the perimeter of the site. The building, which is placed on wooden pillars, adopts the organic outline of the existing pond and tree stands. The walls, green roof as well as large-scale platforms provide a habitat for animals, plants, and micro-organisms.

The project is a sculpture museum for contemporary art and art of the 20th century that closes a gap in Vienna's existing range of museums. The transitions between indoor and outdoor spaces create a unique exhibition experience, where the works of national and international artists get in close context with the natural surroundings. The connection of the building with nature is intended to strengthen people's awareness of the natural environment.

Keywords:
Sustainable building,
museum architecture,
timber construction,
elevated architecture,
living space in facades,
Terraced platforms,
waterfront architecture,
sustainable construction,
minimally invasive architecture

[1] 2020 Global Status Report for Buildings and Construction, 2020, S. 4
[2] H2020 FET Open Forschungsprojekt Ecolopes www.ecolopes.net

Schlagwörter:
Nachhaltiges Bauen,
Museumsarchitektur,
Holzbau,
aufgeständerte Architektur,
Lebensraum in Fassaden,
Terrassierte Plattformen,
Architektur am Wasser,
Nachhaltiges Bauen,
minimal invasive Architektur

Abstrakt

Die Bau- und Gebäudewirtschaft ist Verursacher, von fast 40% der globalen CO2-Emissonen.1 Diese Tatsache, stellt ArchitektInnen weltweit vor eine neue Herausforderung und bringt damit eine große Verantwortung mit sich. Der Forschungsansatz Ecolopes2 soll dabei eine Lösung für die zunehmende Verdichtung der Städte bieten. Das Augenmerk wird dabei auf die Gebäudehülle gelegt, sie soll zusätzlich zu den vielen Aufgaben in architektonischer Hinsicht, auch ein Habitat für unterschiedliche Spezies bieten und dabei auf die Bedürfnisse von Menschen, Tieren, Pflanzen und nützlichen Mikroben eingehen.

Das Planungsgebiet, mit dem sich die Diplomarbeit auseinandersetzt, liegt im Naturschutzgebiet Wienerberg. Der Entwurf greift gezielt Defizite des Gebiets auf, um in der gestalterischen Umsetzung eine Verbesserung der Situation zu bewirken. Wichtig ist dabei, die Eingriffe in die bestehenden Strukturen zu minimieren und Nutzungen

Der architektonischer Entwurf ist ein Skulpturenmuseum für zeitgenössische Kunst und Kunst des 20 Jahrhunderts, um somit eine Lücke in der Wiener Museumslandschaft zu schließen. Die Räume schaffen, durch die fließenden Übergängen von Innen- und Außenraum, ein einzigartiges Ausstellungserlebnis, in dem sich die Werke, nationaler und internationaler KünstlerInnen präsentieren, und in einem engen Kontext mit der Natur erfahrbar sind. Durch die allumfassende Verbundenheit des Gebäudes mit der Natur soll das Bewusstsein für die Umwelt beim Menschen nachhaltig gestärkt werden.

---

[1] 2020 Global Status Report for Buildings and Construction, 2020, S. 4
[2] H2020 FET Open Forschungsprojekt Ecolopes www.ecolopes.net

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I would also like to thank my family and friends for the support during this time and all fellow students who accompanied and inspired me during my studies.

1

RECREATION AREA WIENERBERG

Fig.1: (left) Spinner on the Cross 1900

Fig.2: (right) Triester Strasse 1930

Fig.3: (left) Wienerberg Brickworks 1900

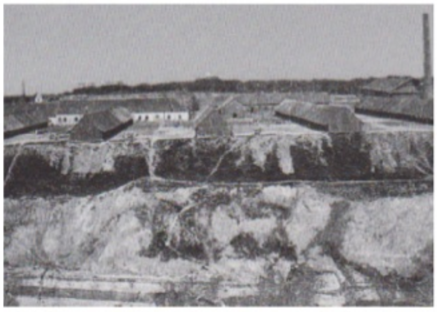

Fig.4: (right) Wienerberg Brickworks, end of 19th century

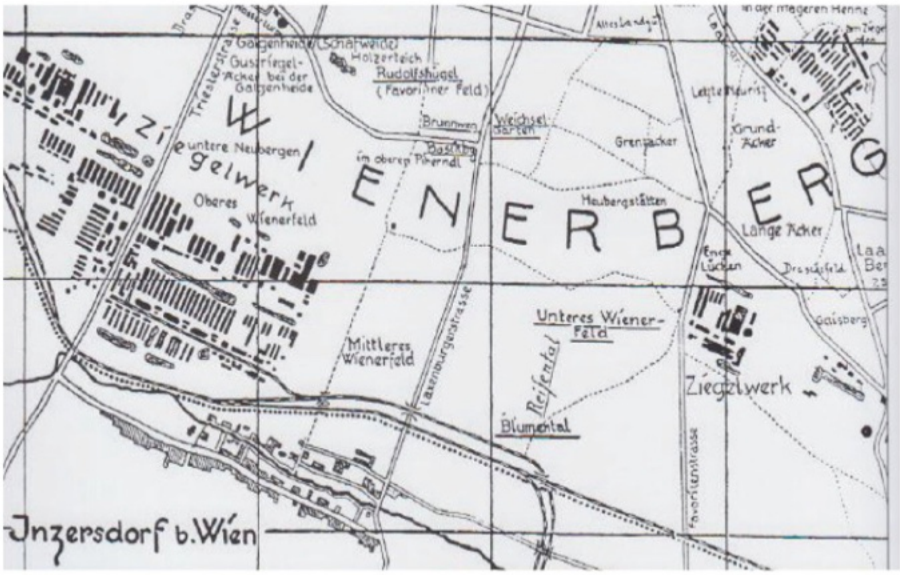

Fig.5: Map Wienerberg 1928

1.1 History of the origins of Wienerberg

The Wienerberg recreation area is located on the north-western border of Vienna's 10th district, Favoriten. The nature recreation area covers 123 hectares of green space, of which about 16 hectares are occupied by the Wienerberg pond. The Wienerberg forms the gateway to Vienna in the south of the city, together with the Wienerberg City Towers, which can be seen from afar, and the Biotope City, which will be completed in 2021.

The Wienerberg was not always characterised by flourishing landscapes and biodiversity. For many centuries, the Wienerberg, which belonged to the Lower Austrian dominion of Inzersdorf until 1938, was isolated from the capital city Vienna. Situated south of the city of Vienna, it was separated from the city by the wall. The "Linia", as it is colloquially known, was a fortification and offered protection to the city and separated it from the surrounding countryside, which also made clearly recognizable differences in infrastructural development. This effect was also intensified by the strong difference in altitude, whereby the villages to the south became increasingly isolated. The development was characterized by small-scale farmland, pastures, vineyards, and forests. Already in the 18th century, the appearance of the southern slopes of the Wienerberg was influenced by the private brickworks and the brickworks used for military purposes.

At that time, the southern surroundings of Vienna were largely used for waste disposal, as well as for the execution of death sentences and the subsequent burial of corpses. The gallows not far from the "Spinnerin am Kreuz" was a place of horror for travelers to Vienna until 1868. Then as now, Triester Street was one of the most important connections to Vienna and had to be passed by all travellers. In former times it was the only

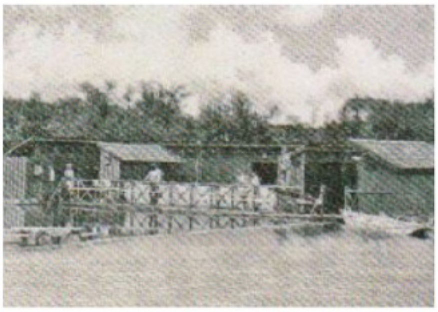

Fig.6: (left) Swimming school Inzersdorf 1900

Fig.7: (right) Favoritenstraße 1897

Fig.8: (left) Garbage disposal at the Wienerberg

Fig.9: (right) Pile of rubbish

Fig.10: Wienerberger site 1961

connection between the city of Vienna with the towns that were located further south. The Trieste Road initially ran as far as Wr. Neustadt and was later extended to Carinthia and further to Trieste because there were important military access points to the seaport located . The first small settlements developed along the Trieste Road, including Neustift, which at that time developed from a small brickyard into farmland.

The development of the brickwork was mainly developed by the ban imposed by Emperor Franz I in the 19th century, according to which factories were not allowed to settle within the town wall. Rapid settlement development took place mainly in the west and south of the wall. With the factories, mainly workers settled in the vicinity of the factories, which led to strong discrimination of the workers. A large- scale brickwork factory was built on the Wienerberg in the middle of the 19th century, where people not only worked but also lived. In addition, factory housing estates were built in which the workers and their families lived.

When Alois Miesbach bought the land, the mining of the Inzersdorfer Tegel went up sharply. Brick production became increasingly industrialized, and to cope with the rising demand and large orders, the site was rebuilt. As a detriment for the workers, the drying sheds were extended, slides were laid to facilitate transport and dozens of factory chimneys were built. The workers' quarters became smaller and smaller and over time degenerated into barracks. Since the workers could not leave the brickwork areal without permission, they mostly stayed by themselves and developed their own customs and traditions. The workers from Bohemia are particularly well known and were usually referred to derogatorily by others as the "Ziegelböhm". The pace of their work was extremely fast, but the almost 100 Residential buildings, did not offer enough space for the 5,000-10,000 inhabitants.

Fig.11: (left) Orthophoto 1938

Fig.12: (right) Orthophoto 1956

Fig.13: (left) Orthophoto 1976

Fig.14: (right) Orthophoto 1992

Fig.15: Orthophoto 2020

Alois Miesbach's nephew, Heinrich Drasche, went on to manage the brickwork factory and developed it into the largest brick factory in Europe. The infrastructure of the housing estate was very well developed for the time. There were bathrooms and wash houses, day-care centres for children, as well as a small spa. Since the workers' dwellings were close to the Bendateich, there was even a swimming school at the Zwillingssee. Vegetables and fruit were also grown on the grounds of the brickwork areal to provide the workers with fresh food.

In the middle of the 19th century, the first amusement parks developed, including the Bohemian Prater, which was established on the hilltop of the nearby Laaerberg. However, the Prater was hardly used by the workers on the Wienerberg, it was mainly the Viennese citizens who saw the Prater as a destination for their excursions. Due to the economic upswing, excursion tourism increasingly developed, for which the Viennese suburbs were particularly popular.

The construction of the Southern Railway and the Eastern Railway between 1839 and 1846 led to a renewed upswing in industry and technology, which meant that several thousand additional workers were needed. More and more businesses settled along the tracks. Not only the suburbs were built on, but also more and more buildings were erected within the ramparts to accommodate the large population growth. The railway and city roads contributed to an improvement in mobility and accelerated the development of buildings. Due to the increasing density of the buildings, the multi-storey apartment buildings with narrow corridors and dark flats, green space development became an issue in urban planning for the first time.

The Tiester quarter was first settled around 1900 using the block grid without any specific aesthetic requirements. However, gaps the size of a block grid were left in the development, where parks developed, with play facilities for children and benches for resting.

However, due to the shortage of building space near the railway, the workers' housing remained on the site of the brick factory. The exploitation of the workers became increasingly severe. Due to the lack of workers, children were also forced to help in the factory. Poor hygiene led to outbreaks of diseases and infections. What began as an exemplary enterprise ended in neglect and deplorable conditions due to the economic urge. In 1888, the psychiatrist and doctor for the poor Viktor Adler pointed out the devastating conditions on the Wienerberg in a publication in his magazine "Gleichheit". Soon there was the first successful strike, which led to improvements in the working situation.

In the 1960s, when clay mining became unprofitable on the Wienerberg, the factory was closed down and the Wienerberggründe were bought by the City of Vienna in 1972. Since it was customary at that time to fill empty gravel pits with rubbish and even more, there was no waste separation or waste incineration, the land was used from then on to deposit household waste and building rubble. However, due to the strong increase in consumption by the population, all the pits were quickly filled.

Until the 1970s, the Wienerberg area lay fallow, and the rubbish heaps formed a steep slope to the groundwater-filled clay pit, which was heavily furrowed by erosion. The district head of Meidling, Kurt Neiger, came up with the idea of creating sports fields according to international standards at the Wienerberg.

The aim was a accessible sports an play area for the population of vienna. Since large parts of the Wienerberg belonged to the protected area “Wald- und Wiesengürtel” (Forest and Meadow Belt), the landscape planner Wilfried Kirchner was commissioned by the City of Vienna in 1982 to develop the area into a landscape space that was to become a recreational area for 150,000 people. Coming from the south towards Vienna, the Wienerberg create a green city entrance as a contrast to the then newly built “Philipshaus”. Even before the contract for the creation of a recreation area on the Wienerberg was awarded, the first competition for the development of the southern areas of the Wienerberg were announced. It was specified that the closed development edge should be preserved, and the development should be realised with a lower density. The overall impression of the Wienerberg should not be destroyed by taller buildings. In the second round of the competition, the plan for the renaturation of the Wienerberg site was already confirmed.

Looking at the Wienerberg site today, it can be seen that the renaturation has worked well, and Vienna’s green belt has been significantly extended by the Wienerberg. The Wienerberg creates a large-scale, supra-regional recreational area for Vienna and makes the historical background visible through the terracing included in the planning.

1.2 The Wienerberg as part of Vienna's green belt

The Wienerberg is part of an open space system of the Urban Development Plan 2005 (STEP 05), which aims to create a wide green belt around Vienna. In 1905, Vienna made planning history with the decision to secure the Viennese forest and meadow belt, which brought the city much closer to the vision of a green belt around the city.

In 1893, the Vienna City Council announced a competition for a "general regulation plan", in which it had already been decided to keep the main open spaces, such as the Prater, Schönbrunn, but also the Vienna Woods, free. At the time, Eugen Fassbender was one of three runners- up in the competition. With his idea of a "People's Ring for Vienna", he proposed a 600-metre-wide green belt around the city of Vienna, which was to be located only 5 kilometres from the city centre. Fassbender fought for his idea and wrote several publications in which he reported on his proposal, which made the mayor Karl Lueger enthusiastic about his idea. Thanks to his international experience in green space planning, the director of the municipal building department, Goldemund, was able to further elaborate the plans and gave the Volksring the name "Wald- und Wiesengürtel" (Forest and Meadow Belt). The base for the green belt was based in 1905, when the municipal council placed almost 6,000 hectares of green space in Vienna under protection.

However, the events that took place in 1870, when the City of Vienna terminated the existing contract with the timber merchant Moritz Hirschl against the economic interest, were trend- setting. This meant that large parts of the Vienna Woods in the west of the city could be saved from deforestation. In 1898, the first draft for the creation of a wide zone on the periphery, which had to be kept free of any building, was drawn up by the Austrian Association of Engineers and Architects. An important step towards the implementation of the forest and meadow belt was the incorporation of some western parts of the city.

The first plan for the project was drawn up in April 1905. The Wienerberg is also included in the forest and meadow plan, as well as several other areas, including the Küniglberg, the Rote Berg, Schönbrunn, as well as the Laaer Berg, the central cemetery and other areas. According to the report, 4400 hectares of land are included in this plan.

It was not until 1934 that Vienna was the last federal state to pass the Nature Conservation Act, after which the Lainzer Tiergarten was handed over to the City of Vienna by the federal government with the stipulation that a nature reserve should be created there. After further areas of Vienna became part of the forest and meadow belt, the plan now covers an area of about 5000 hectares. Due to the war and the necessary war facilities, several hectares of grassland are lost through clearing at the oil port. With the following years and numerous re-designations, the green belt gains more and more area. At the end of the 1970s, the first urban planning ideas competition was held, which marked the beginning of the design of the local recreation area. Around 10 years later, the Wienerberg was completed as a landscape conservation area.

In 1955, the Vienna City Council adopted the plan "Grüngürtel Wien 1995" (Vienna Green Belt 1995). During this development, specific programmes were elaborated, whereby public green spaces were developed all over Vienna. The programme enabled the area of the green belt to be extended to 19,250 hectares. By 2005, the green belt grew in area up to 21,500 hectares.

Fig.16: Forest and meadow belt Wienerberg 1905

Fig.17: Green Belt Vienna 1995

In the following years, the urban development plan was renegotiated and adopted every 10 years. In addition, there is an ongoing monitoring and reflection process to ensure that the goals are being achieved, and whether planned initiatives are successful. The current Urban Development Plan 2025 (STEP 2025) focuses on Vienna's steadily increasing population and the population's desire for high-quality green and open spaces. Vienna has a green space share of more than 50%, which should remain so in the future, despite rising population figures. "Green space justice" is a central theme of the urban development plan. Every citizen has the same right to a high-quality supply of green and open spaces. Therefore, the development of a robust open space network as well as the securing of the necessary areas is the goal to be able to offer future generations high-quality green and open space in a rapidly growing city.

In 2021 work began on the new Urban Development Plan 2035. The goal is clearly defined: life in Vienna should continue to be affordable and of high quality. Particular attention is being paid to the further rise in temperatures and the increasingly extreme weather conditions. Above all, the effects of the climate crisis on our everyday lives are the focus of the elaborations. Important future-oriented points are also the supply of living space and the associated resource-saving use of building materials and raw materials.

1.3 Value of the Wienerberg as a recreational area

Many decades have passed since the Wienerberg's constant transformation from one of Europe's largest brick factories, later to a landfill site, to today's recreational area. The recreation area is not characterised by well-kept flower beds, perfectly mown lawns or streetlamps, the Wienerberg is characterised by its complete naturalness. Here you will find fields, high meadows, wild bathing areas, footpaths and play areas. Precisely because the Wienerberg does not correspond to the typical image of an urban park, it has enjoyed great popularity in recent years. The great diversity of the green space offers added value for every public. Here, children can play and romp without disturbing anyone, athletes have enough space to run their laps, and even anglers get their money's worth from the rich fish supply of the Wienerberg pond. Above all, Wienerberg Park is ideal for taking a walk and unwinding after a hard day's work.

The Wienerberg is surrounded by numerous residential buildings and is therefore the main recreational area for many Viennese. Alone 50,000 people live within a 15-minute walking distance. Over the years, more residential buildings have been built in the immediate vicinity, around the Wienerberg. The Biotope City , which was be completed in 2021, created additional living space for many Viennese with 950 flats, which has also greatly increased the number of daily visitors to the recreational area.

A study carried out in 2002 made it possible for the first time to carry out visitor monitoring, it was recorded how many people visit the park, as well as which places in the park were more frequented than others. On average, the visitors are 45 years old and have been using Wienerberg as a recreational area for 10 years. Most of the users live in the 10th district of Vienna, only just under 2% of the visitors were not from Vienna. Two thirds of the people stated that they visit the park at least once a week in winter, in summer this was even the case for 81% of the respondents. The length of stay varies considerably in winter and summer; in winter, most of visitors spend just under an hour at Wienerberg, whereas in summer the stay is extended by bathing activities and lasts for several hours. Two thirds of the visitors come on foot, some come by car, and only a small proportion use public transport to reach the recreation area.

The group size was rather small with an average of 1.5 people, as half of the people visit the park alone and one third come to the park in pairs. Recreation was the main reason for most people to visit Wienerberg, followed by dog walking and sporting activities, with nature and the landscape playing a role for only 22% of respondents. The landscaping is particularly appealing to older people and women. However, the play and sports facilities were criticised particularly negatively in the survey.

The survey specifically asked about disturbing factors and potential for improvement in the Wienerberg recreation area. The increasing amount of litter and vandalism were often mentioned negatively. Dog excrement and the high number of dogs in general were also perceived as disturbing. The lack of infrastructural facilities, such as toilets, snack stands, benches

Fig.18: Wienerbergteich

and rubbish bins, was listed as a shortcoming by almost 10%.

Measured over a year, the Wienerberg records 1.24 million visits, resulting in a density of 10,500 visitors per hectare and year.

Approximately 3,400 visitors can be expected per day, with daily visitor numbers fluctuating between 431 and over 10,000. This makes the recreation area one of the more intensively used recreational areas in Vienna. However, tourist destinations such as Schönbrunn Palace Park or the Belvedere are much more frequented.

As a summary of the survey, it can be stated that the Wienerberg offers high recreational qualities. The visitors particularly mentioned the landscaping and the possibility of using the pond as a bathing place in summer. However, the Wienerberg is under high pressure due to the increasing population in the surrounding area, which can be seen in the increasing number of visitors and the resulting decline in the quality of stay. The Wienerberg needs a better infrastructure in order not to lose recreational quality with the increasing number of visitors.

1.4 Ecology of the Wienerberg

The Wienerberg was not always so rich in nature and biodiversity. At the beginning of the 1970s, it was not easy for plants to take over the Wienerberg as a habitat. The brick quarry with partly old buildings, storage areas, large quarrying areas, access roads and the pits sinking into the groundwater hardly offered a chance for plants to spread. In addition, an uncertain water supply and changeable weather conditions made it difficult for various plants to settle. Only the pioneer plant Huflattlich managed to germinate on the humus-free, sterile soil, thanks to its far-flung fruits. Soon it covered the soil with its carpets of runners and thus created the possibility for other plants to settle.

The piles of rubbish that had accumulated over decades in the north of the Wienerberg were later covered with some soil and rubble when a little conservation awareness was developed. Now the wilderness could spread further, and the first trees should have sprouted soon, but the dry, nutrient-poor soil made this development vehemently difficult. Elsewhere, on the areas prone to waterlogging, numerous reed plants quickly established themselves and covered large areas. One or two water-loving willows were also able to establish themselves in the early times when vegetation was still scarce.

Plants had a particularly hard time on the alternately wet or dry areas, which are very wet in spring or after rain, but otherwise tend to be very dry. These areas were mainly found in the east of the Wienerberg, where the clayey soil only allows water to seep in for a very long time when it rains, and when it subsequently dries, the fine capillary tubes in the soil suck out all the moisture again. The red dogwood, which is spread by birds over long distances, is the species that can best cope with the conditions at the Wienerberg. Once it has established itself, it can take over large areas with its underground branches.

On the loess slopes, too, the development into forest proceeded very hesitantly. Until today, hardly any trees have settled here; the appearance is characterised by sparse grasslands with smooth oats and ryegrass.

After nature had struggled to settle on the Wienerberg for years and only a few species had really managed to do so, MA49 decided to give nature a helping hand. On a certain part of the Wienerberg, trees selected according to ecological criteria were planted and seeds were distributed. Dry grass was used on the dry areas and meadow grasses were sown on the wetter areas. Large areas, however, remained natural, as envisaged in the original plan.

In the west, a seed was sown in the spring of 1996, and in the years that followed, one could marvel at a true flowering splendour. However, 12 years after the artificial sowing, only selected plants were still present, yet species-rich meadows were created that would not have developed in this way in the south-east of Vienna. Especially the conspicuously flowering plants such as viper's bugloss, dyer's woad and dyer's chamomile were able to establish themselves. In the meadows, on the other hand, lush stands of butterfly plants such as red clover and creeping clover grew. The valuable thing about these plants are the microorganisms that live in small nodules on their roots and can bind nitrogen from the air.

Another special feature of the western part of the Wienerberg site are the small ponds and mud banks, which provide an ideal habitat for pond frogs, but also backswimmers, water striders, water speedwell and poison penstemon. The grey-green spotted green toad also lives on the banks of these pools and benefits from the moist muddy bank zones. It is precisely these pools that are becoming a rarity in the natural world due to the constantly rising temperatures.

On the Wienerberg, the ponds benefit from an ingenious system of terrain steps, ditches, and catchment areas, which ensures that the ponds are mostly filled with water and yet are protected from damage by heavy rain.

In the 1990s, not only meadows were sown but also several hectares of forest were afforested, but only native tree species were used. On a hill in the west, downy oak, field maple, wild service tree, European aspen and several shrub species were transplanted. The young plants grew surprisingly fast despite their low growth height of 20- 40 centimetres and the exposed location. The application of sandy excavated material from the Danube area deliberately made the vegetation patchier and richer in moss, which allowed other plant species to settle, among others the calyx stonecrop, the panicled knapweed, the dyer's broom, and the steel dandelion.

In the east, the vegetation is already more advanced than in the west since the development there began in 1983. At the time of the brick factory, the spoil heaps were located to the west of the Wienerberg pond, which means that the landscape is still characterised by sandy- loamy slopes today. Below the hill grows a real speciality of the Wienerberg, the Bocks hauhechel, which is not found elsewhere.

It is a relic from 150 years ago, when this plant was more common on the Wienerberg. The "Great Clay Pond" in the east is the result of a merger of several smaller ponds that took place during the development of the recreation area. As is typical for the wet areas around ponds and lakes, a dense reed belt developed very quickly here as well. The wide reed zone provides shelter for many water birds from the many visitors, whereby even rarer bird species find a retreat in the reeds.

Fig.19: (left) Coltsfoot

Fig.20: (right) Reed

Fig.21: (left) Raygras

Fig.22: (right) Reed gras

Fig.23: (left) Blueweed

Fig.24: (right) Dutch clover

Fig.25: (left) Great crested grebe

Fig.26: (right) Reed warbler with offspring

One of the bird species living there is the Great Crested Grebe, which can easily be recognised by the reddish-brown cap on its head that gives it its name, and which is imposingly erected for courtship purposes. The coot can also be found in the reed belts of the Wienerberg pond. Its pitch-black plumage quickly attracts attention. Its food, which it seeks in the open water, is exclusively vegetarian. Only during the breeding season does it retreat to inaccessible reed zones. The reed warbler lives mainly between the dense blades of the reed zone. On the Wienerberg, two subspecies of the reed warbler can be found, the pond warbler and the blackbird-sized great reed warbler. In winter, you can usually still see the remains of their impressive bowl-shaped nests, which they have woven around some reed stalks halfway up the hill.

In the south, behind the Chadim, there are several small ponds that served as wastewater collection basins for the workers' housing complexes in the days of the brick factory. Over the years, a thick layer of silt has settled at the bottom of the ponds, which has an enormous negative impact on the water quality. Plans to suck the silt from the bottom of the ponds were too expensive. As a more favourable solution, the large Wienerberg pond to the north was connected with a small stream to the lower small ponds. The surplus water of the Wienerberg pond could thus simply be channelled into the small ponds, which benefit from the fresh water even in midsummer and thus do not suffer from a drastic drop in water quality, despite hot spells.

On the Wienerberg, fields and fields were also preserved to provide fodder for the workhorses. When the fields lie fallow and wild plants such as poppies, cornflowers and larkspur blossom, not only the wild bees but also the visitors enjoy the colorful sight.

On a small hill, which consists of sandy rock material that was deposited there, there is more and more exposure of the raw soil due to drought, on which the pink-flowered common heron's beak likes to settle in spring. The shiny silvery spikes of Transylvanian pearl grass are particularly striking, and the stone chat likes to look for a suitable place to build its nest among the stalks. Most of the time, you can see the feathered birds sitting in their hiding places or peering into the treetops for prey. The dense tall grasses are also popular with field hares, which can hide well between the stalks from predators. In contrast to rabbits, their offspring are born with sight and are hidden by their mothers in ground sinks in the tall grass.

2

MUSEUM

2.1 History of the Museum

In recent decades, museums have become one of the most popular cultural institutions, and new buildings are constantly being constructed or existing ones converted into exhibition spaces. However, hardly any other cultural institution has undergone such a strong transformation in recent years as the museum. In the past, the main tasks of a museum were collecting, preserving, researching, and presenting. Today, the demand on a museum is to take the visitor into a world of experience and at the same time to convey information, ideally in a playful way, in digitalised form. The classic long display cases, such as those found in the Natural History Museum in London, are no longer used in modern museums. Museums that are currently being planned have, in addition to the exhibition areas, equally large event areas, restaurants and shops. Museums are often used as a flagship for cities, the best example of the so-called "Bilbao effect" being the Guggenheim Museum designed by Frank Gehry. The architecture of the buildings comes to the fore and, in extreme cases, competes with the exhibits. Often the museums are not visited because of the exhibitions shown inside, but because of the extravagant architecture.

As a contrast to the museums, which are conspicuous for their expressive architecture, SANAA's art gallery or David Chipper field's literature museum in Marbach are examples. Renzo Piano, too, does not place his design emphasis on the exterior expression of the building, but on a technically and creatively sophisticated lighting concept, which can be seen impressively in the museum extension of the Kimbell Art Museum.

In the end, it does not matter whether an extravagant or restrained architectural language is used, the design must ultimately correspond to the respective task and its requirements.

The museum has its origins in the temples of all cultures, regardless of whether they were the temples of the Egyptians, Chinese temples, or the temples of the Near East. Based on the human instinct to collect everything, objects of their rituals were kept in these cultural sites. The museum is only mentioned by name later in Greek history, in the form of a small temple that functioned as a treasure house. In these treasure houses, however, the valuable objects were not stored for the sake of education, preservation, and research, but rather to display the precious achievements of their military campaigns.

At the same time, in Greece, beautiful minds invented the museum, at least in name, as part of their linguistic exercises. They called the place of the muses the "musio", which embodied art and science. At that time, a statue of the Muses stood at the consecration site of the schools. It was not until the 14th century, when the treasure house was reduced to a "grotta" and the school to a "studiolo", that both found space directly next to each other in the courtyards. Sometimes the most impressive pieces, the grotta, were even displayed in showcases in the studiolo for teaching purposes. However, the architectural aspect of the rooms hardly played a role at that time. It was only with the wealth of the Romans that wealthy citizens began to decorate their homes with fragments of old stucco or sculptures to express their prosperity.

More than a century passed until finally, in the Renaissance, a separate art space was dedicated to art, but at that time still in the open air. The Cortil del Belvedere was built shortly after 1500. A Cortile Ottagonale, designed by Bramante, lined up the sculptures in wall niches. This was the starting signal for further museum approaches, all of which had one thing in common: the desire to flood rooms with daylight. The Pantheon in Rome was inspired by Bramante's idea. In contrast to its predecessor, here the space is covered by a large dome; only a circular opening at the apex of the dome brings daylight into the interior, which is finely distributed via the concave arches. It was not until the 16th century, 12 centuries after Caesar Hadrian had the Pantheon built in Rome, that Buontalenti transferred the concept of the Pantheon to the museum building, as he did when he redesigned the Uffizi in Florence. Until 1800, numerous museums were built that were not far removed from their forerunners in terms of their design, long necked or central circular. At that time, however, the museum was not accessible to the public and was subject to the regiment of its builder. Only selected guests were granted access and the precious treasure inside was revealed. This only changed with the rise of the bourgeoisie, who owned little but were at least aware of it. Through a testamentary endowment, the British Museum, once based on a private collection, became common property. Admission was regulated by a code that was equally strict to all visitors, regardless of their status or rank. Only occasionally, to appease people's greed, were the art houses opened. The failure of this concept was demonstrated by the French Revolution, when Louis XVI was beheaded and the royal private coffers were nationalized. After this event, in 1793, the Louvre

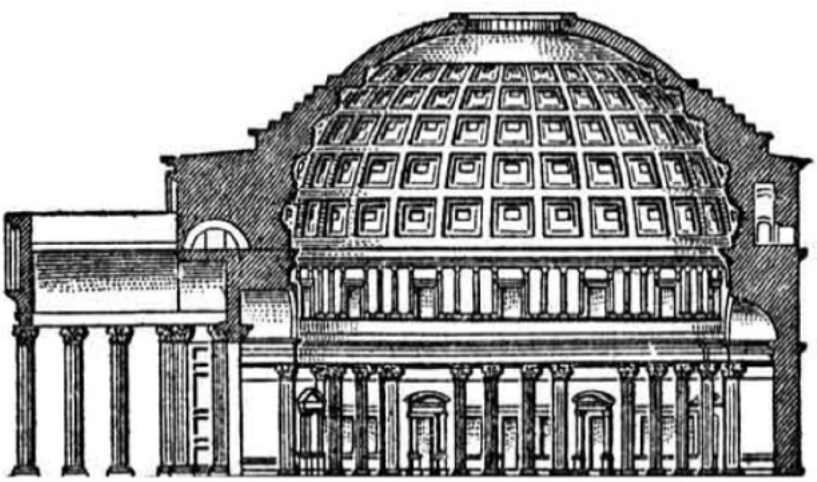

Fig. 27: Pantheon Rome: Universal temple of the gods as a godfather for museum buildings.

became the first museum that was open to visitors at all times. Since then, it has been impossible to imagine the public without the museum as an institution.

Due to the larger audience that museums have enjoyed since then; the spatial program has also expanded, and museums are being planned as free-standing buildings for the first time. Wherever there is sufficient interest for a museum, new museums are established, in metropolises even several. The outward appearance also undergoes a change. The portals are becoming ever larger and more ostentatious to draw visitors into the building. Even the columns, which were only to be found in front of the portal in historical forerunners, are now extended to the entire front of the building. The Old Museum in Berlin by Friedrich Schinkel, which was built in 1830, serves as a prime example. The large number of visitors posed the architecture, especially regarding the interior, with the question of spatial organization and guidance. After the utopian concepts of a spatial grid in which visitors could freely decide which way they wanted to go, as in the design by Étienne- Louise Boullée, the concept of the tour was more successful. The method was used, for example, in the Glyptothek by Leo Klenze, which opened in Munich in 1830. The concept was easy to explain, the forced routing meant that visitors could not turn away from the works of art until they reached the end of the exhibition, in extreme cases the routing was even continued over several floors. Due to the constant barrage of information, the visitor quickly became tired of the overload and the educational value was low.

From then on, a mixed form of museum building prevailed, in which several paths lead away from a main room and the works of art are brought together in a context. But the search for the ideal sequence of rooms has not yet been found, and to this day no architect can escape this important design question.

Fig.28: Altes Museum Berlin, Friedrich Schinkel,1830

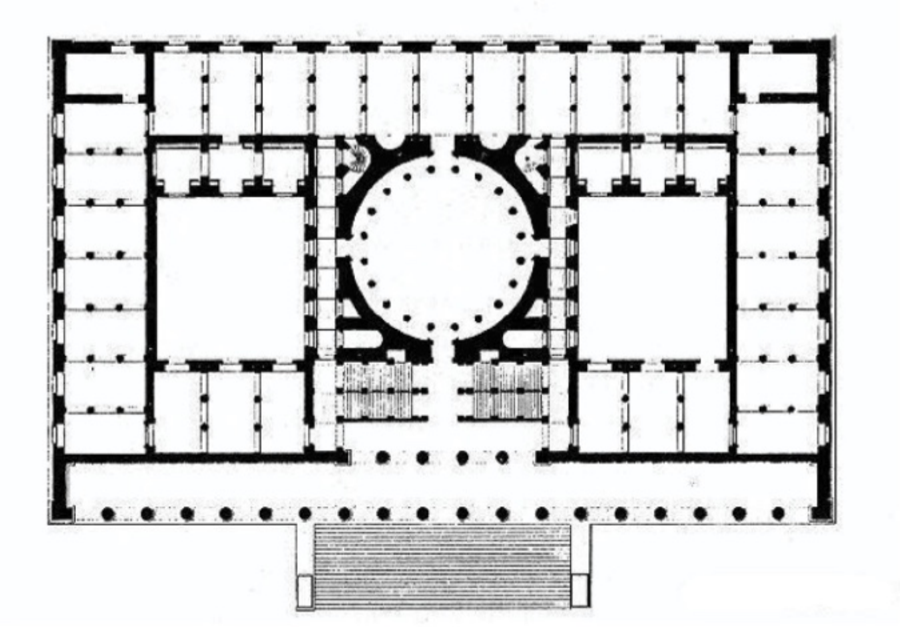

Fig.29: Floorplan, Altes Museum Berlin

At this point in time, the aesthetics of the building shell as well as the interior are still stuck in the past and adorn themselves with the tried and tested. The step into modernity took several more decades and did not go smoothly. It was not until after the Second World War that museum architecture made its breakthrough into modernism. Frank Lloyd Wright took up the entire block front with his Solomon R. Guggenheim Museum. On an almost invisible base rests a cylinder that swells upwards, interrupted only by three skylights, in its monolithic form, but which clearly identify the building as a museum. The visitor explores the works of art via a spiral ramp. To this day, the building is considered a century-old structure in the history of architecture.

From the 2000s onwards, there were also more and more private collectors and companies that built their own museum buildings. Especially in the automobile industry, an arms race of superlatives began. Volkswagen expanded its antique car fleet into a gigantic 22- hectare car city in 2000, and other car manufacturers followed in the next years. A paradigm shift is taking place that is also affecting public museums. State subsidies are often insufficient for the ever more conspicuous and larger designs, and the museums are dependent on donations. In the meantime, the primary focus of museums was no longer on art and historical collections; the path to modernity could also be seen in the exhibitions. Technical museums or museums dedicated to space travel increasingly developed. A clear trend was discernible, because not only the architectural language but also the exhibitions themselves turned their backs on the past and turned towards the future. In the meantime, hardly anything remains of the original idea of the treasure house. The change continues to move away from the display of all collected exhibits towards a presentation of individual selected exhibits, in which each piece is given a large individual display space. The interiors and their design are also

Fig.30: (left) Guggenheimmuseum, New York City, Frank Lloyd Wright, 1959

Fig.31: (right) Centre Pompidou, Paris, Renzo Piano, Richard Rogers, 1977

Fig.32: (left) Jewish Muesum, Berlin, Daniel Liebeskind, 1999

Fig.33: (right) Quadracci Pavilion, Milwaukee, Santiago Calatrava, 2001

Fig.34: (left) Kunsthaus Graz, Graz, Colin Fournier, Sir Peter Cook, 2003

Fig.35: (right) New Museum of Contemporary Art, New York City, Kazuyo Sejima, Ryue Nishizawa, 2007

subject to constant change. With the advent of modernism, the neutral clean room with white walls established itself as the so-called "white cube", which from then on became an integral part of museum architecture. The change did not stop at the non-exhibition spaces either. At that time still a small part of the museum, today it takes up two thirds of the space, even the entrance hall is blown up enormously. But also shops and restaurants, the former helping museums to stay profitable, which often have their own merchandise. Some designs even go so far as to include hotel rooms, thus blurring the boundaries between museum and accommodation.

Meanwhile, the method of conveying information has also undergone a major change. Whereas previously the emphasis was on instruction through long texts, the focus has now shifted to interactive entertainment. Through the visitor's active involvement, the information is more easily remembered in the collective memory.

Since the beginning of its invention, the museum has been developing steadily, moving away from a purely scientific collection activity and more and more towards the entertainment of the visitor and the creation of impressive experiential spaces.

With the Centre Pompidou by the architects Renzo Piano and Richard Rogers, the two made a daring push of museum architecture into modernity in 1977. Richard Rogers said of the building itself that it should be "a place for all people, young and old, rich and poor, people of all religions and nations - a mixture of Times Square and the British Museum". For Rogers, buildings have to function like a clock, and you should recognize all the components and not hide the mechanics of a building. He also implemented this idea in the Paris Museum, where the entire technical system was exposed on the outside of the building shell. Escalators in tubes along the façade take visitors to the different floors. All this ensures maximum flexibility of the spaces inside the museum.

In the 1980s, numerous museums developed that were influenced by the "architecture parlante", the "speaking architecture" propagated in postmodernism. Daniel Liebeskind designed the Jewish Museum in Berlin in 1999, the "sailing ship" Quadracci Pavilion of the Milwaukee Art Museum, by Santiago Calatrava, followed in 2001. With the Kunsthalle, Peter Cook and Colin Fournier created a real eye-catcher in the centre of Graz in 2003, and the New Museum of Contemporary Art in New York, designed by SANAA, which looks like stacked parcels, was also part of the signet architecture that had a great influence on museum architecture and its development. In the last thirty years, a building boom has developed, and the number of museums worldwide has doubled, in some countries such as China it has even increased eightfold.

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In the meantime, hardly anything remains of the original idea of the treasure house. The change continues to move away from the display of all collected exhibits towards a presentation of individual selected exhibits, in which each piece is given a large individual display space. The interiors and their design are also subject to constant change. With the advent of modernism, the neutral clean room with white walls established itself as the so-called "white cube", which from then on became an integral part of museum architecture.

The change did not stop at the non-exhibition spaces either. At that time still a small part of the museum, today it takes up two thirds of the space, even the entrance hall is blown up enormously. But also shops and restaurants, the former helping museums to stay profitable. Some designs even go so far as to include hotel rooms, thus blurring the boundaries between museum and accommodation.

Meanwhile, the method of conveying information has also undergone a major change. Whereas previously the emphasis was on instruction through long texts, the focus has now shifted to interactive entertainment. Through the visitor's active involvement, the information is more easily remembered in the collective memory.

Since the beginning of its invention, the museum has been developing steadily, moving away from a purely scientific collection activity and more and more towards the entertainment of the visitor and the creation of impressive experiential spaces.

2.2 Design relevant museum references

2.2.1 Visitor Center in Kosterhavet National Park

Architecture Office: White architekter
Construction Site: Sydkoster, Sweden
Construction Year: 2012

Fig.36: Structural drawing of the Visitor Center in Kosterhavet National Park, White architekter, Sweden, 2012

The visitor centre was built in 2012, as part of the declaration of the region around Kosterfjord as a maritime national park. The centre has a spacious exhibition room where visitors are informed about the flora and fauna of the region. The building also houses a lecture room, as well as office space, not only for the staff, but also for the employees of the national park.

Thanks to the skilfully chosen architectural language, the new building blends in well with the existing structures in the surrounding area.

The gables of the main façade, which are arranged in rows, are also oriented towards the geometry of the surrounding boathouses. The division of the roofs makes it possible to fit the proportionally more voluminous building well into the smaller local structures. The irregular ground plan and the diagonal roof ridges create a complex architectural geometry.

In the interior, the geometry can be seen from the folded ceiling, which contribute to the impressive interior effect. The building envelope is only opened at a few deliberately placed positions, resulting in deliberate views of nature. The choice of materials is dominated by wood, from the wood-panelled ceilings in the interior, the pine wood floors, to the outer shell of spruce formwork treated with wood tar, most of the building is constructed from sustainable, pollutant-free materials

Fig.37: View from the water - Visitor Center in Kosterhavet National Park, White architekter, Sweden, 2012

Fig.38: (left) Showroom with wooden roof, Visitor Center in Kosterhavet National Park, White architekter, Sweden, 2012

Fig.39: (right) Aerial view of the port, Visitor Center in Kosterhavet National Park, White architekter, Sweden, 2012

2.2.2 Pavilion of the Écomusée de la Grande Lande

Architecture Office: Bruno Mader
Construction Site: Sabres, France
Construction Year: 2008

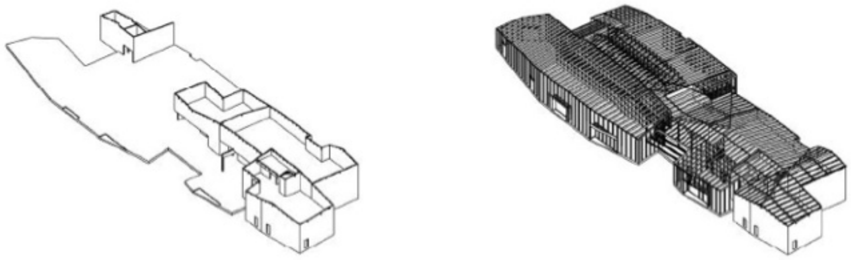


Fig.40: Structural drawing of the Pavilion of the Écomusée de la Grande Lande, Bruno Mader, France, 2008

The open-air museum Écomusée has been showing an insight into the simple country life of the 19th century since 1970. Not far away, right next to the railway station, is the pavilion designed by the architect Bruno Mader, which was reopened in 2008. Similar to an elongated shed, which is clad on the outside with regional pine wood, the large- volume building fits in well with the surrounding structures. If you take a closer look at the structure of the building, you can see several structures with their own functions. The spacious, white room for temporary exhibitions is located directly next to the entrance on the left. The glazed rear wall of the room connects the exhibition space with the natural surroundings of the building. The ceiling develops into a shed roof, which is glazed on one gable surface, allowing light to enter the room.

The wide wooden beams below the roof openings filter the light and disperse it evenly in the interior. The room can be connected to the adjacent auditorium.

In the permanent exhibition, which is equipped with a large skylight, oversized box-type windows with an external wooden lamella cladding provide optimal lighting. In the foyer, a long window offers a view of the collections in the depots below.

Due to the irregular building shape chosen, which is composed of straight components prefabricated in the factory, the building can adapt to a change in use over the years. As protection against the weather, the wooden lamellas that enclose the building from the outside are thermally pre-treated. They also extend over the roof surfaces and prevent the interior from heating up too much in summer.

Fig.41: Pavilion of the Écomusée de la Grande Lande, Bruno Mader, France, 2008

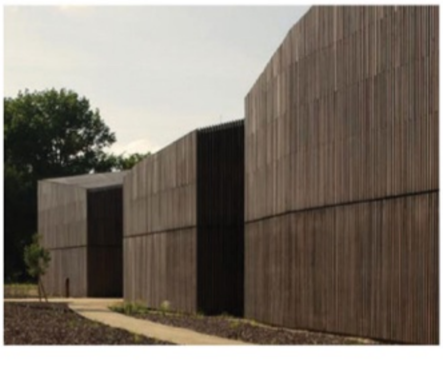


Fig.42: (left) Facade detail, Pavilion of the Écomusée de la Grande Lande, Bruno Mader, France, 2008

Fig.43: (right) Showroom, Pavilion of the Écomusée de la Grande Lande, Bruno Mader, France, 2008

2.2.3 Kap Skil

Architecture Office: Mecanoo
Construction Site: Oudeschild, Netherlands
Construction Year: 2010

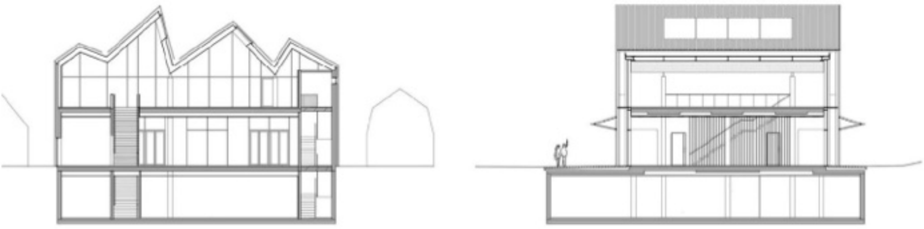


Fig.44: Longitudinal and cross section, Kap Skil, Macanoo, Netherlands, 2010

The Kaap Skil Museum is located on the West Frisian Island of Texel, which has been important for shipping since the 17th century due to its roadstead. The museum design is based on the building structures of the time and uses recycled hardwood planks on the façade, like the driftwood façades of the past. Behind the slatted façade are generous glass fronts and skylights that provide a view of the sky. The structures of the façade fall into the interior as long, narrow shadows, creating an interesting play of light.

The gable surfaces with different inclinations rest on a steel roof truss, which in turn rests on steel supports that are embedded in the reinforced concrete of the floor slab. The architecture fascinates with the interplay of light and dark, open, and closed spaces and the sensible use of natural and artificial light.

Fig.45: (left) Position in the local structures, Kap Skil, Mecanoo, Netherlands, 2010

Fig.46: (left) Showroom, Kap Skil, Mecanoo, Netherlands, 2010

Fig.47: (right) Detail of the foldable wooden facade, Kap Skil, Mecanoo, Netherlands, 2010

2.3 White Cube vs. alternative museum concepts

In the middle of the early 20th century, with the increasing abstraction of modern art, the so-called “white cube” established itself as a new form of exhibition space. The main driving forces behind the developments at that time were the De Stijl and Bauhaus artist groups, who wanted to present their works in front of white walls to minimise distraction from the surroundings. Yet, as O`Doherty explains in his series of articles “Inside the White Cube”, the White Cube did not develop by chance. With its gleaming white walls, the White Cube embodies the character that sacred temples used to convey, where sculptures once found their place. Thus, the white exhibition space, which is still popular today, is understood as a substitute for the former sacred space.

To this day, the exhibition concept of the White Cube has changed remarkably little. At first glance, it appears to be a seemingly neutral background for numerous exhibits. The supposedly characterless room quickly became an export hit in museums worldwide and embodied Western modernism there. Characteristics of the White Cube are windowless white rooms, a ceiling that illuminates the room through indirect lighting without dazzling and a reduction of the furniture in the room to the minimum, so that the shadowless room appears clean and artificial. In the space, which is so strongly reduced by impressions, the sculptural effect of each exhibit is intensified and emphasised as a work of art.

Even with the emerging museum boom in the 1980s and the increasingly impressive architectural languages of the outer shell of museums, surprisingly little developed inside the museum. The more expressive spaces were increasingly used for the museums' growing culture of experience. Thus, the exhibition rooms continued to be dominated by white walls, while the restaurants, shops, and foyers of the museums, in addition to the expressive exterior, became the design flagship of each museum.

Only very tentatively does Abu Dhabi break out of the concept of the "White Cube". The silver dome surrounded by water skilfully envelops the white exhibition cubes below. Thanks to a payment of 950 million euros, the Louvre Abu Dhabi Museum is allowed to call itself the Louvre Abu Dhabi and, with the brand name, has also bought the loan right to part of the collection. An exhibition area of just under 9,200m2 seems like a lot at first glance, but not when you consider the enormous total area of 64,000m2 . Since the focus of the museum is now moving away from the exhibitions and more and more emphasis is being placed on the consumption and recreation areas, the white exhibition boxes only differ from the white cube conventions by their coloured interior walls.

The chosen colours of brown, grey and blue, and the light coming in from above, nevertheless create the same aura as is usual for a white cube. By adhering to certain standards, including the exhibition concept of the White Cube, museums are trying to establish themselves on an international level.

Fig.48: (left) Louvre Abu Dhabi, Abu Dhabi, Jean Nouvel, 2017

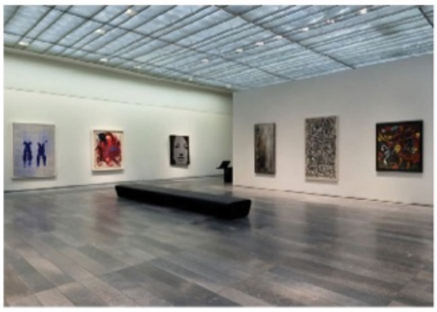


Fig.49: (right) Showroom Louvre Abu Dhabi, Jean Nouvel, 2017

Fig.50: (right) Showroom, Zeitz Mueum

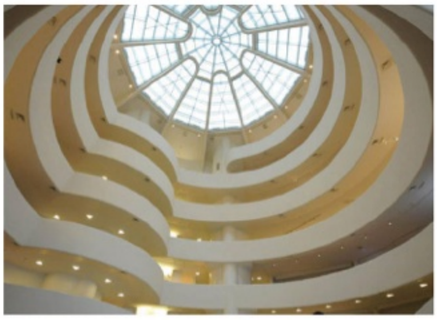


Fig.51: (right) Guggenheim Museum - New York - Atrium with domed light

Fig.52: (left) Atrium - Zeitz Museum

Opened in 2017, the Zeitz Museum of Contemporary Art Africa, in Cape Town, has African art as its exhibition focus, making a statement to promote the local artists. The tall concrete tubes inside the building hint at its former use as a grain silo. The tubes were cut into an elliptical shape by the Heatherwick Studio in London, creating an impressive atrium. Today, part of them serves as an elevator shaft, but there is also space for spiral staircases in the tubes.

In the Zeitz Museum, too, the focus is on the experience economy and not on the exhibition rooms. Of the nine floors that have been newly built, only four are used for exhibitions; on the other five floors there are restaurants, a library, reading rooms and several shops. There is also a sculpture garden on the roof of the building and a luxury hotel on the top floor, which means that visitors do not even have to leave the museum at night.

But even in the Zeitz Museum, the characteristics of the external appearance of the museum and the atrium are not continued in the exhibition rooms. The walls are white and there are no references to the outside space, let alone to the building's former use as a grain silo. According to founder Jochen Zeitz, the white cube exhibition concept is intended to comply with international conservation standards. According to Peter Schneemann, the main aim is to meet the modern ideal of an exhibition space that is as flexible as possible and to be able to present each work of art interchangeably at any time.

For O'Doherty, the way out of the white cube was to abolish the boundaries between art space and the outside world. With the advent of modernism, more and more architects dared to make a certain attack on the White Cube. This was always done with great caution, however, because if architecture interfered too much with the exhibition space, it would compete with art. This problem is illustrated by Frank Lloyd Wright's Guggenheim Museum in New York. The visitor moves through the building along a ramp that spirals around an atrium. The succession of artworks and the walk along the predefined spiral path create the false impression of a development in the progress of art.

According to Christian Teckert, the ideology of the exhibition and its changeability should ideally be a constant theme. Together with the architecture collective as-if-berlin-wien, he was able to realise this ideal in a new building for the Gallery for Contemporary Art in Leibzig, also known as GfZK-2. Opened in 2004, the one-storey irregularly shaped building rests on a recessed plinth embedded in the surrounding park. The rooms of the 1,000m2 seem to penetrate each other and are intersected. This creates interesting spatial situations through the interplay of windows, sliding walls and the overlapping of inside and outside. Due to the high flexibility, the rooms can be used multifunctionally, so that an exhibition room can be used as a shop, but also as a video room. The hierarchy between exhibition and consumption space is renegotiated. It remains questionable whether such a potential will be used, but the claim to eternity and the isolation of the exhibition space is updated by the new form of flexibility.

The question of the ideal museum presentation space cannot be answered conclusively. The ideals of Western modernism still play a major role in the ideology of the exhibition space, which means that the dominance of the white cube can hardly be weakened in the future. Especially for very large museums with high visitor numbers and representative status, the white cube has always proven itself with slight modifications. Because of this, there is still little effort to develop true innovations in exhibition design. This development is additionally reinforced by the stronger experience orientation of today's museums, as a result of which the space for art exhibitions continues to shrink.

Fig.53: (left) GfZK-2, Leibzig, Architecture Groupe AS-IF, 2004

Fig.54: (right) Showroom, GfZK-2, Leibzig, Architecture Groupe AS-IF, 2004

2.4 Lighting concepts based on exemplary museums

Natural lighting is an essential design factor for the museum building type. Depending on the planning, the incidence of light has an impact on the effect and perception of the room and the exhibits displayed in it. However, the lighting concept not only plays a major role in the perfect illumination of the works of art, but also in the orientation of visitors in the museum.

When working out a suitable lighting concept in the design, however, some decisive variables must be considered. Depending on the material of the exhibits, no natural light may fall into the room, or only diffused light and never direct sunlight. The visitor must be able to move freely in the room without being in the light and the exhibits should be well lit from different angles. Especially in museums, it is often a challenge to work with natural daylight; due to the sensitivity of some exhibits, special attention must be paid to defined limit values. Daylight is nevertheless highly desirable, as the colour rendition of an object remains unsurpassed in daylight. To ensure a fluctuation- free illumination of the room, daylight openings and artificial light are usually ingeniously combined.

In the following, some exposure strategies of well-known museums are shown and explained as examples.

2.4.1 Kimbell Art Museum

Architect: Louis I. Kahn
Construction Site: Fort Worth, Texas
Construction Year: 1972

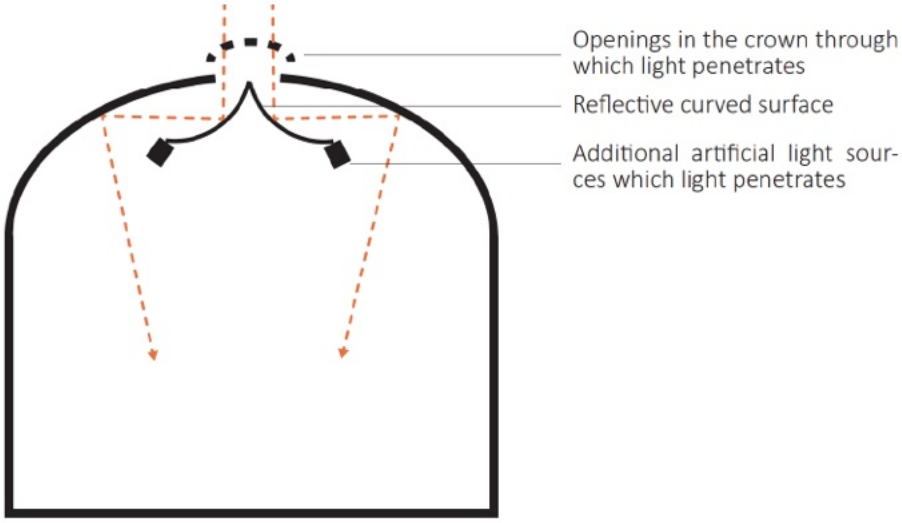


Fig.55: Exposure concept - Kimbell Art Museum, Louis I. Kahn, Texas, 1972

Louis Kahn received the commission for the Kimbell Art Museum in 1966 and immediately began with the first designs, whereby it was clear to him from the beginning that the building should be built in a longitudinal structure. He divided the building into elementary units that strongly characterise the structure of the building. The construction can already be seen on the exterior façade, where the barrel vault is also visible on the outside.

Thanks to the barrel vaults, each of which rests on four supports, it was possible to achieve a high degree of flexibility in the interior. At the apex of each barrel there is a slit-shaped opening through which sunlight can enter. On the inside, directly below the opening, there is a curved perforated steel sheet that reflects the light and illuminates the room.

Fig.56: Showroom Kimbell Art Museum, Louis I. Kahn, Texas, 1972

Fig.57: (left) Illuminated barrel vault Kimbell Art Museum, Louis I. Kahn, Texas, 1972

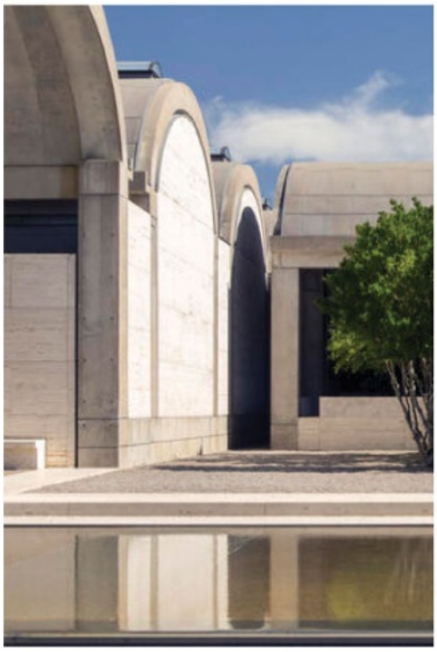


Fig.58: (right) Exterior view Kimbell Art Museum, Louis I. Kahn, Texas, 1972

2.4.2 Menil Art Collection

Architect: Renzo Piano
Construction Site: Houston, Texas
Construction Year: 1987

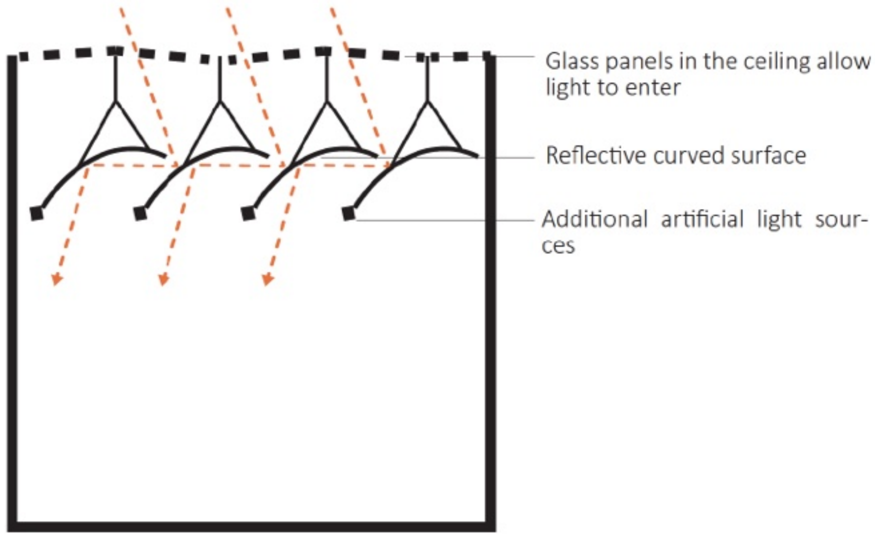


Fig.59: Exposure concept - Menil Art Collection, Renzo Piano, Texas, 1987

When the art collector Dominique de Menil planned the new building in the small park, she not only envisaged a house of art, but also a centre for music, theatre, and art education. Her demands were high, because she wanted a building free of any stylistic borrowings and at the same time it should be openly designed. The most important thing for her, however, was that the exhibited works should shine in natural light. The architect Renzo Piano therefore focused his attention on precisely this aspect. His idea was a roof made of thin ferro-cement, which was laid like "leaves" over the interior spaces as well as continuously over the exterior spaces, and to which artificial spotlights could easily be attached.

Fig.60: Main Entrance, Menil Art Collection, Renzo Piano, Texas, 1987

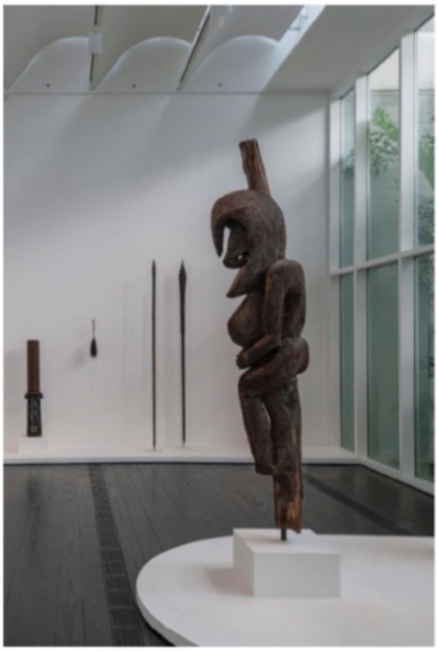


Fig.61: (left) Showroom Menil Art Collection, Renzo Piano, Texas, 1987

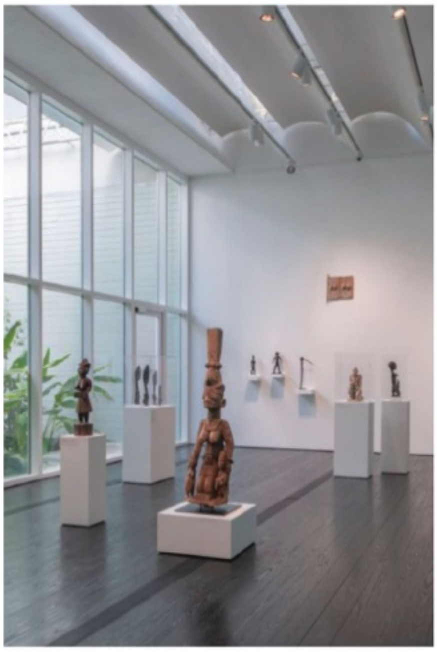


Fig.62: (right) Showroom Menil Art Collection, Renzo Piano, Texas, 1987

2.4.3 Folkwang Museum

Architect: David Chipperfield
Construction Site: Essen, Germany
Construction Year: 2010

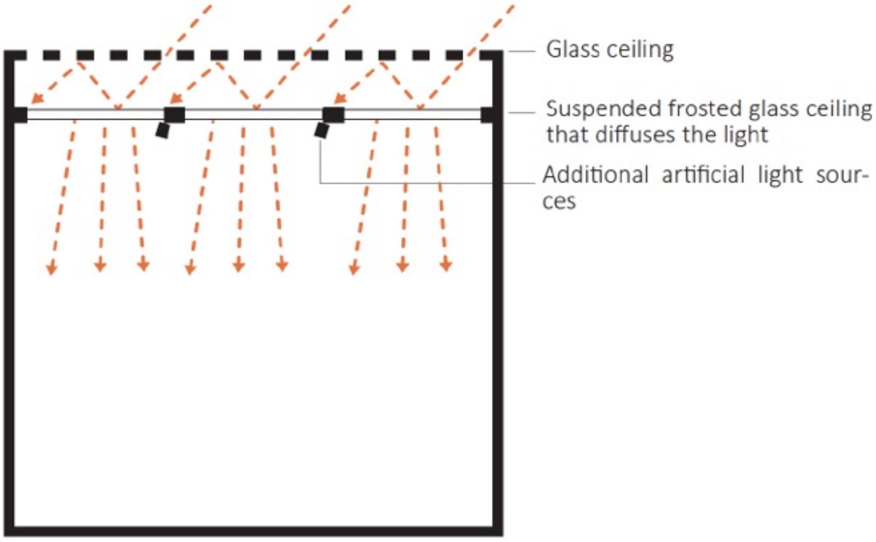


Fig.63: Exposure concept - Folkwang Museum, David Chipperfield, Germany, 2010

Based on the structures of the previous north wing, the new building with its green inner courtyards will open in 2010. A generous flight of steps leads to the entrance, which is raised from street level. A total of six cubes arranged around several inner courtyards provide space for numerous works of art. A shimmering green, translucent glass ceramic skin decorates the façade. In the interior, increased emphasis was placed on the distribution of light. The rooms are simple white cubes, which in nine out of ten rooms are supplied with daylight through roof lanterns of different sizes, glazed on five sides. A double-covered membrane construction in a metal frame ensures a glare-free light supply to the interior rooms. In addition, there is artificial lighting in the space between the ceilings to compensate for fluctuations in lighting.

Fig.64 Streetview Folkwang Museum, David Chipperfield, Germany, 2010

Fig.65: (left) Showroom Folkwang Museum, David Chipperfield, Germany, 2010

Fig.66: (right) Courtyard Folkwang Museum, David Chipperfield, Germany, 2010

2.4.4 Dia Art Foundation

Architect: Open Office Arts + architecture collaborativ
Construction Site: Beacon, New York
Construction Year: 2011

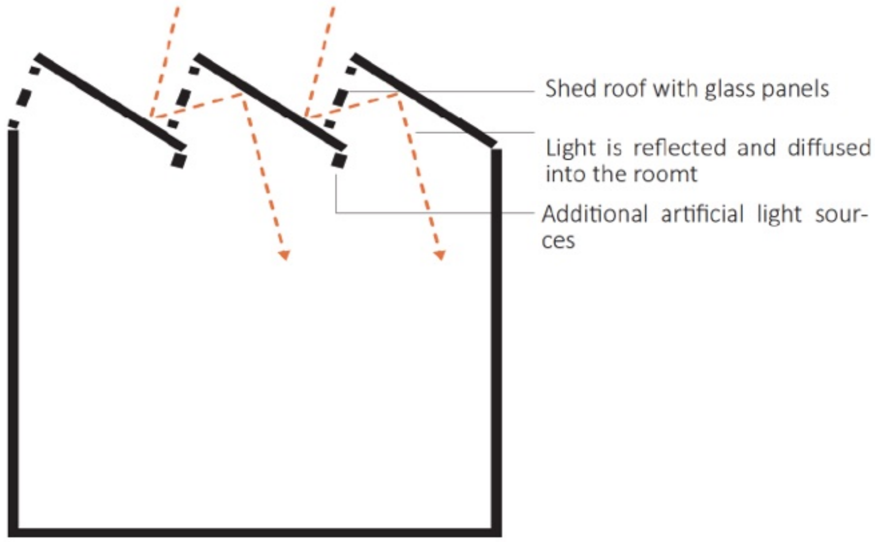


Fig.67: Exposure concept - Dia Art Foundation, Open Office Arts, New York, 2011

The building of a former biscuit packaging factory was converted by the newly founded New York architecture firm OpenOffice. The existing space was gutted down to the supporting structure and targeted openings were inserted, always in coordination with the planned exhibits and the curator. New walls were created, which do not disturb the overall impression of the hall, however, as they were only pulled up to just below the ceiling structure. The existing shed roof was cleared of unnecessary installations to optimally direct the incident northern light into the interior. However, the favourable lighting conditions of the building were already predetermined, as the shed roof already existed when the building was used as a factory.

Fig.68: Showroom Dia Art Foundation, Open Office Arts, New York, 2011

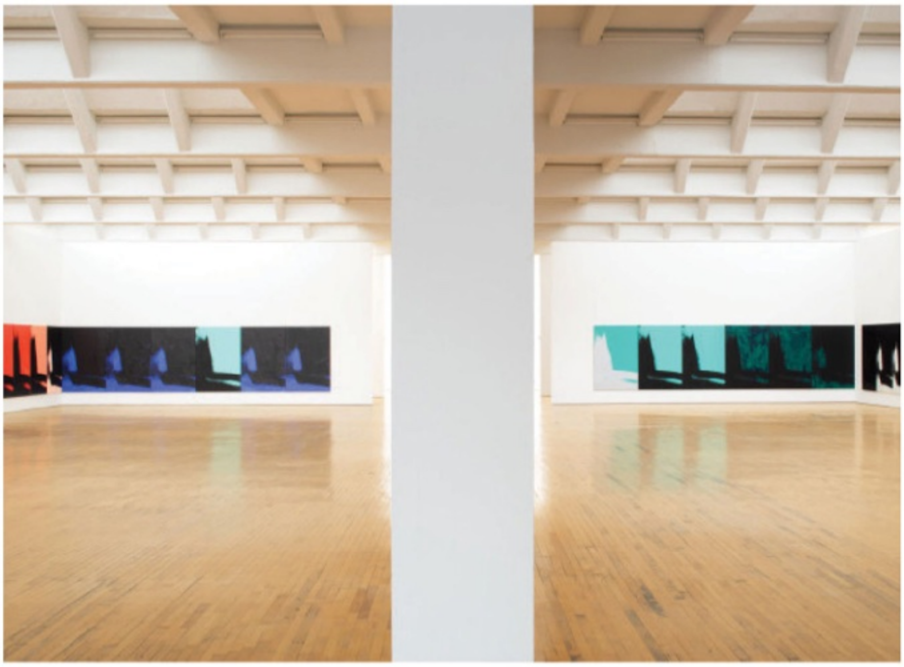


Fig.69: Andy Warhol exhibition: Shadows, Dia Art Foundation, Open Office Arts, New York, 2011

Fig.70: Exhibition by Charlotte Posenenske - Work in Progress, Dia Art Foundation, Open Office Arts, New York, 2011

3

ART OF THE 20TH AND 21ST C.

3.1 Development of art in the 20th and 21st centuries

Until the end of the 19th century, works of sculpture were strongly bound to iconographic models, which in turn were decisive for the time or narrative period depicted. With the development processes of sculpture that began in the 20th century, a detachment from iconographic foundations was achieved. Until then, the human body had always been the central focus of 19th century sculptural art.

At the beginning of the 20th century, the rise of abstract and non- objective sculpture brought about a change in art. With the advent of industrialisation, new materials and production possibilities emerged for artists. Above all, Marcel Duchamp's ready-mades, in which he presented everyday or natural objects in a new context, are described by the art critic Thierry de Duve as a transition from painting to sculpture. Art finally freed itself from the topos of the fixed statue using moving components, as can already be seen in Marcel Duchamps' Rotoreliefs. When the art movement stagnated in the 1960s, it was the minimalists, above all Donald Judd, who created art that was neither painting nor sculpture with his "specific objects".

In the 20th century, art, as well as sculpture, was much freer and explored its limits to overcome them. This led to new forms of outdoor art, which is called Land Art. The art historian Rosalind Krauss divides Land Art into three categories: marked places, place constructions and axiomatic structures. Through this subdivision, new terms were also found in the interior, so that there were now classifications in categories such as living sculptures, body art and performance art. With increasing technological progress, art was increasingly influenced by film and video photography and multimedia installations quickly developed.

In the 21st century, contemporary art can hardly be assigned to a specific medium. There is an increasing overlapping of different disciplines, such as architecture and sculpture, but also theatre, nature, painting, photography, film, and graphics.

The art movement is increasingly moving in a direction in which artists take a critical standpoint that is reflected in their works of art. The viewer is forced into the role of the recipient and encouraged to rethink.

Fig.71: (left) "Specific Object", Donald Judd

Fig.72: (right) "Fountain"," Bicycle Wheel" and "Bottle holder" from Duchampes

3.2 Representatives of the art of the 20th & 21st centuries

3.2.1 Alfred Hrdlicka

Birthplace: Vienna - Austria
Birthyear: 1928

Alfred Hrdlicka studied at the Academy of Fine Arts in Vienna from 1946 to 1952 under Albert Paris Gütersiohn and Josef Dobrwsky. Later, in 1953, he studied sculpture with Fritz Wotruba at the Academy. He consciously resisted all kinds of contemporary trends and completely rejected passing fashions. He saw himself as an "Old Master of Classicism" and consistently represented his own independent position. Hrdlicka always made a political statement with his works; his themes ranged from war to violence to fascism.

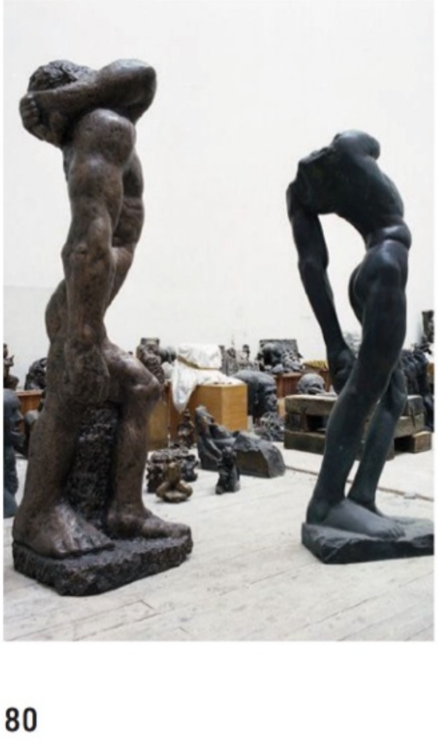


Fig.73: (right) Street washing jew, 1984

Fig.74: (right) Stage Design from Faust II., 1982

Fig.75: (left) Hrdlicka studio, 2008

3.2.2 Franz West

Birthplace: Vienna - Austria
Birthyear: 1947

West studied at the Academy of Fine Arts in Vienna with Bruno Gironcoli. Early on, he began to work with "passport pieces". These were free, transportable abstract forms made of plaster, but also of other materials such as papier-mâché or metal. He tried to visualise neuroses with his sculptures. For him, art was a means of communication and interaction. Later, he also created seating furniture of all kinds, some of which was highly alienated or ironic.

Fig.76: (left) Generally, 2007, Munich

Fig.77: (left) "Lemurenköpfe" , 1992, Studio

Fig.78: (right) "Room in Vienna", 2010, Vienna

3.2.3 Ulrike Truger

Birthplace: Styria - Austria
Birthyear: 1948

Ulrike Truger graduated in sculpture from the University of Applied Arts in 1975. A certain love, or even attachment, to stones became apparent early on. For her, stones are a gift of nature from the feminine abundance of the earth. Ulrike Truger says of herself: "I think in stone. For her, thinking and acting have always been inseparable. She is also known beyond Austria's borders for her monumental works and advocates with great vehemence for her works and the contextualisation and placement of these in public space.

Fig.80: (right) "Sich erheben"

Fig.81: (right) "Liegen und Aufbruch"

Fig.79: (left) "Der große Schritt"

3.2.4 Erwin Wurm

Birthplace: Styria - Austria
Birthyear: 1954

Erwin Wurm studied at the University of Applied Arts and at the Academy of Fine Arts. For several decades he has been working on multi-layered works that can be described as sculpture or sculpture in the extended conception. He became known to the public through his "One Minute Sculptures". Wurm photographed the encounter of people and everyday objects in rapid situations. Especially his house standing on the roof, which he placed on the MUMOK in Vienna, caused a great stir. He is known for his bizarre humour.

Fig.82: (left) "House Attack", MUMOK Vienna

Fig.83: (left) "one-minute-sculpture"

Fig.84: (right) "Big Mutter", 2020, Vienna

3.2.5 Brigitte Kowanz

Birthplace: Vienna - Austria
Birthyear: 1957

Brigitte Kowanz studied at the University of Applied Arts. Since the 1980s, Kowanz has been primarily concerned with space and light. In the beginning she used paper and canvas with fluorescent pigments as a medium, later she developed light objects made of bottles, fluorescent lamps, and fluorescent colours. In her more recent works, she used glass and mirrors, which resulted in a variety of superimpositions. Hybrid spaces of light, language and mirrors often emerged, whose boundaries seem clearly defined one moment and completely blurred the next.

Fig.85:(right) Lichtkreise , 2011, Vienna

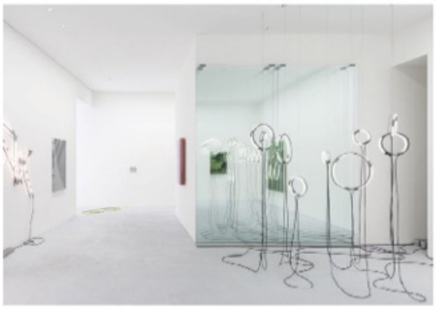


Fig.86: (right) Installation view, 2021

Fig.87: (left) Museum Liaunig, 2007

3.2.6 Geletin

Founding Place: Vienna - Austria
Founding Year: 1978

The four Viennese artists Wolfgang Gantner, Ali Janka, Florian Reither and Tobias Urban met as children at a holiday camp in 1978 and have allegedly been working together ever since. Their works are characterised by humour and are mostly physical and intimate. They often test the limits of what is reasonable for the viewer and often try to overcome them. In many of their works, the audience is actively involved and so, in addition to spectacular installations, the artists often create live performances with the audience. They have been artistically active internationally since 1993.

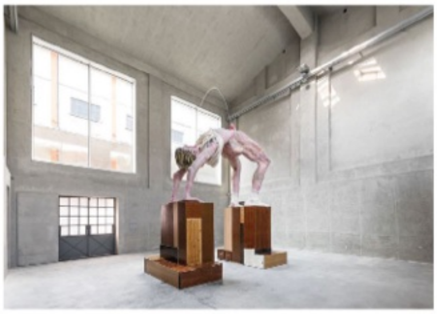


Fig.88: (left) "Arc de Triomphe", 2003


Fig.89: (left) "Vorm-Fellow-Attitude", 2018


Fig.90: (right) "Human Elevator", 2016, Vienna

3.2.7 Yayoi Kusama

Birthplace: Japan
Birthyear: 1929

Kusama grew up under strict parents in Japan, and her mental illness became apparent at an early age. She had strong hallucinations in which she saw dot and net patterns and feared dissolving into them. Her hallucinations were the inspiration for her art. She often integrates whole rooms and people into her artworks. In her later works, she continues to deal with her entire oeuvre, but through room installations with points of light and mirrors, where fascinating room effects were created, which amazed visitors all over the world.

Fig.91: (right) "Infinity Mirrored Room", 2017

Fig.92: (right) "Invisible Life", 2019

Fig.93: (left) "Traveling Life", 2016

3.2.8 Ólafur Elíasson

Birthplace: Coppenhagen - Denmark
Birthyear: 1967

Elíasson studied at the Royal Danish Academy of Fine Arts in Copenhagen. In his earliest works, he worked with fans hanging from the ceiling, which first attracted attention at the Berlin Biennale in 1998. His works were diverse and not limited to one medium. In the Tate Modern Museum in London, he installed an artificial sun, which became a visitor magnet. In Vienna, he is best known for his "yellow fog" light- fog installation, which created a fascinating atmosphere every evening at the Vienna "Am Hof".

Fig.94: (left) Exhibition "Life", 2021

Fig.95: (left) "Yellow Fog", Vienna, 2008

Fig.96: (right) "The weather project", 2003

3.3 Demands of art on the exhibition space

Based on the selected artists and the works of art shown, as well as the spatial installations, it is easy to see that nowadays there are no longer any limits to art. Where there may have been technical barriers in the past and the materials of the time did not allow for certain ideas, today's progress makes almost anything conceivable.

However, this also poses new challenges for architects and museums. Nowadays, exhibition spaces need to be more flexible and adaptable than ever before. Whereas in the past sculptures and sculptures found their representation surface in front of white walls, nowadays entire rooms are often used as a blank canvas for works of art. This happens with an extreme variance in the demands on the space. For one exhibition, the rooms need to be completely dark and full of mirrors and elaborate light installations, whereas for the next presentation they have to be flooded with light and airy.

The best example of the extreme demands on the changeability of exhibition spaces can currently be seen at the Foundation Beyeler, where Ólafur Elíasson includes the entire building as well as parts of the outdoor space in his installation "Life". The rose pond in front of the building was raised by ten centimetres, flooding the exhibition spaces. The result was a flowing transition between inside and outside. Via a wooden walkway that winds through all the rooms, starting at the lawn in front of the building, one moves through the rooms flooded with green still water. The water lilies, which were previously only to be found in the pond in front of the building, spread throughout the entire building during the exhibition. A small wilderness is created between the lawns in the park and the white walls in the museum.

Fig.97: Installation "Life" at the Foundation Beyerle by day

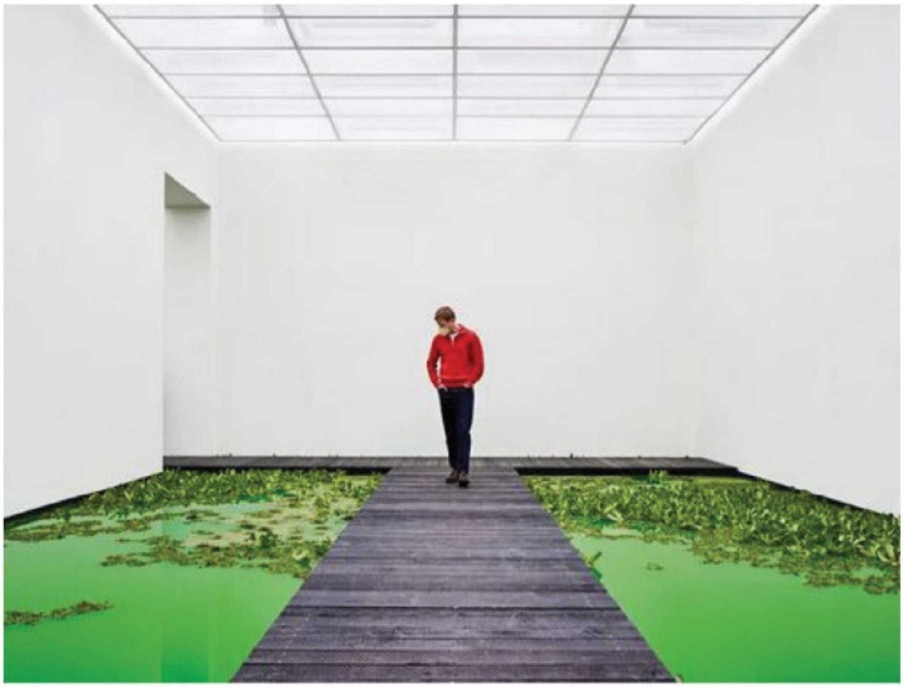


Fig.98: Installation "Life" at the Foundation Beyerle by night

4

ECOLOPES

4.1 Ecological building envelopes

As can be deduced from the name ECOLOPES (Ecological + Envelope), the research area is concerned with the development of ecological building envelopes.

Steady urbanization has become one of the biggest environmental problems of the increasing densification of cities and the associated reduction in green spaces has led to an increased separation of people from nature. The restricted access to ecosystems not only reduces the quality of life in cities, but also the well-being of people. ECOLOPES dares to propose a radical change in urban development. The aim is to develop an architecture that provides living space for humans as well as for other species such as plants, animals, and microbes. In the coming years, ECOLOPES will develop and provide the necessary technology to help realize this vision.

ECOLOPES will also make biological knowledge available for the architectural design process to find architectural solutions that enable synergies and minimize conflicts between the inhabitants. The resulting ecological building envelopes will restore the beneficial human-nature relationship in cities.

4.2 Main goals and components

The ECOLOPES project presents a new radical approach to architecture, the aim of which is to integrate a functioning ecosystem into architecture. Nature should have the opportunity to develop parallel to the city to promote biodiversity. In addition, there are positive effects for human health. Primary focus is placed on the building envelope, regardless of whether it is a new or existing building. The outermost layer of a building is attributed several tasks, it not only has to fulfil the constructional tasks, but should also provide living space for several species. The species can be classified into four groups: humans, animals, plants, and microbes.

A prerequisite for the implementation of Ecolopes projects is a comprehensive computer-aided data framework in which not only expert knowledge is embedded, but also algorithmic processes and applications can be found that provide optimal support for the design task. Important for this is an Ecolopes information model that defines the relationship between the occupants, the architecture, and the environment. Based on numerous parameters and information, design proposals are then generated with the help of the calculation framework integrated in the programme, which in turn are validated by design cases in different urban environments.

Within an Ecolopes project, a variety of animals, plants and microbes can be housed. The resulting dynamics between plants and animals and their multiple interactions, as well as their relationship with the soil and the abiotic environment, can become a key element of building envelopes.

Coordinating the coexistence of multiple species in the building envelope requires a holistic, data-driven design process that is primarily influenced by ecological factors. Depending on the occupants of the ecolope, different framework conditions are needed. The regulation and maintenance of these vital framework conditions is essential for the success of an Ecolopes project. Key Performance Indicators (KPIs) derived from expert knowledge are assigned to each resident to assess the impact of the Ecolopes on the KPIs and vice versa. To understand the trade-offs and hierarchies of the KPIs on the design of the Ecolope building envelope, multi-criteria decision-making strategies are employed. In different evaluation processes, selected criteria are assigned a certain weighting to find targeted solutions for dissbalance within the system.

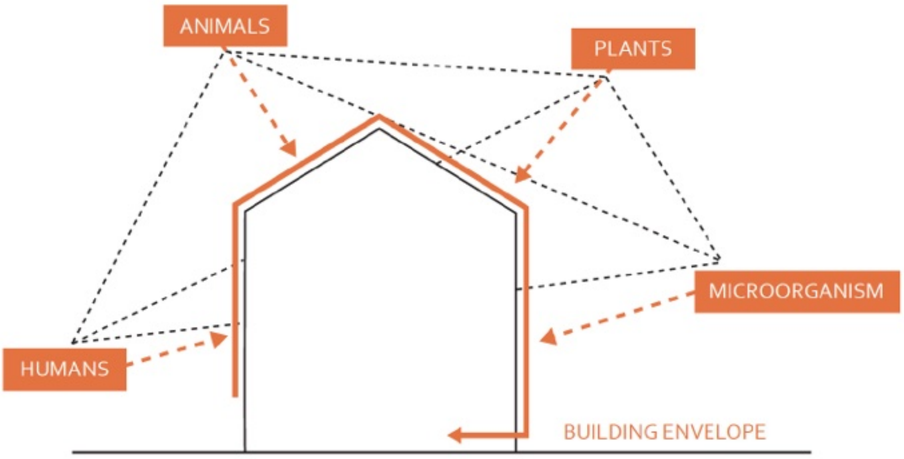


Fig.99: Multispecies approach and their interactions

4.3 Ecolopes-Tools

The front-end tools are part of the Ecolopes design platform and provide architects and planners with all the necessary Ecolopes information material in a clear and concise manner. Embedded in existing CAD programmes, the tool offers optimal support for decision- making and the systemic coordination of planning measures. To promote collaboration between multiple disciplines in the design process, the ECOLOPES web tools will be accessible via a standard web browser without the need for prior knowledge of CAD software. The tools consist of various algorithms compiled from Grasshopper components to allow users to analyse, evaluate and optimise their 3D models based on the developed ECOLOPES approach.

The Ecolopes Information Model (EIM), defines the relationship between architecture, the abiotic environment and all inhabitants (soil, plants, animals, microbes and humans). The EIM ontology plays a central role in decision support. Through it, ecological and technical knowledge can be brought in at an early stage of the project. By linking to the expert database, volumetric and spatio-temporal data can be structured for retrieval. The models are collections of values assigned to a three-dimensional grid with precisely defined resolution. Various tools, in open-source GIS packages, are used to analyse geophysical features such as geomorphology, slope analysis, water runoff and others.

However, the current situation is that existing tools for terrain modelling are not sufficiently integrated and are not designed for the exchange of information. While there is potential for the integration of geo-analysis tools and parametric design processes, there is no certain interface that provides these options. A program needs to be developed that can enable a systemic exchange of data. In a second step, data and models on plant and animal ecology will be integrated.

The Ecolopes design platform will be tested and validated on selected design tasks. In addition, an urban classification method will be developed to systematically select design tasks and facilitate the comparison of the respective performance achieved by an Ecolopes project under different environmental and architectural conditions. The urban classification aims to identify areas with similar conditions in terms of biodiversity constraints or enhancements. The biodiversity enhancing factors are divided into three categories: the biophysical conditions (e.g., climate and topography), the socio-economic environment (e.g., the socio-economic level of the population and the socio-economic orientation of the block) and the built and natural environment of the city (e.g., land use and building height). To describe the built and natural environment, mostly thematic, coarse variables are used for simplification.

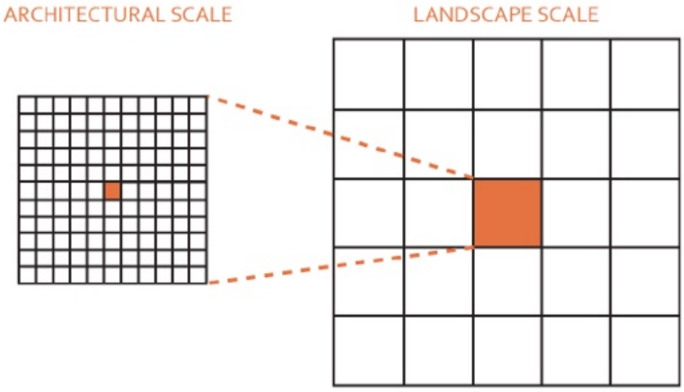


Fig.100: Scale for Landscape Analysis (100m) and Architecture Analysis (10m)

In the Ecolope's analysis procedure, the existing urban classification is examined more closely, and this is done at two different scales. The landscape is analysed at a resolution of one hundred metres, whereby the consideration of local architectural features is considered. The design is based on a ten-metre resolution, as the architectonic features have a great influence on the design elaboration.

The vision of Ecolope is to create a dynamic habitat for animals, plants, and micro-organisms, which leads to a regulation of environmental influences such as sunlight and water/humidity, to synergistically connect Ecolope's inhabitants and the well-being of the people.

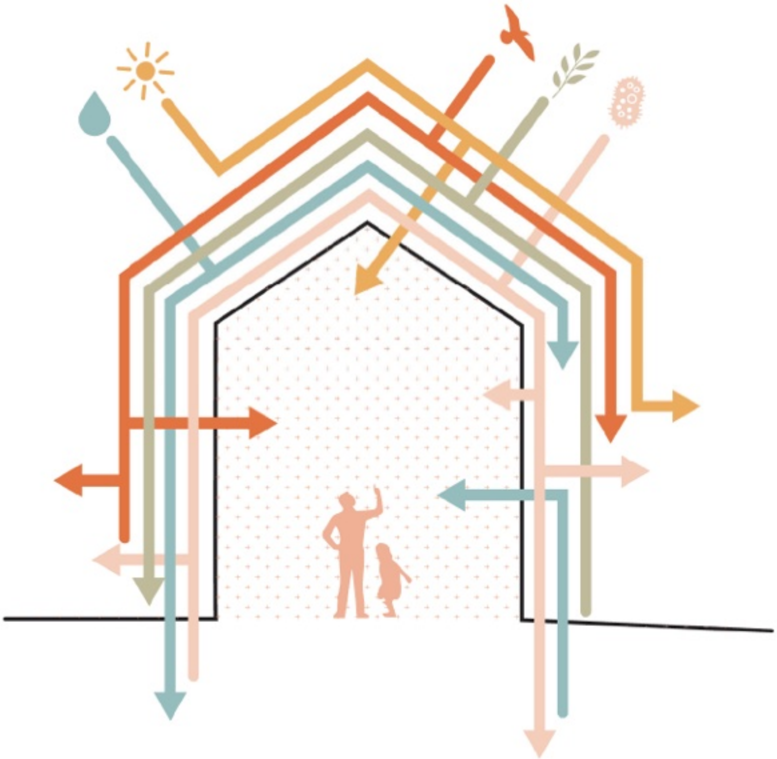


Fig.101: Synergistic interaction of all Ecolopes residents with the environment

5

THE DESIGN

5.1 Design Task

Due to the progressive global warming, the requirements and demands on architecture are increasing. Architects should not only create social qualities with their designs, but must also critically examine the consumption of resources, the ecological performance and longevity of buildings.

The required design goes beyond the classic requirements of architecture and, in addition to creating a living space for people, should also provide a habitat for animals, plants, and microbes. The primary focus of the design task is on the building envelope, which should provide a habitat for several species. The design potential that can be developed from the "Ecolopes" theme is being investigated.

As an architectural space program, a sculpture museum for contemporary art and art of the 20th century is to be developed. Since Vienna is an important center of the fine arts with outstanding artists and educational institutions, but there is hardly any institution with a focus on three-dimensional art. The numerous renowned Austrian artists (Erwin Wurm, Brigitte Kowanz and Gelitin, among others) are to be given a curated presentation, supplemented by contemporary and international art.

The sculpture garden, that is part of the design task, offers an extension of the curatorial exhibition possibilities. Objects that where designed, with the purpose to present themselves in the context of a natural environment, get a designated platform to do so.

5.2 The construction area

The recreation area Wienerberg, in the 10th district of Vienna, is characterized by a terraced landscape rising towards the north, which was created by the clay mining of the brick factory in the 19th century. Later, the area was used a long time for waste disposal85, which resulted in steep slopes, especially in the north-east and south-west, where hardly anything can grow. If you move south along one of the many paths, you quickly reach the 16-hectare pond, which has filled with groundwater after the brick factory was closed. In addition to the large pond, there are smaller water-filled ponds to the west and east of the Wienerberg pond. The flatter part in the south is characterized by agricultural fields and a dense tree population. To the east of the pond there is a building with pensioners' flats and a playground, as well as a cycle track for children. Above the playground are horse stables and a maintenance house of the Wienerberg. The Wienerberg forms a green gateway in the south of Vienna as a counterpart to the high-rise buildings of the Wienerberg City.

Fig.102: Othofoto recreation area Wienerberg 2020

5.3 Accessiblity

The Wienerberg recreation area is in the south of Vienna and can currently be reached by public transport with two tram lines. To the north, the nearest tram stops on line 1 is at Stefan-Fadinger-Platz. On Neilreichgasse, which runs east along the Wienerberg, there are three tram stops on line 11, which then has its turning point south of the Wienerberg at Otto-Probst Platz. From the respective stops, the perimeters of the recreation area can be reached in a few minutes on foot. The Triesterstraße, which runs parallel to the Wienerberg, and the two car parks to the north and south make the area easily accessible by car.

Fig.103: Nearest transport connections of the Wienerberg

Currently they are working on the extension of the U2 underground line, that has been going on for several years. The extension to Wienerberg should be completed by 2028 , which will make the Wienerberg recreation area accessible from the greater Vienna area in a short time.

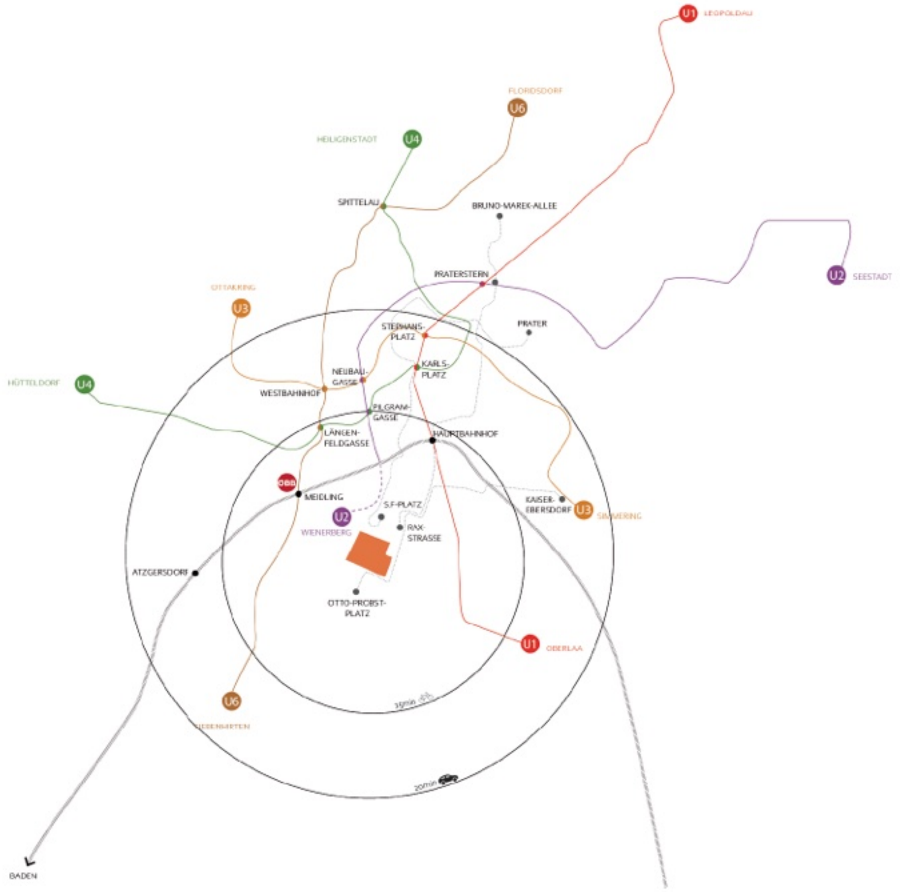


Fig.104: Large-scale transport accessibility of the Wienerberg

5.4 Diversity of nature on the Wienerberg

Shaped by the history of its development, a wide variety of areas with different characteristics have evolved on the Wienerberg.

Most of the recreation area is characterised by dense tree stands that extend over the entire area. A wide variety of trees can be found here, including acorns, maples, ash trees, plantains, and hornbeams. The large forest areas provide the ideal habitat for numerous birds and insects, but ground-dwelling animals such as mice, badgers, foxes, and hedgehogs also find enough space to live here. On the terraces of the northern slope, there are long stretches of tall grass, some of which is mown to make room for the meadows and the dog zone. It is above all the unmown wild meadows that provide the much- needed habitat for hares and voles, for example. The insect world also enjoys the abundant supply of wild flowers and their nectar.

A wide reed belt grows around the Wienerberg pond, where some birds build their nests above the water and fish and frogs lay their spawn in the water. The so-called reed zone is an important part of the ecosystem in the recreation area. In addition to the pond, there are two small ponds that are particularly popular with toads and terrapins. But water-loving insects such as dragonflies also like to lay their larvae here in the still, calm waters. On the dry steep slopes, which are in the north but also in the west of the pond, mainly amphibians enjoy extensive sunbathing.

The 123 hectares of the Wienerberg are home to a large diversity of natural areas that provide habitats for a wide variety of plants and animals.

Fig.105: Area mosaic of the different structures at Wienerberg

5.5 The chosen building site

The site chosen for the sculpture museum is located at the intersection of many different natural spaces. The Wienerberger Pond, a pond and an outflow from the pond to the smaller ponds to the north meet here in a relatively small area. In addition, the surrounding landscape offers a great deal of diversity. Dense forest areas, followed by sandy steep slopes with sparse vegetation, as well as parts of the reed belt lie directly next to each other.

This circumstance allows the building to be immersed in different natural spaces, where, with the development of an Ecolopes façade, a variety of plants, animals and microbes can profit from the added value through the developed architecture.

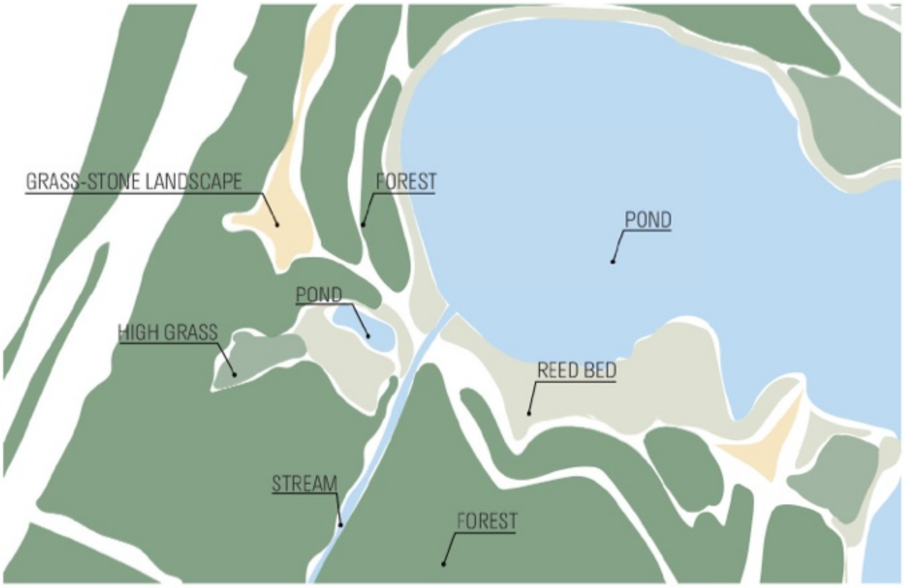


Fig.106: diverse vegetation at the construction site

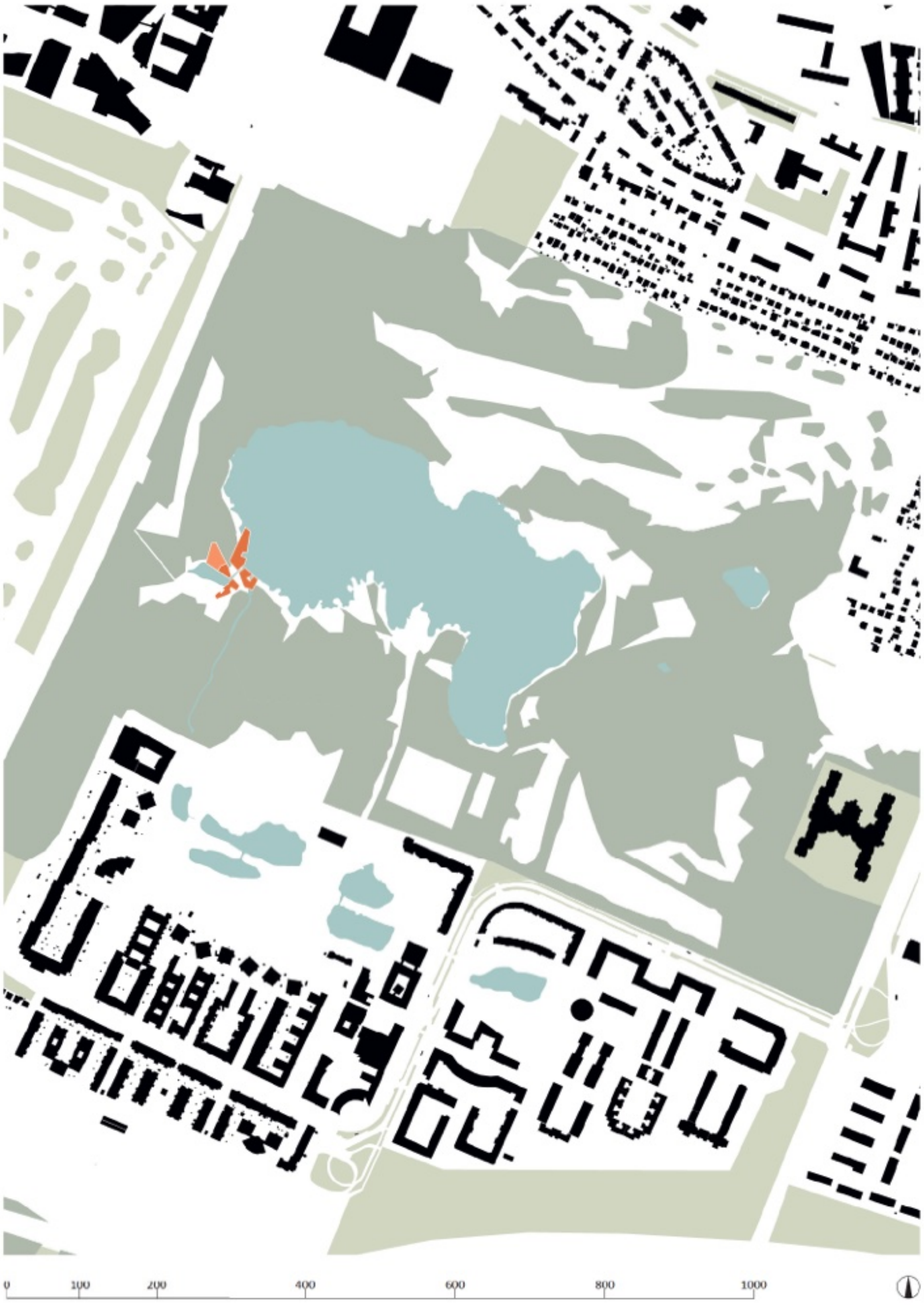


Fig.107: Site plan 1:10 000

5.6 Design concept

The natural structures of the chosen building site are formative for the design. These include the existing trees, the contours of the adjacent waterways and the pathways through the park. Shaped by the surroundings, there are four individual building parts that stretch out in all directions. In the middle between the volumes is the path. Some of the buildings protrude over the adjacent body of water. The opening of the centre leads to a deceleration of the visitor's walking movement and creates a place to linger. The greater distance between the buildings provides the interior spaces with a better supply of light and fresh air. The bevelling of the surrounding walls expands the space created between the buildings upwards and the focus is directed towards the sky. The view widens visually, integrating the nature behind the buildings into the design. Since the

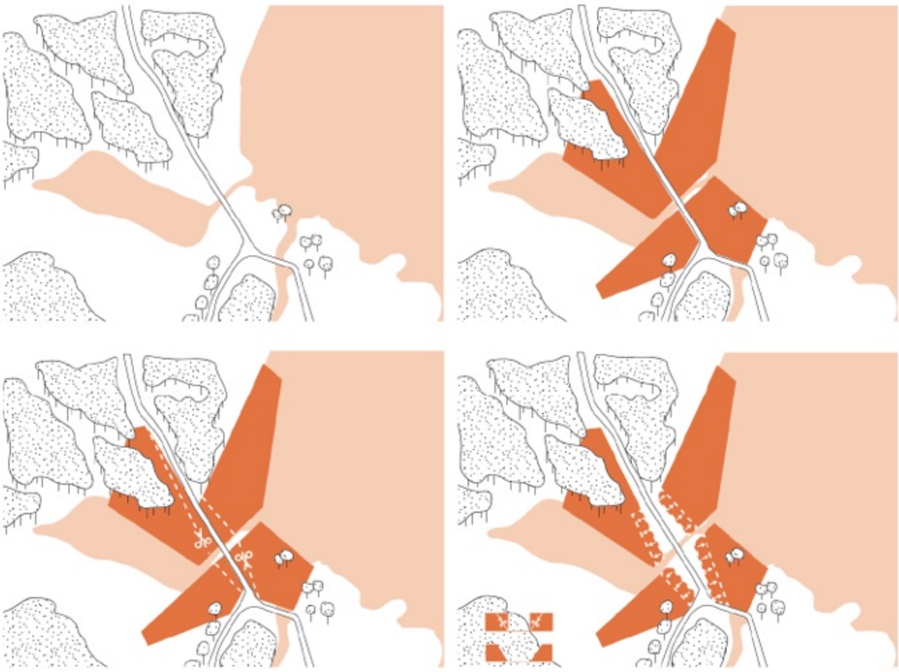


Fig.108: Concept diagrams

trees are to be preserved, there are a view differentiated cuts in the volume of the building. The building in the north-west is completely opened, due to the excessive tree stand. In addition to the big opening, two further cuts were made. The cuts open the building to the adjacent natural spaces and thus create a direct visual connection between the exhibition rooms and nature. Depending on the location, the space opens to the water, the reed belt, the forest or the paths laid out in the park. A sculpture garden expands the spatial programme and extends largely between the trees in the north-western part, but there are also open-air exhibition areas in front of the respective entrances to the buildings to stimulate the visitor's interest. To influence nature as little as possible, the building is elevated, leaving important connections below the platform undisturbed. The platforms visibly approach the ground to establish targeted connections.

Fig.109: Concept diagrams

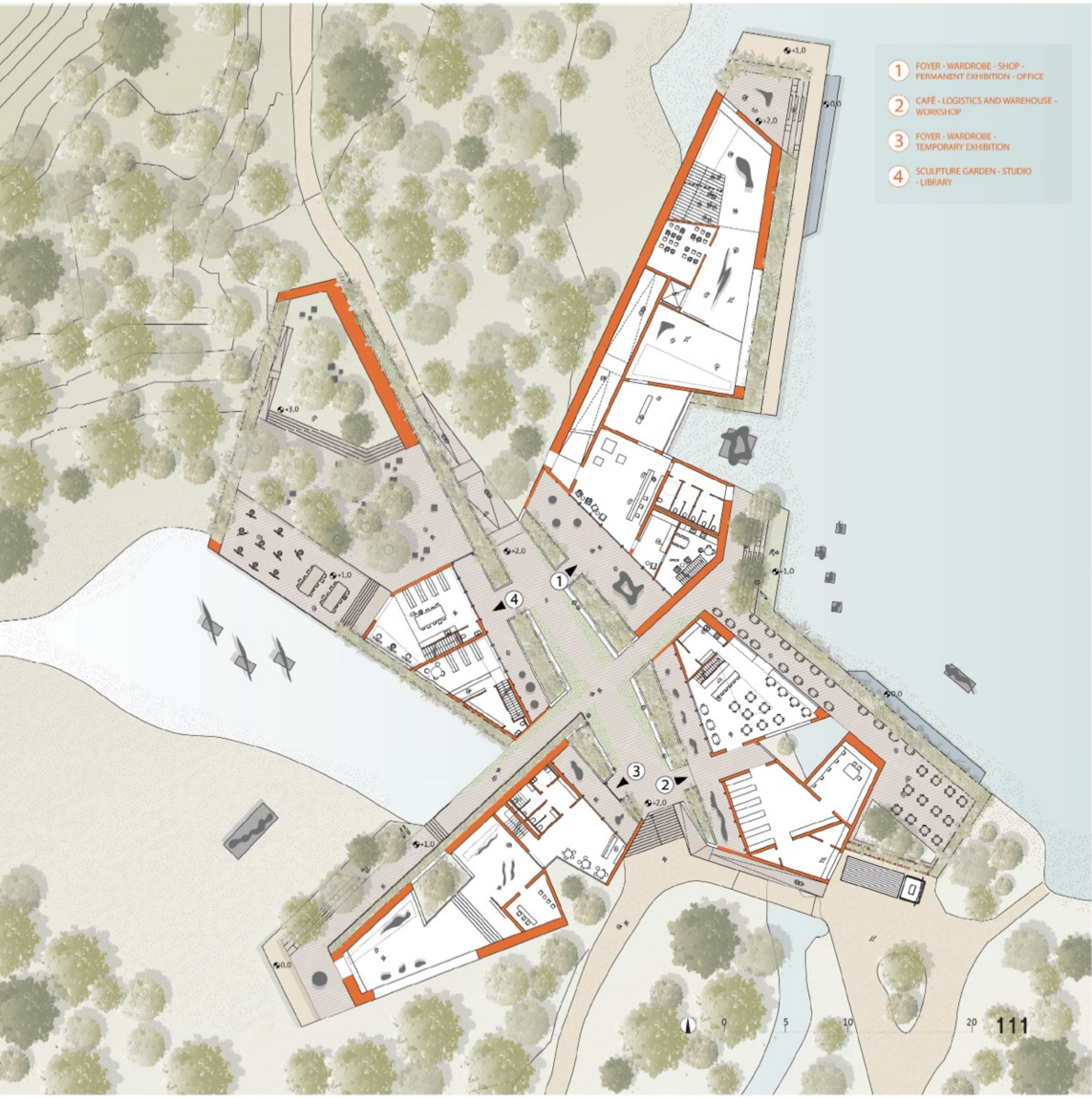
5.7 The Design

5.7.1 Ground floor plan

The floor plan is divided into four independent buildings that are connected to each other via a platform. Building number 1st houses the permanent exhibition, a foyer with museum shop, cloakroom, and toilets as well as an office. The exhibition rooms are accessed via a long ramp and extend over two floors. The open, high- ceilinged rooms offer a variety of curatorial possibilities. The large, glazed recess in the building connects the interior with the exterior and integrates nature into the spatial structure. Towards the north, the exhibition space extends outwards over a footbridge, across the water.

In addition to the delivery via the forecourt in the south-east, the warehouse, and the workshop as well as a spacious café are in the second building. A deliberately placed cut creates a spatial separation of the uses and creates a visual connection with the river flowing underneath the building. The café is extended by an elongated terrace, which is also elevated. Large glazed areas brighten up the interior and create a visual relationship with the natural space in front of the building.

Fig.110: Ground floor plan 1:500


① FOYER - WARDROBE - SHOP - PERMANENT EXHIBITION - OFFICE
② CAFÈ - LOGISTICS AND WAREHOUSE - WORKSHOP
③ FOYER - WARDROBE - TEMPORARY EXHIBITION
④ SCULPTURE GARDEN - STUDIO - LIBRARY
+1,0
0,0
+2,0
+3,0
+2,0
1
4
+1,0
+1,0
0,0
3
2
+2,0
+1,0
0,0
0
5
10
20

5.7.2 Upper floor plan

The 3rd building is used for temporary exhibitions, where a variety of exhibitions are presented at intervals of a few months. Since the building has its own foyer, cloakroom, toilets, and offices, it functions independently of the permanent exhibition building and can therefore be visited autonomously. In addition to the large exhibition space, which is divided by a cut and a one-metre level, there is also a smaller separate room that can be used by school groups for meetings or, for example, as a dark room for light installations.

Characterised by several existing trees that poke through the platform, the sculpture garden in the 4th building is integrated into the natural level of the site. Adjacent to the sculpture garden is a studio with a terrace facing the water. Art courses and workshops can be held here. Due to a difference in level between the terraces outside, museum visitors have visual contact with the artists but no direct access. Next to the studio is a two-storey library, which is connected to the outside space by generous glass fronts.

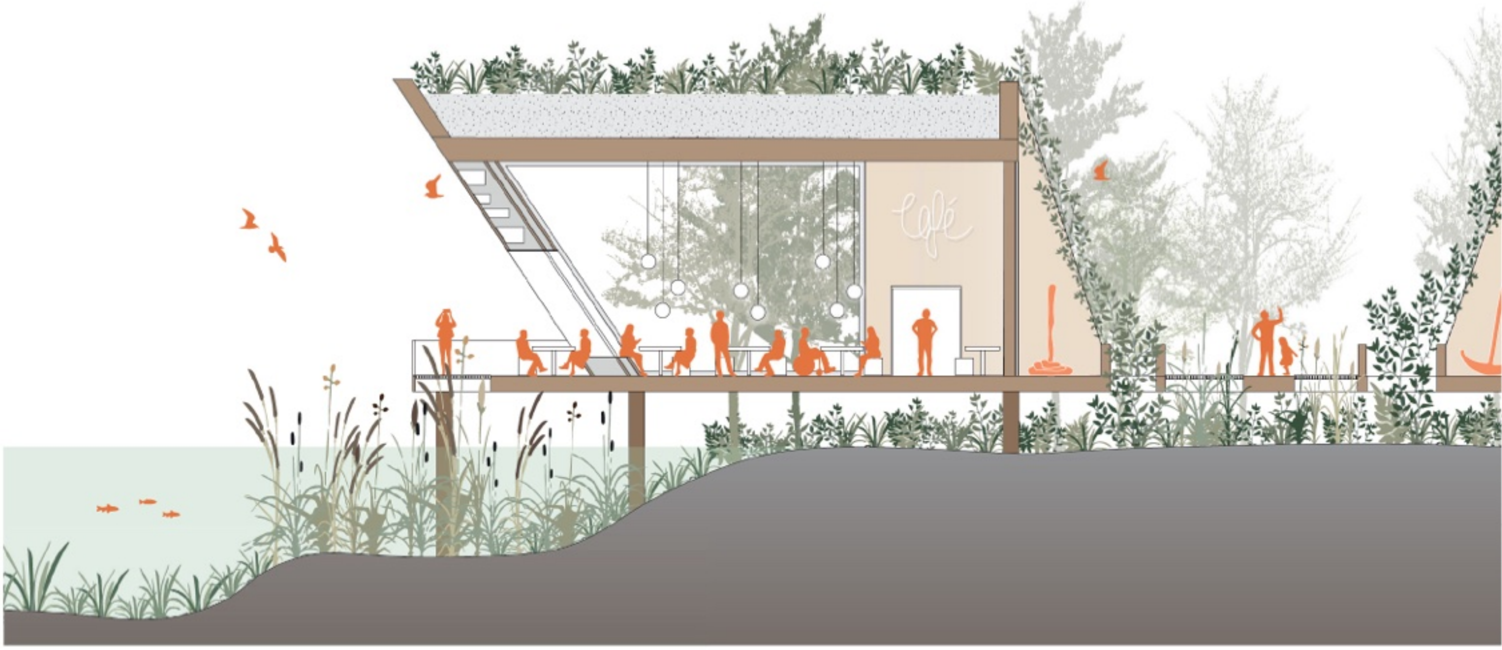
Fig.111: Upper floor plan 1:500


0
5
10
20

5.7.3 Section A-A

Through the exhibition space of the temporary exhibition, shows the one-metre-high jump of the floor-levels inside the buildings, that create a zoning of the exhibition rooms.
The glazed incision in the building naturally illuminates the space and connects the exhibition space with the outside.

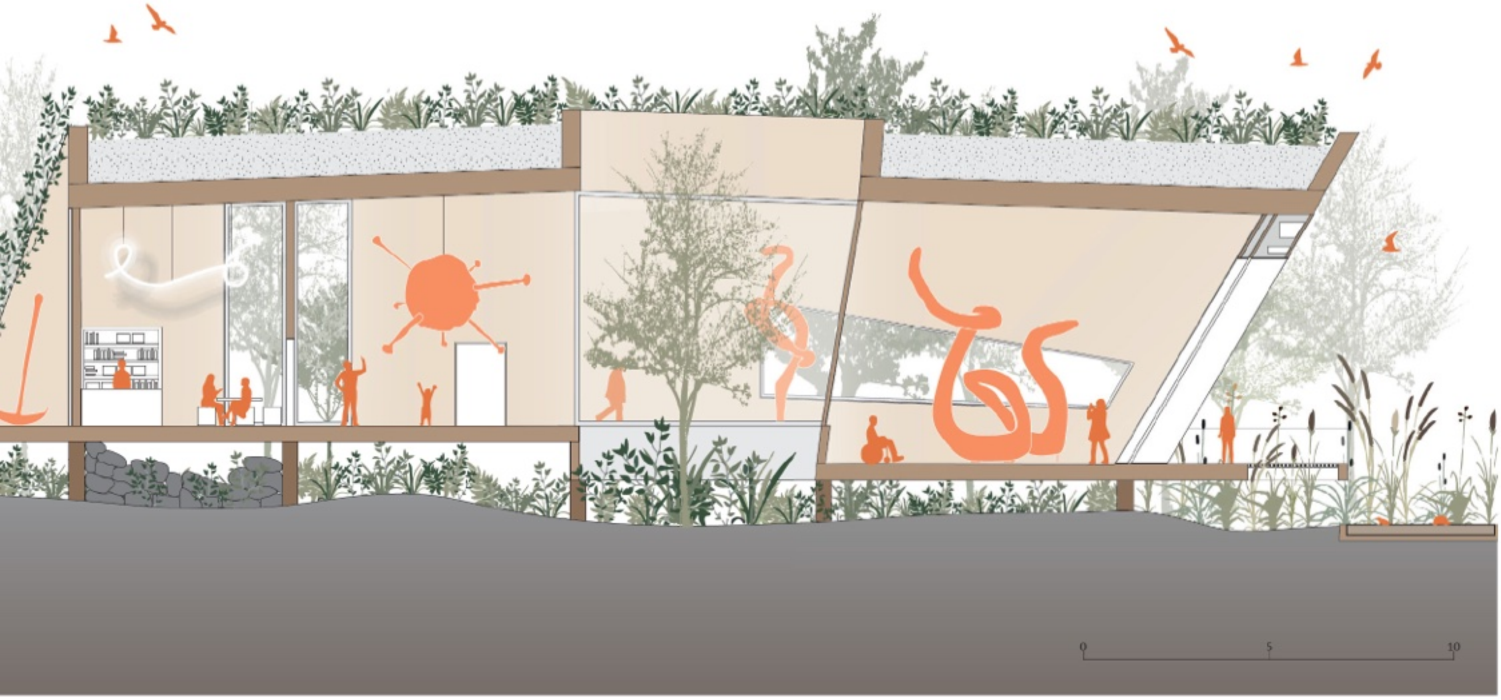
The exhibition space extends over a footbridge into the reed belt, where it connects to the ground via a sand-filled platform, providing much- needed space for various animals to lay their eggs. Birds can also use the platform to take a sand bath to



protect themselves from parasites. In front of the foyer is a swell room in which further sculptures are displayed.

The platform is protected by a climbing net and climbing plants that run diagonally to the roof. In front of the trellises are large openings in the platform, which connect the ground below with the building and provide natural light and irrigation for the soil below. Behind the opposite threshold space is the café, with a glazed recess. The sloping outer walls protect the guests sitting below and provide a habitat for sand martins and kingfishers, that tend to nest in overhanging riverbanks.

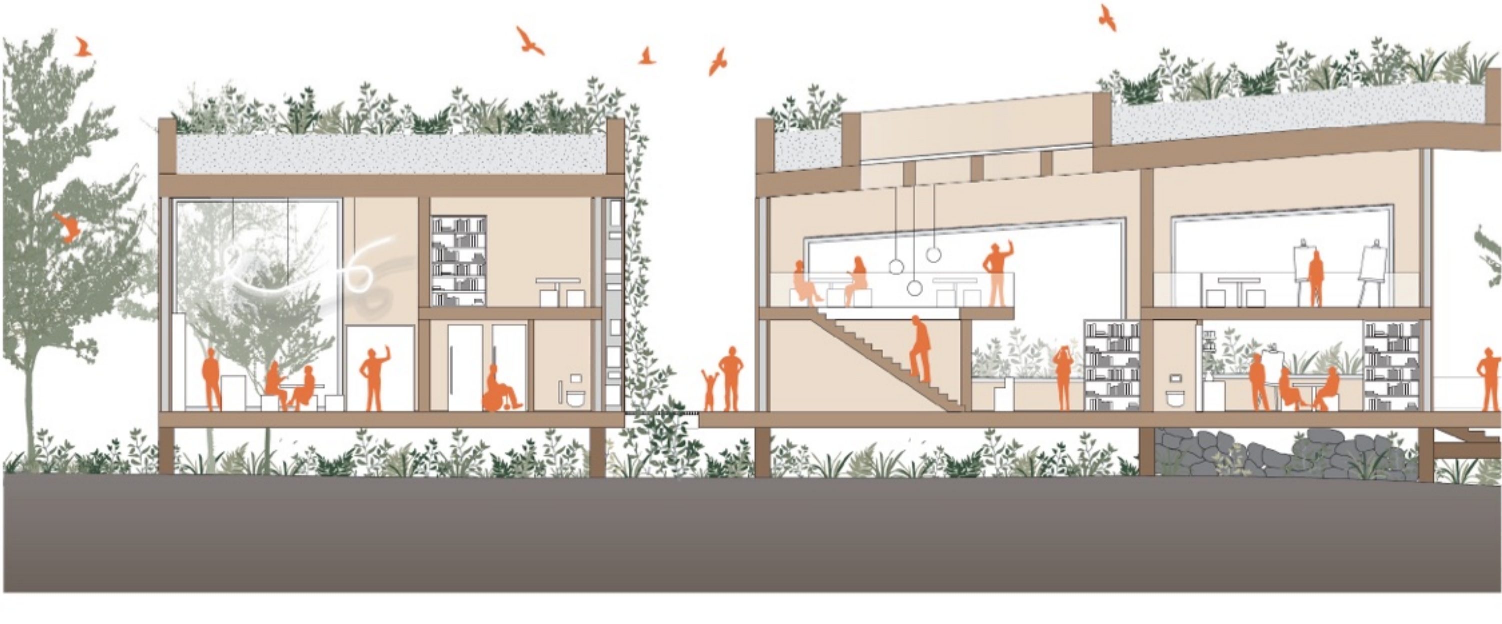
Fig.112: Section A-A 1:200



5.7.4 Section B-B

Through the sculpture garden, studio, library, and the foyer
The section B-B running through the sculpture garden shows the flowing transition of the platform, via a generous flight of steps, into the natural height development of the landscape. The sculpture garden expands into the adjacent forest, the trees become part of the architecture, whereby art is experienced in direct context with nature.

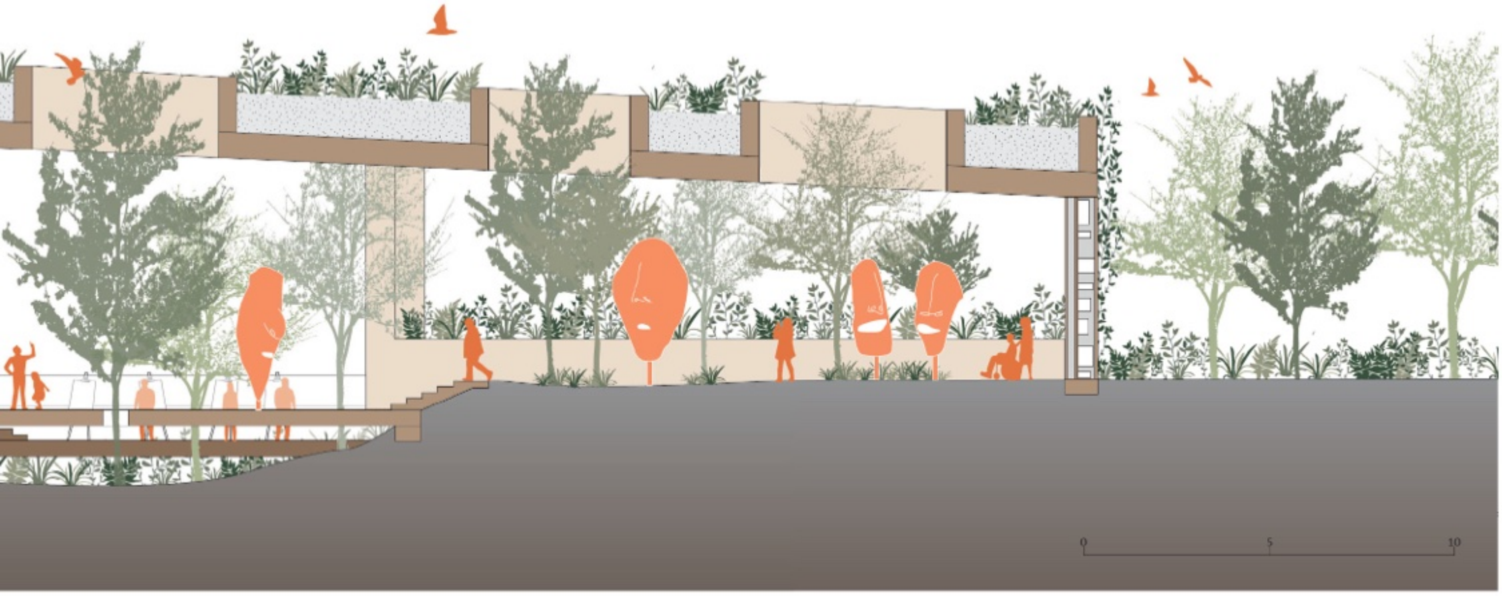
The existing trees push through the platform and penetrate the ceiling through large openings, so they get enough light as well as water. Next to the sculpture garden, a two-storey studio space is located, with its own terrace facing the water.



The library is directly adjacent to the studio, which allows the artists to be inspired by various books at any time.

The library has a gallery on the second floor that invites you to relax and read. Large roof openings and panorama windows with a view of the pond behind them not only brighten up the room, but also allow nature to become part of the interior. The building on the left houses the foyer of the temporary exhibition, as well as an office and the cloakroom. Here, too, nature is brought into the interior of the building via large glass fronts.

Fig.113: Section B-B 1:200



5.7.5 East View

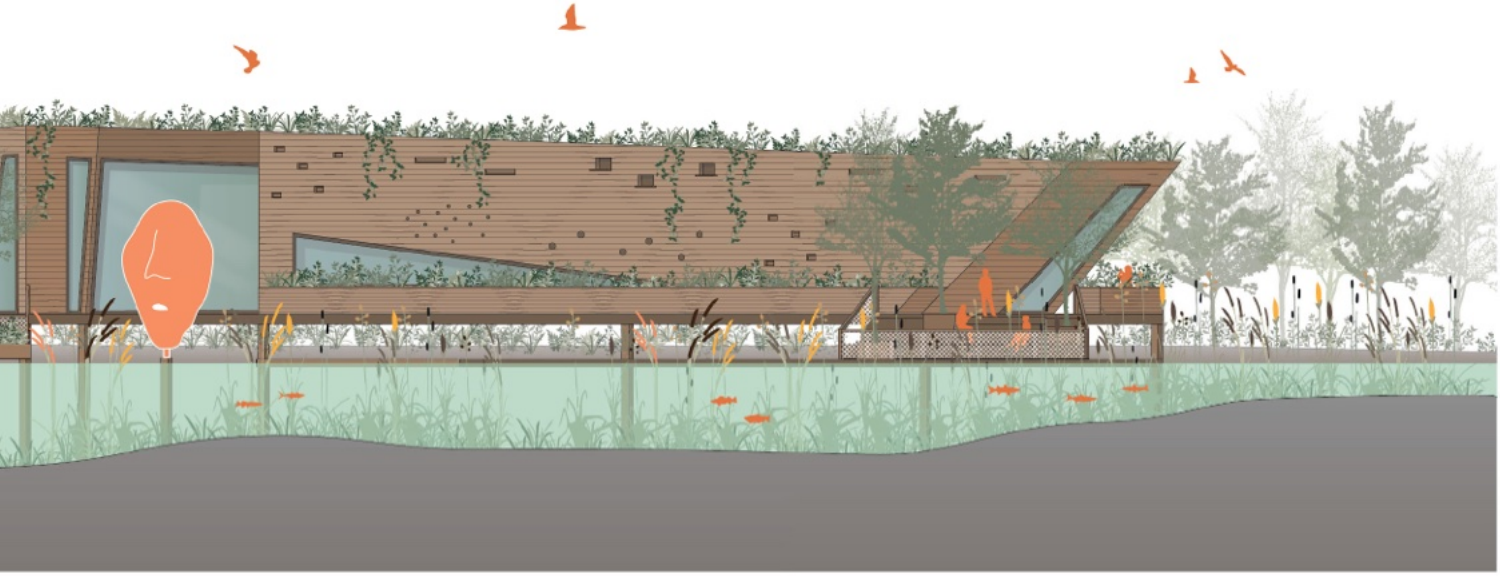
The view of the east façade, which faces the Wienerberg pond, shows the building on the left, which houses not only the logistics and the warehouse, but also the workshop and the café. The wall facing the water creates urgently needed nesting places for birds through the nesting openings in the upper part of the façade.

The steep wall is specifically adapted to the needs of the kingfisher and the sand martin, which normally nest on overhanging banks. In front of the café is a spacious terrace with plenty of seating for café guests. The platform extends downwards, over several seating steps, into which large plant troughs with trees are integrated.

In front of the seating stairs, the platform develops into a green space that cannot be walked on, on which numerous plants find space. The various plants create a habitat for insects, microbes but also for small mammals.

The building on the right houses the permanent exhibition, which opens onto the pond through several windows. In front of the long façade is a plant trough that ends exactly at the lower edge of the window. The façade behind it offers a habitat for many insects as well as birds through the different openings.

Fig.114: East View 1:250



5.7.6 West View

On the left side of the view, the sculpture garden can be seen, which is integrated into the surrounding environment. The green roof not only creates a visual connection with the building, but also protects the exhibits from strong environmental influences. The existing trees, which are retained in the design, poke through the platform as well as the green roof and thus become a connecting element to the ground below the platform as well as to the sky. The studio and the library are located next to the sculpture garden.

The temporary exhibition is in the right-hand part of the building, which partially protrudes into the reed belt. The footbridge in front of the building is set back one metre from the façade, allowing living creatures and plants to live undisturbed on and in the façade. The large glazed recess in the building not only gives visitors a small glimpse into the exhibition rooms, but also creates a visual link between inside and outside.

Fig.115: West View 1:250

5.8 Space Program

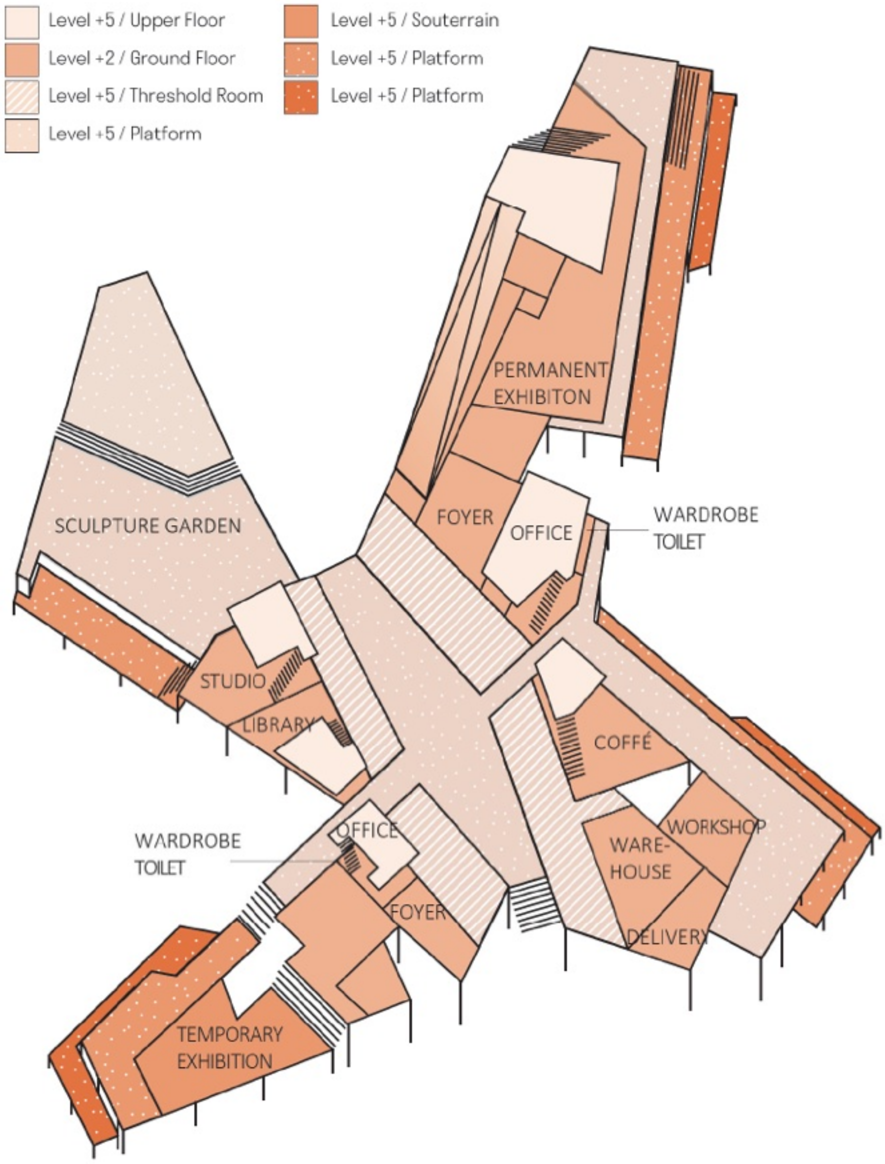


Fig.116: Space Program & height development

The platforms develop over different heights to adapt to the structures provided by nature. At some points they approach the ground or the water surface and are located at +1 metre or 0 metre height. The entrances to the four buildings are each at +2 metres. The temporary exhibition jumps down by one metre both outside and inside and thus sinks deeper into the surrounding reeds. The sculpture garden rises by one metre in the middle, thus levelling out with the adjoining terrain. In all four parts of the building, some rooms extend over two storeys, with a floor level of +5 metres.

In addition to the permanent and temporary exhibitions, the spatial programme also includes a sculpture garden and a sculpture threshold room located in front of the entrances to all four buildings. There is also a large café, a library, and a studio space with a terrace. The infrastructure requires an area of 435m2 and includes the office, the logistics, the workshop, the depot, but also the foyer and shop, as well as the cloakrooms and toilet facilities.

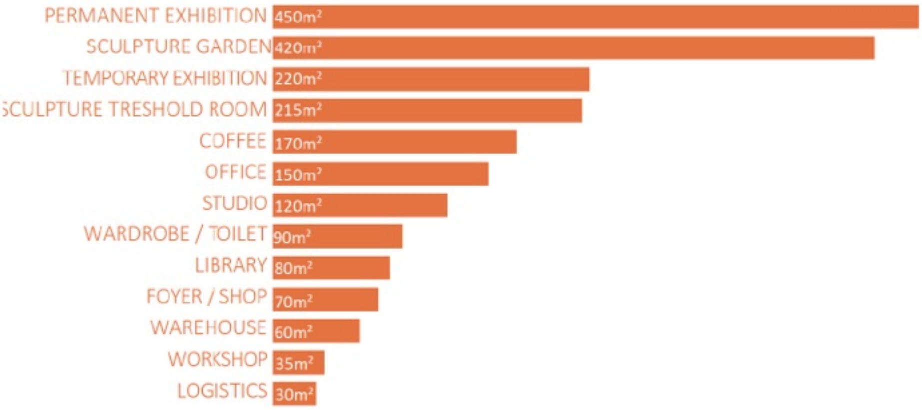


Fig.117: Area distribution

5.9 Sight relation

The orientation and arrangement of the four buildings on the site create numerous different visual relationships with the surrounding nature. To the north, there is a visual axis to Biotope City and the water tower. To the east, there is a view of the Wienerberg pond as well as the Art-Lepa art gallery and the Karl Wrba Hof. To the south, there is a view of the historic restaurant "Das Chadim". The view to the west offers a breathtaking panorama across the pond with its reed belt to the Schneeberg.

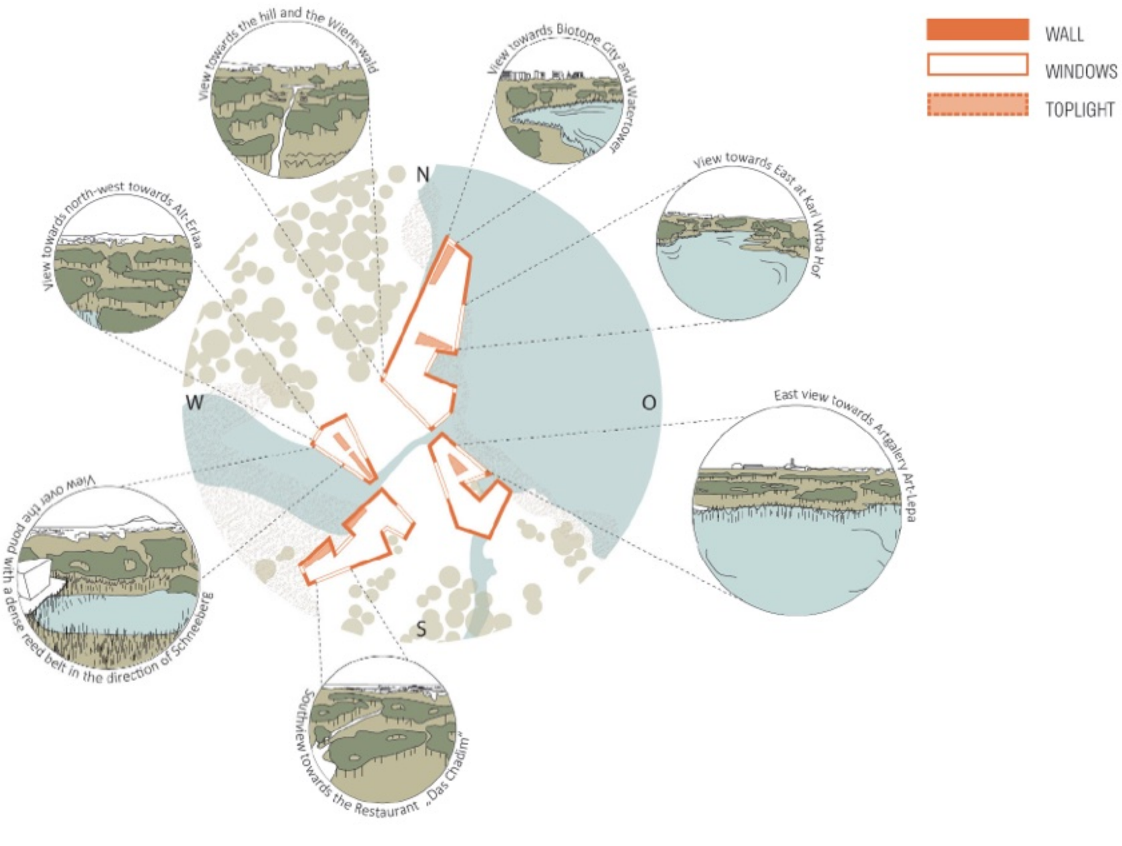


Fig.118: View of the surrounding area

5.10 Lighting concept

5.10.1 Exposure in the building

The supply of natural daylight is essential for sculptural displays. Lateral light is of particular importance, as it enhances the three-dimensional perception. Moreover, no light can reproduce colour fidelity as perfectly as daylight. Artificial and natural lighting are combined to ensure fluctuation-free lighting in the interior.88 The design works with both skylights and lateral window openings. The ceiling openings are located above a suspended ceiling. Rotatable, reflective louvres are installed in the ceiling cavity, which can be aligned according to the position of the sun and thus diffuse the light into the interior without glare. Depending on the requirements, an additional sun protection device with UV filter can be pulled in front of the glazing, both on the ceiling and on the side openings, to protect sensitive exhibits or to completely darken the room, for example for light installations.

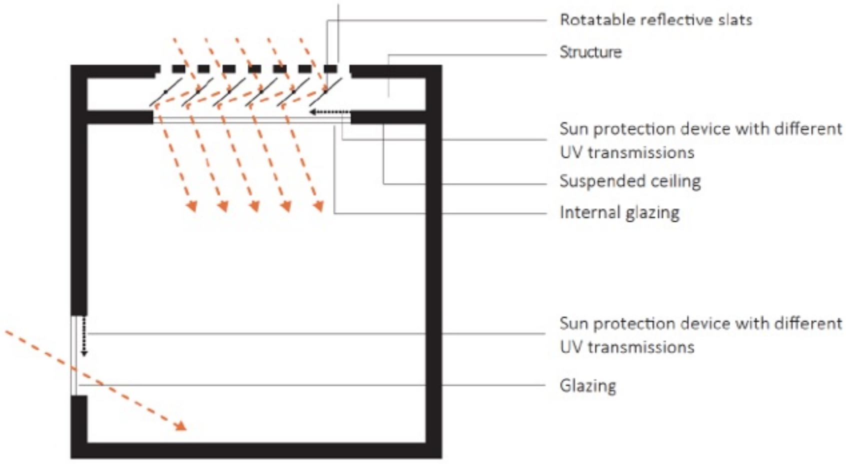


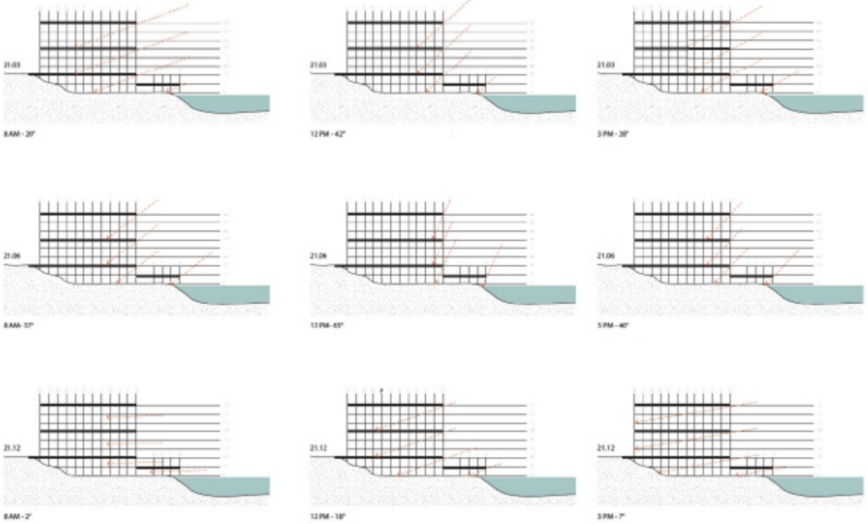
Fig.119: Lighting scheme

5.10.2 Exposure under the building

To guarantee the lighting under the platform, a drawing analysis was carried out for the design to determine how far the light can penetrate under the platform on three specific days. On an average spring day, 21.03, the light reaches an average of 3.5 metres below the platform. Due to the steeper angle of incidence of an average summer day, 21.06, the sunlight only reaches an average of 1.8 metres under the platform, whereas the flat light of 21.12 shines an average of 8 metres under the platform.

To ensure sufficient lighting of the green areas below the platform, several large openings were made in the middle of the platform. Furthermore, the lateral cuts in the building volumes create an additional improvement of the lighting in these areas.

Fig.120: Analysis - exposure below the platform at different times on three specific days of the year



5.11 Tour of the permanent long-term building

The tour through the building of the permanent exhibition gives an insight into the exhibition rooms of the museum. The tour begins in front of the building. You then enter the foyer through the sculpture threshold room. The exhibition is entered via a long ramp. Once you reach the end of the ramp, you find yourself in a gallery, from where you move down a wide staircase into the large exhibition room. The exhibition ends in a smaller room that connects to the Wienerberg pond via a large glass front.

Fig.121: Tour scheme

View of the building entrance of the permanent exhibition

The view of the building of the permanent exhibition shows the trellis on which various climbing plants climb up from the ground through the openings in the platform. In front of the trellis, on the right-hand side of the entrance, there is an integrated bench where you can watch the activity on the platform. The platform is raised two metres from the ground and is connected to the adjoining railing via a long flat ramp. This makes it easy for visitors and walkers to get on and over the platform. The sculptures can be easily guessed from the outside and thus arouse the interest of people passing by.

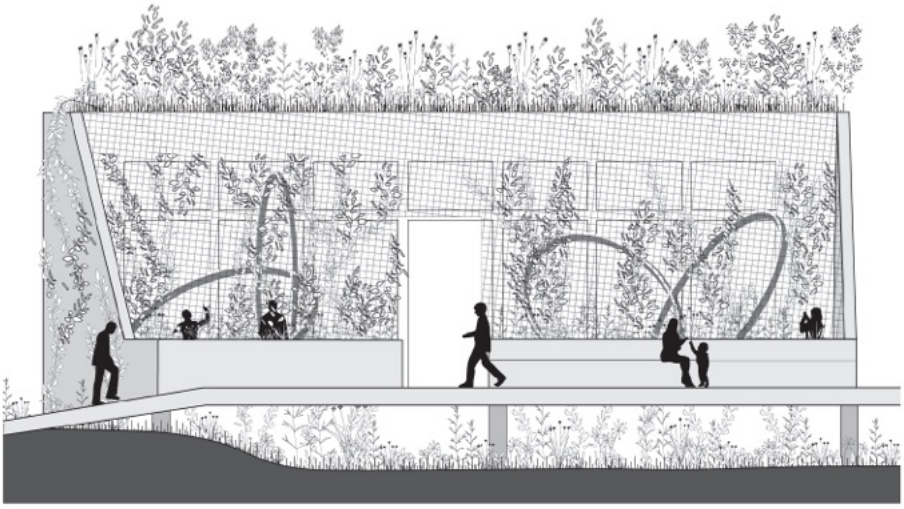


Fig.122: (A-A) View: Entrance of the permanent exhibition

Cross section of the sculpture sleeper room

The sculpture threshold room is still connected to the outside air, but on hot days it is protected from the strong sunlight by the leaf canopy. In winter, the leaves fall through the trellis and collect in the corners where they are allowed to remain, thus offering insects protection from the cold. For humans, the threshold room offers a pleasant semi- temperate room in winter, as it is slightly warmer than the outside air due to the heating in the interior and the protective walls on the sides.

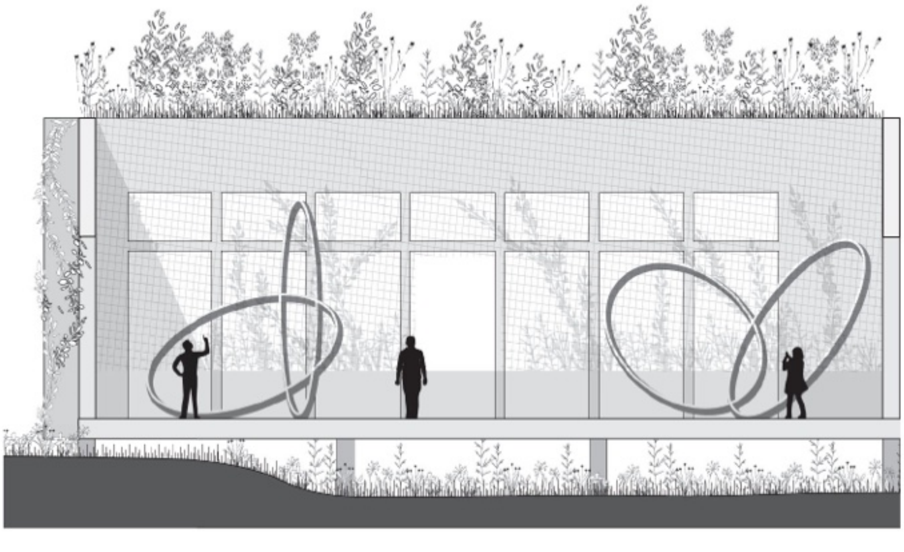


Fig.123: (B-B) Cross section through the sculpture threshold room

Cross section of foyer, ramp, office, and checkroom

The visitor's first glance in the 6-metre-high foyer is at the large glass pane on the back wall, which reveals a small section of the Wienerberg pond. On the left side of the foyer is an open-plan shop. In the cloakroom to the right of the foyer, visitors can leave their clothes. The employees enter the two-storey office from here. The exhibition is entered via a long ramp adjoining the foyer on the left.

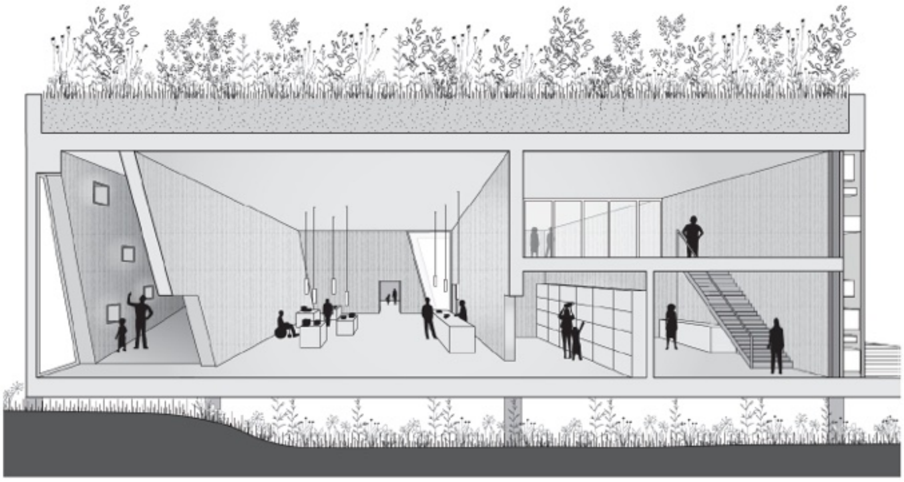


Fig.124: (C-C) Cross section through the Entrée

Longitudinal section through the ramp

The long ramp that leads the visitor into the large exhibition room looks like another world. On the left side of the ramp are numerous small windows in the façade, behind which nesting holes or places of retreat or hiding places for various animals are concealed. The slow upward movement on the ramp and the different heights of the window openings result in ever-changing views of the forest behind the wall. At the beginning of the ramp, for example, the sight level is still at the level of the herb layer of the forest; at the end of the ramp, one can now see the crowns of the trees.

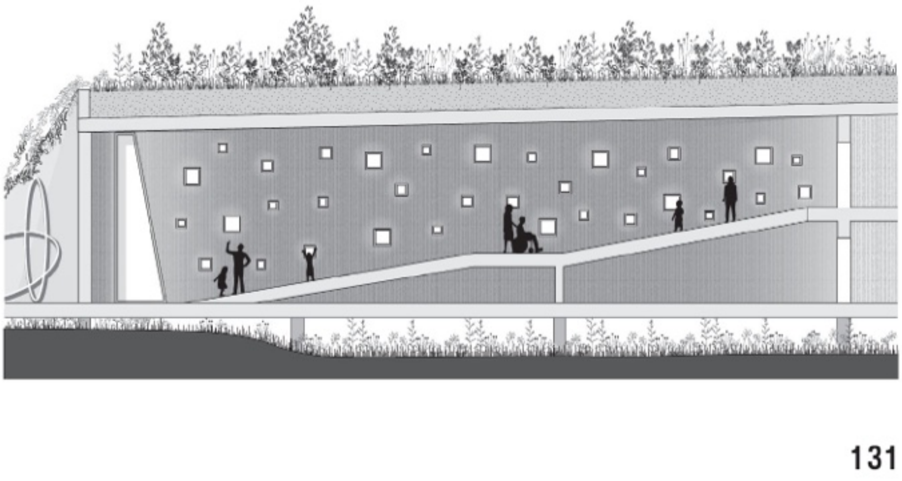
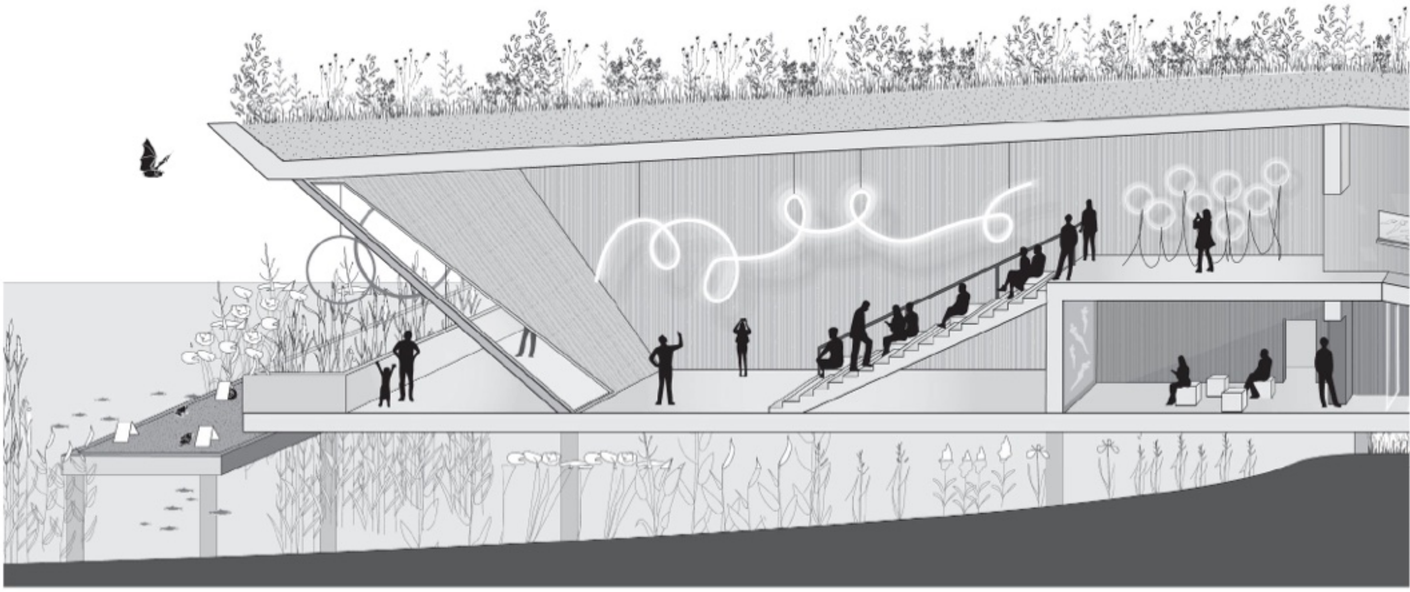


Fig.125: (D-D) Partial section through ramp

Longitudinal section through the entire building

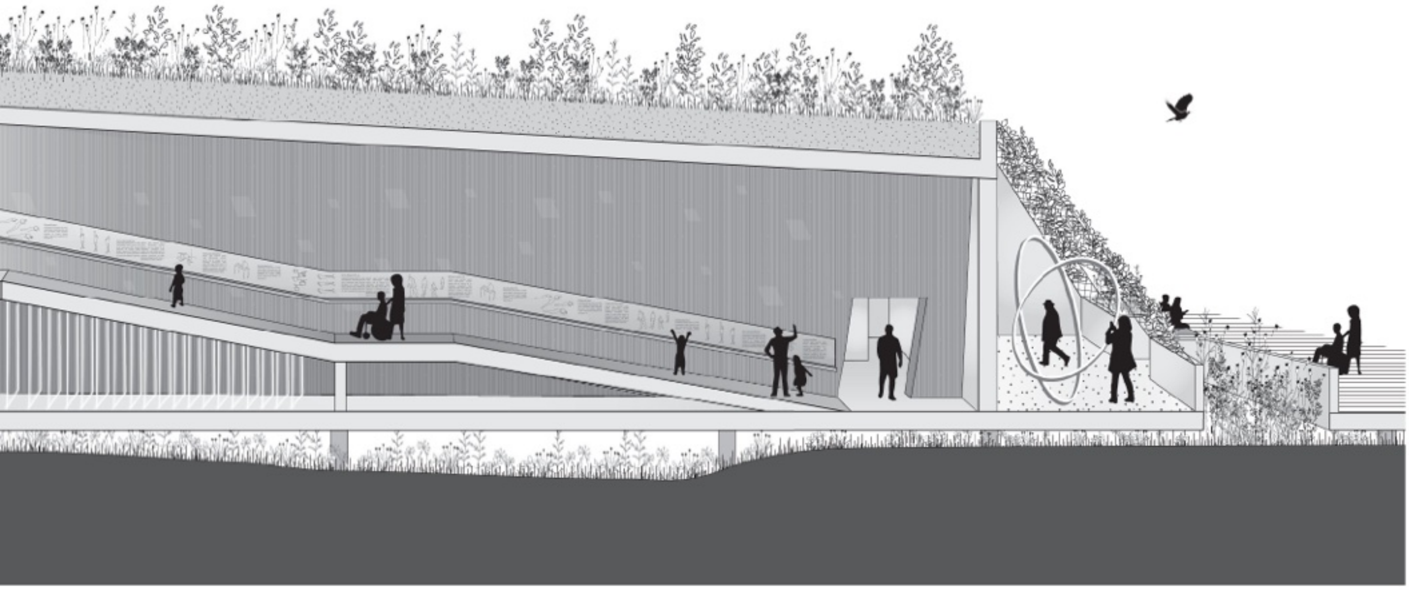
On the opposite side of the ramp, a wall niche displays information about the following exhibition. At the top of the ramp, there is a large window with a view of the water. The gallery offers the visitor the opportunity to orientate himself in the room and gives a complete overview of the exhibits. Visitors reach the lower exhibition area via a wide staircase, from which the sculptures can be observed. The exhibition space is connected to the platform in front of it via an opening and can thus be extended in good weather.



The stepped platform underneath is just above the water level and thus provides space for animals to lay their eggs or sunbathe. The space under the ramp is also used as an exhibition space. Light installations or video graphic content can be shown here.

The section on the right shows once again the threshold space in front of the building and the trellis, which is connected to the ground through an opening in the platform.

Fig.126: (E-E) Longitudinal section through Exhibition Building



Cross section of the large exhibition space

The cross-section through the permanent exhibition space shows the wide seating staircase in the view, where school groups can also gather. The integrated nesting boxes can already be seen in the outer walls of the building. Some of them poke through the wall and thus develop into a visual connection of the exterior space with the interior. There is an elongated skylight on the ceiling above the staircase, which provides a good view of the sky. Below the gallery, a long continuous exhibition space opens, which can be subdivided as needed. A side opening at head height offers a panoramic view over the Wienerberg pond.

Fig.127: (F-F) Cross section through showroom

Cross section of the small exhibition space

The small, separate exhibition space captivates with its full-surface glazing facing the water. Here, sculptures can either be placed in the interior or on pedestals on the water. Through the large windows, the visitor has a perfect view across the pond to the opposite bank, as well as of the exhibits on the water, which are thus brought into a direct context with nature. When the weather is fine, the room can be opened completely, further blurring the boundaries between inside and outside.

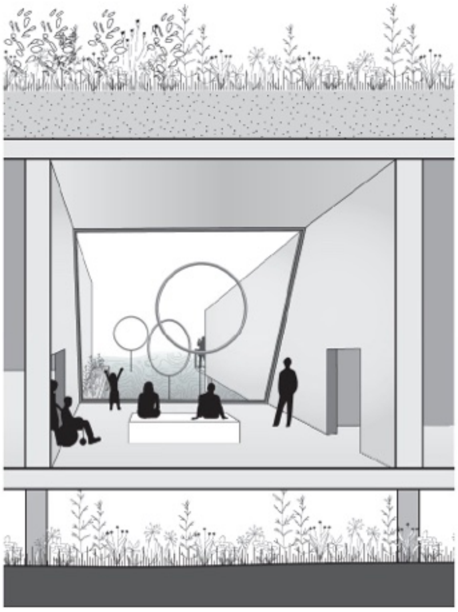


Fig.128: (G-G) Partial section through showroom - view towards pond

5.12. Ecolopes - Concept

Just like the Ecolopes concept, the design manages to integrate habitat for several species on all levels of the building. Thus, animals, plants and microbes find a diverse range of habitats in the green roof, the walls, and the platform.

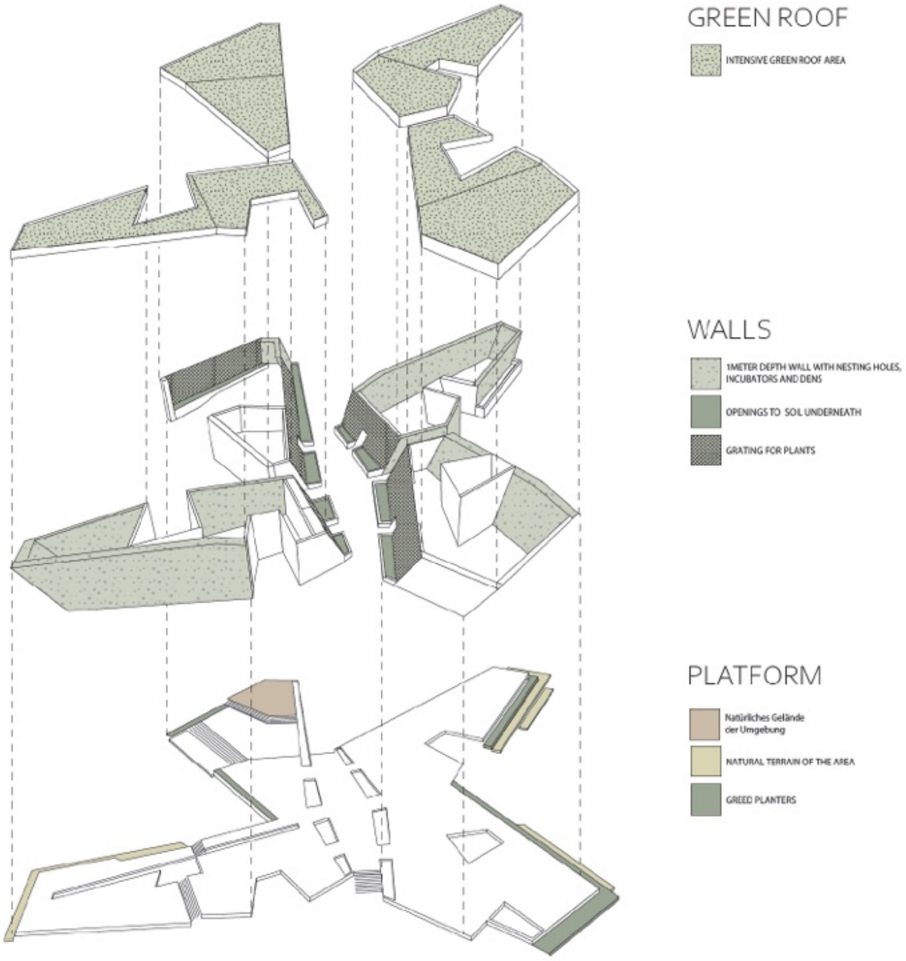


Fig.129: Space Program & height development

5.12.1 Ecolopes - Green Roof

Starting in the uppermost area, the green roof with a 100-centimetre substrate layer provides a valuable breeding ground not only for plants, but also for microbes, insects and small animals living in the soil. Via the structured walls, climbing plants can grow up to the roof and connect with the soil there. For insects, the wide range of flowering plants provides ample food in the form of nectar, as well as a valuable habitat. For numerous bird species, the green space serves as a source of food, but also as a breeding ground.

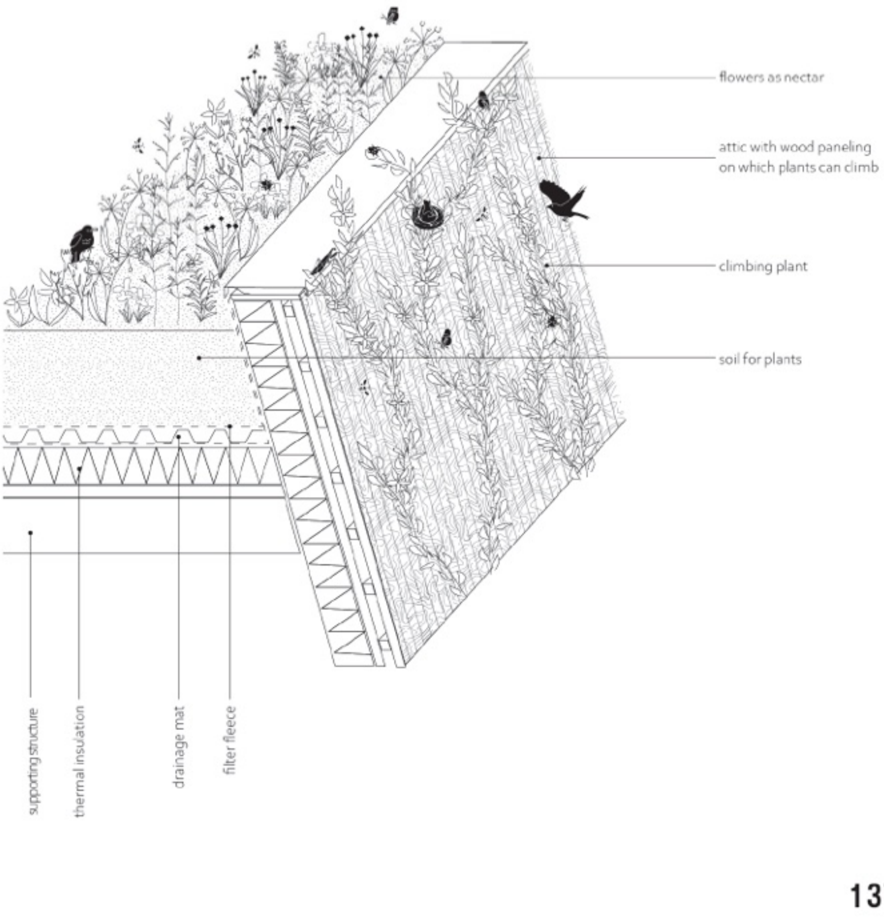


Fig.130: Green roof as a habitat for animals, plants and microbes

5.12.2 Ecolopes - Nesting Wall - Variation 1

The walls, which are up to 100 centimetres deep, integrate numerous different nesting boxes and openings to create habitats for animals. The openings offer retreats for birds and insects, but also for mammals, which can use the caves in the lower part of the wall as nesting holes or for hibernation. Due to the special construction of the façade, the thermal envelope is decoupled from the habitat wall, which means that the depth of the Ecolopes wall can vary to meet different requirements. The timber façade provides sufficient texture for climbing plants to grow on the façade.

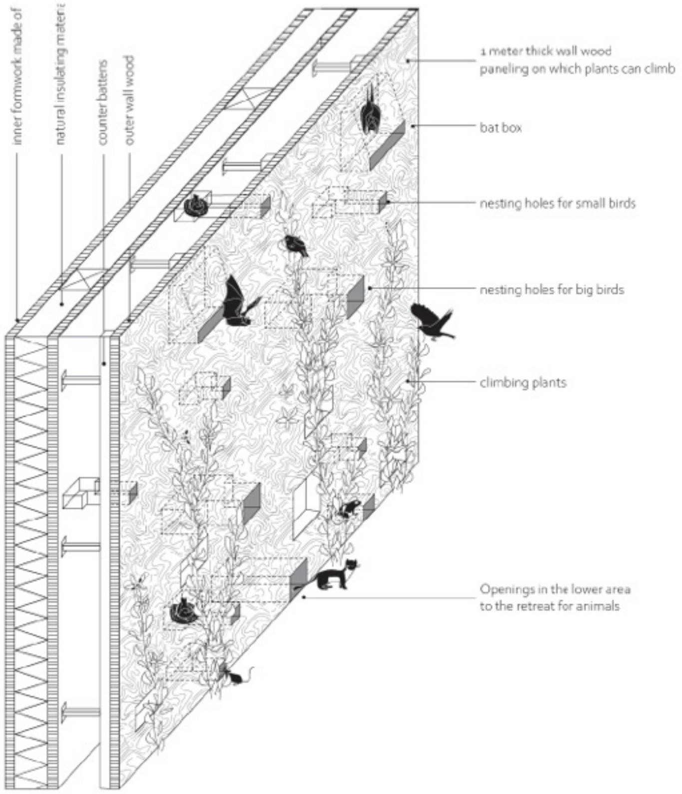


Fig.131: Ecolopes facade with various openings for animals

5.12.3 Ecolopes - Nesting Wall - Variation 2

In addition to the deep habitat walls, narrower wooden facades are integrated, which offer a wide variety of insects a place to lay their eggs or to hibernate safely through various boreholes in the outermost layer of wood. The holes are popular with bees, bumblebees, and wasps, but also with lacewings, butterflies and various beetles. As protection against predators, a net can be installed in front of the façade to keep birds away, for example. The net serves as an additional climbing aid for climbing plants.

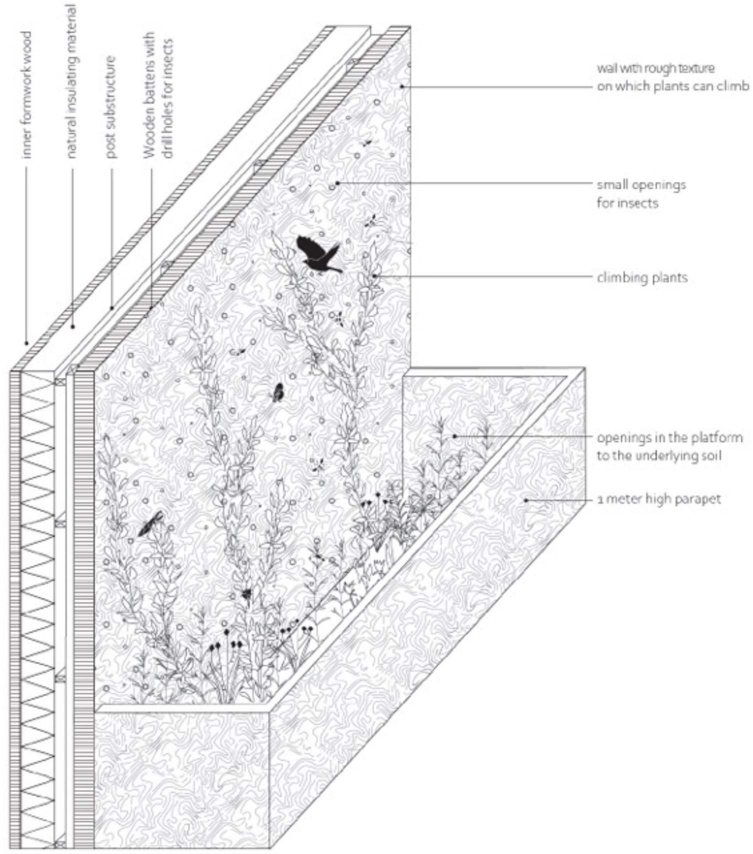


Fig.132: Insect wall with opening to the floor

5.12.4 Ecolopes - Ranknet

In front of the entrances to each of the four buildings are trellis nets that extend down to the ground through large openings in the platform. The openings in the middle of the platform not only create a visual reference to the ground below, but also provide natural lighting and irrigation of the ground. The plants growing underneath the platform can protrude through the opening and partially grow along the trellis net up to the green roof. The plants provide a habitat for insects and birds, which not only find a place to retreat between the leaves, but also sufficient food in the form of nectar and fruit.

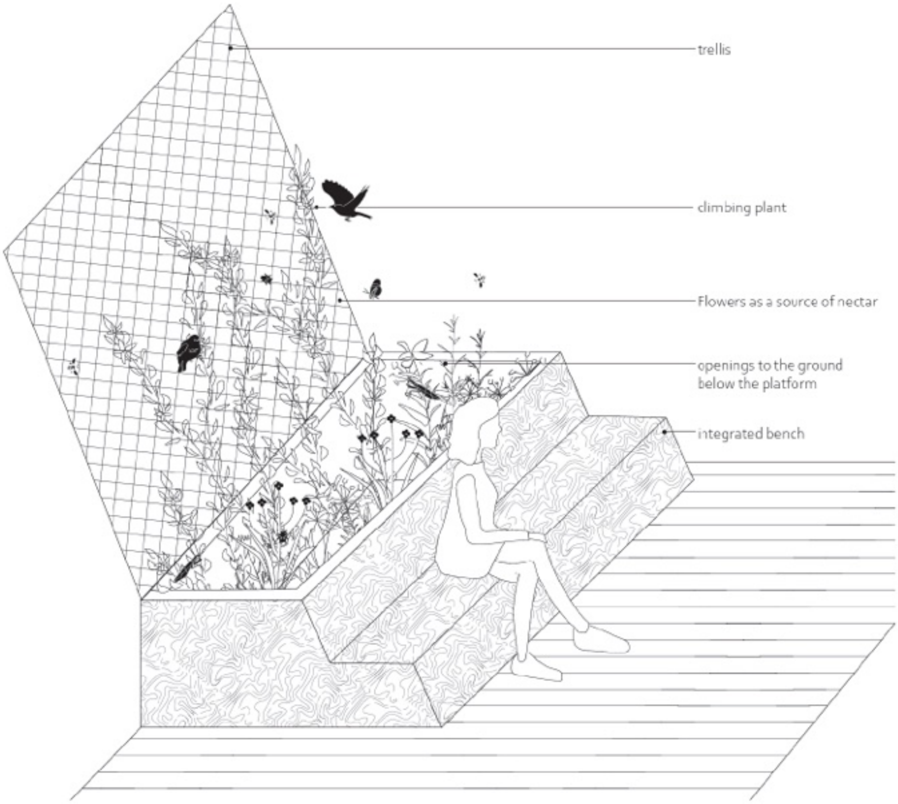


Fig.133: Trellises connect to the ground through platform openings

In summer, the trellis provides shade due to the dense leaves, which cools the warm air from outside, which then flows into the museum and provides fresh cool air.

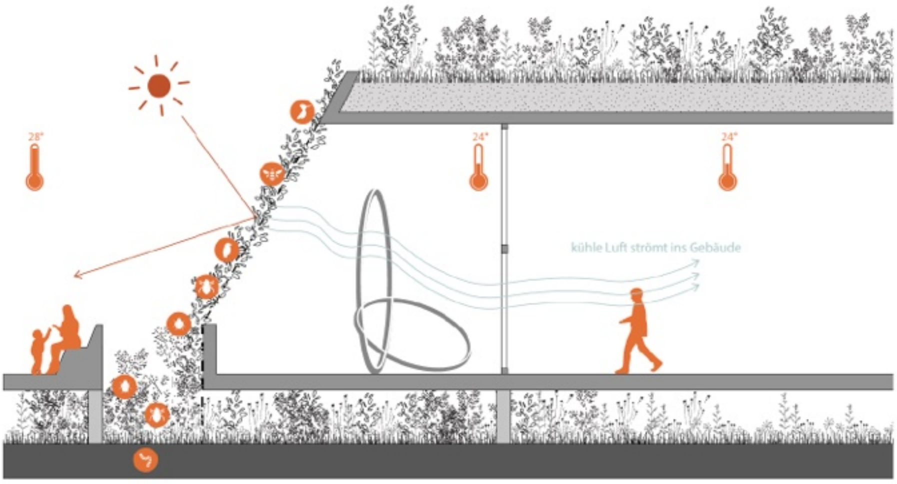


Fig.134: Outside sculpture room in summer

The low-angle sun light during winter penetrates deep into the interior of the building. The threshold space provides shelter for animals through foliage and warmth.

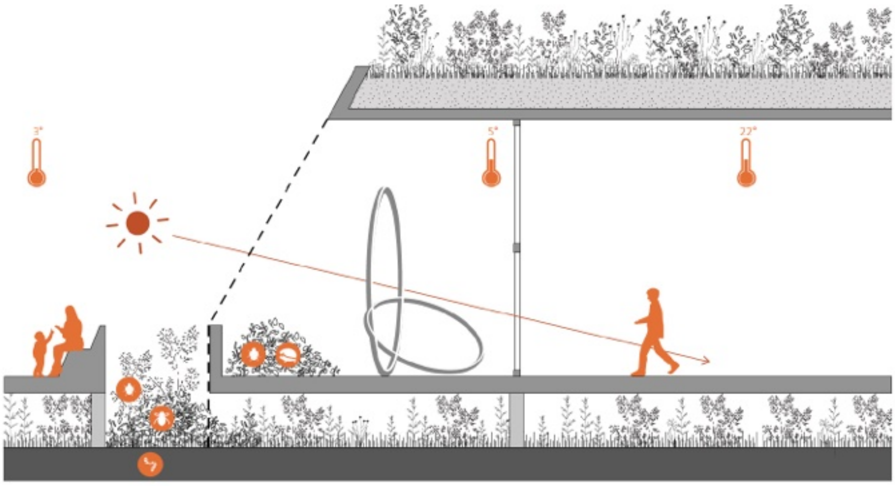


Fig.135: Outside sculpture room in winter

5.12.5 Ecolopes - Platform

The platforms are shaped differently and are located at different heights depending on the terrain and the surroundings. Some of the one-metre-deep earth troughs are located directly on façades and thus provide additional habitats for plants and microbes. The sand or gravel platforms are connected to the surrounding terrain at ground level. They expand the already existing habitat on the Wienerberg and offer amphibians as well as birds the opportunity to lay their eggs or for a nourishing sand bath. Insects, such as the wasp, also enjoy the loose soil to lay their eggs. The platforms, which are at or slightly below water level, offer water birds the opportunity to build a nest, but also for frogs or fish to lay their eggs in the shallow water areas, some of which also have substrate areas for plants.

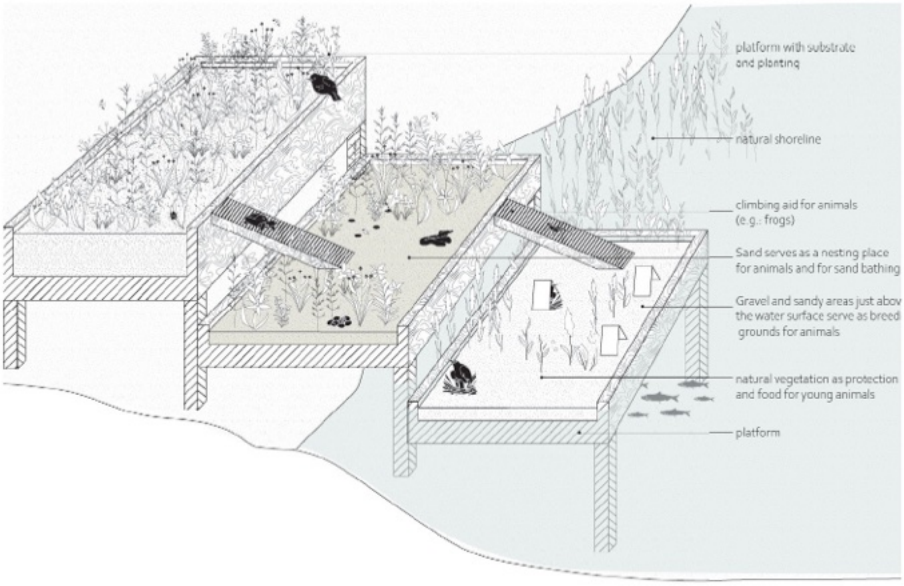


Fig.136: Ecolope's platforms with different characters

5.13 Exemplary configuration of the facades

Depending on the orientation and location of the Ecolopes façades, there are different possibilities and requirements. In the following, three different façades are explained and an example of how the façade can be used is shown:

1. North-west façade - towards the forest
2. East facade - direction Wienerberg pond
3. North-west façade - towards reed belt and pond

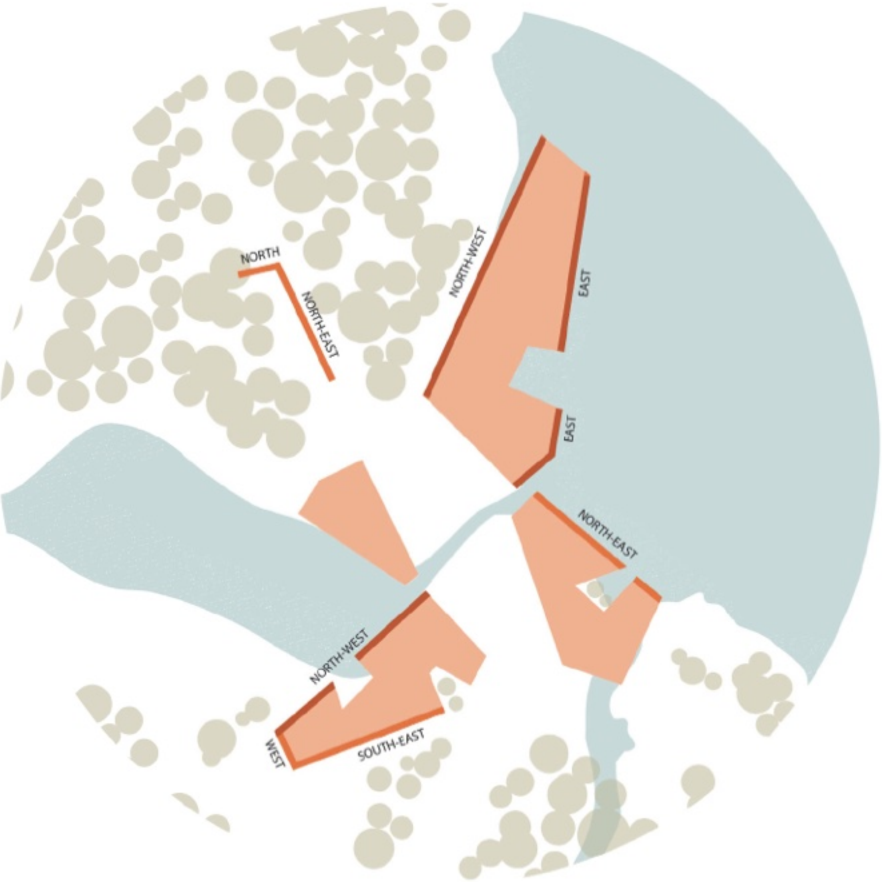


Fig.137: Ecolopes facade orientations

5.13.1 Food pyramid

When designing the Ecolopes façades, an understanding of the food pyramid is essential. At the base of the pyramid are the producers, who are the primary producers of plant biomass. Next come the primary consumers, which include all herbivores. Secondary consumers are smaller carnivorous animals that feed on the primary consumers. At the top of the pyramid are the end consumers, which have no natural enemies, except humans. The number of individuals decreases towards the top of the pyramid, with the size of individuals increasing towards the top.

Depending on the habitat, certain food chains must be considered when arranging the nesting holes and burrows in the façade. This then results in specifications and distances to be observed when placing the openings.

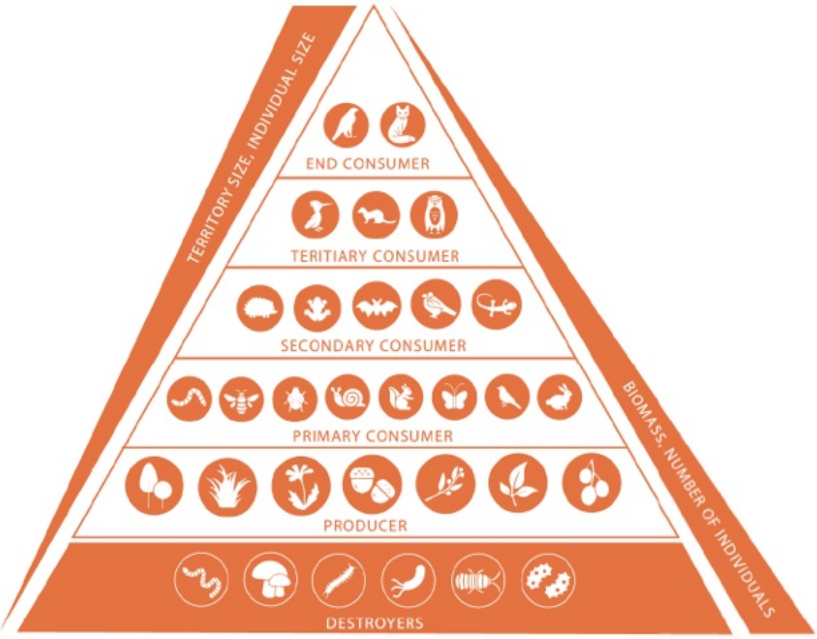


Fig.138: Food pyramid by trophic levels

5.13.2. North-west facade - towards the forest

For the façade with adjacent forest, the focus is on birds but also on small mammals living in the forest. Where the façade adjoins the terrain, caves can provide shelter for mice or weasels. In the upper part of the façade, there are nest openings for larger birds, bats, and squirrels, making sure that the openings are five metres apart. In the lower area there are nesting holes for small birds that cannot fly very far and high. The plants growing on the façade provide shelter and food for animals.

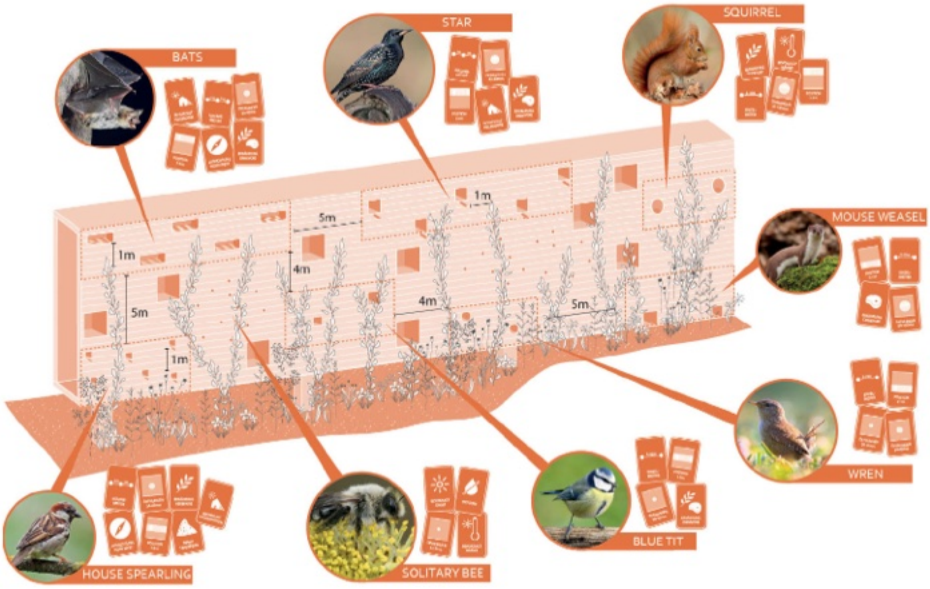


Fig.139: Exemplary design on the facade in the direction of the forest

5.13.3. East facade - towards Wienerberg pond

The Ecolopes façade facing the Wienerberg pond is equipped with nesting holes for water birds in the upper area. Directly in front of the façade is a large earthen trough that provides ample space for plants and microbes. The various plants provide food for the birds and insects that have settled in the façade through their nectar or berries. The nesting places for insects are located at a height of one metre, directly behind the planting. At the height of the water level there is a platform with sand and gravel, which provides an ideal nesting place for turtles but also for terns. Floating anchored platforms in the pond help water birds to find a suitable nesting site. They can build their nests on the rafts and are protected from the wind by the façade.

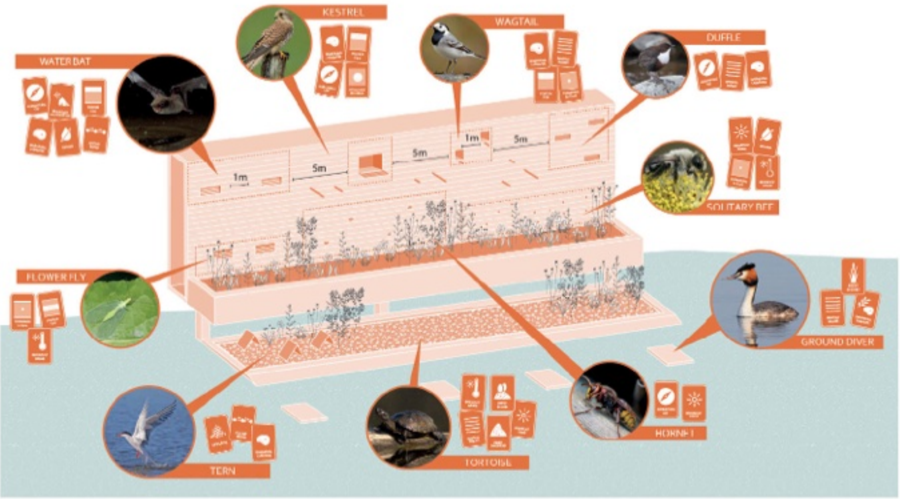


Fig.140: Exemplary design of the facade , towards the water

5.13.4. North-west facade - towards reed belt and pond

The nesting wall in the direction of the reed belt and pond connects directly to the ground to provide a habitat for animals living near the ground. In the lower part of the façade there are openings for toads, hedgehogs and snakes and weasels, whereby a territorial distance of 5-10 metres must be ensured for different positions in the food pyramid. In the middle part of the Ecolopes wall, nesting holes for insects are provided, which are well protected by the reeds growing in front of the façade. At a height of 5-6 metres there are openings for larger birds, such as the goosander or the grey flycatcher. Slit-shaped openings in the upper part of the façade are also provided for the water bat.

Fig.141: Exemplary design of the facade , towards the reed belt and the pond

5.14 Facade structure - connection inside & outside

Different window openings that penetrate the façade create a relationship between the nature outside and the inside. Depending on the height of the openings, different views of the surrounding natural spaces are created. The nesting boxes have various dimensions adapted to the respective animal species, whereby the openings of the respective boxes are also adapted to the inhabitants.

The load-bearing layer of the façade is a timber frame façade with a layer of natural insulation material in between. The load-bearing layer is thus on the same level as the insulating layer. In front of the load-bearing layer, i.e. thermally independent of it, is a wooden cladding that can be installed at any distance from the load-bearing layer by means of spacers.

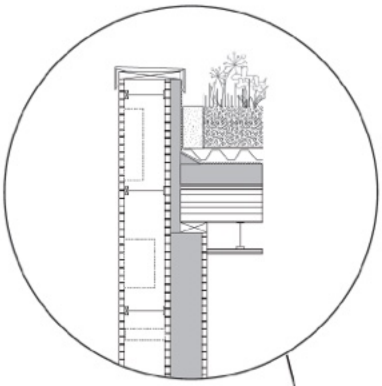


Fig.142: Zoom 1:100

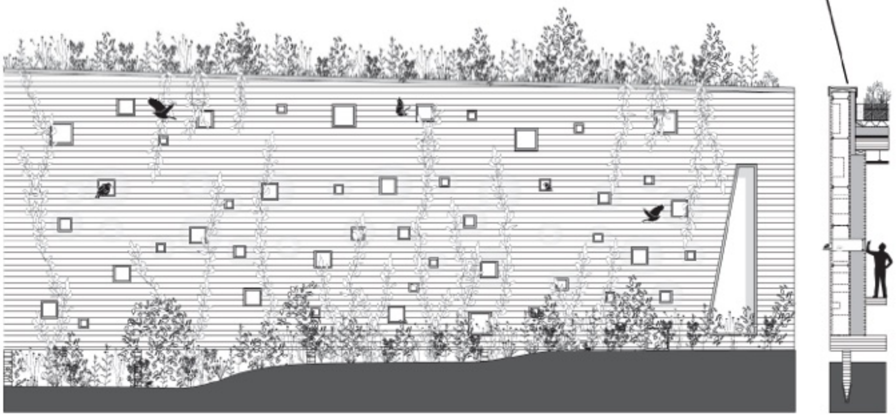


Fig.143: Outside facade structure - connection between interior and exterior 1:200

The nesting boxes are then installed behind the ventilated façade. The outermost layer is formed by horizontal wooden battens. Due to the given structures, climbing plants can easily climb up the façade. The intensively greened inverted roof, with a substrate layer of up to 100 cm, offers enough soil for a wide variety of plants, from which animals and microbes can benefit.

Fig.144: Zoom 1:100

The loads of the green roof are taken up by the glulam beams and transferred to the ground via the wooden posts of the façade. Additional bracing at the façade level creates a load-bearing building envelope. Below the glulam beams is a suspended ceiling, and there is space for technical installations in the ceiling cavity.

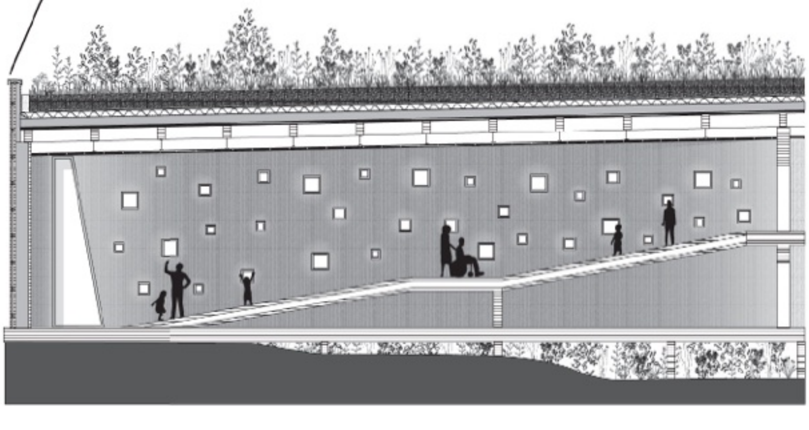


Fig.145: Inside wall structure - connection between interior and exterior 1:200

5.15 Model photos

Fig.146: Model 1:200 - view from above with roofs

Fig.147: Model 1:200 - view from above without roofs

Fig.148: Model 1:200 - view from east

Fig.149: Model 1:200 - view between the buildings

5.16 Illustrations

Fig.150: Entrance situation of the four buildings on the museum deck.

Fig.151: Water walkways around the museum, enable a unique experience of art in harmony with nature.

5.17. Conclusion

With the rapidly advancing re-densification of cities and the resulting decrease in green spaces, we are now facing a problem that we did not have a decade ago. Green space in cities is being reduced more and more in favour of new building areas, and in some cases even eliminated. The important and necessary connection between humans and nature is almost completely lost. Due to the constant separation, the awareness of climate and environmental protection continues to decline, which is worshipful in the current situation in which we find ourselves in the climate crisis.

The Ecolopes approach aims to give more space to nature in the city without restricting the urgently needed, newly created living space for people. The close interconnection of nature and people is intended to strengthen the idea of the environment. The design examines the extent to which the Ecolopes theme may intervene in the architectural structures at the Wienerberg recreation area, away from the urban structures, without serious disadvantages for the architecture and the people. A sculpture museum for contemporary art and art of the 20th century, plus a sculpture garden, provides the architectural design framework for the work. During the diploma thesis, various approaches were analysed and evaluated in order to generate a holistic design proposal for an ecolope sculpture museum.

The analysis of the surroundings as well as the understanding of the flora and fauna on site are essential to develop a coherent Ecolopes concept. During the design process, the Wienerberg area was analysed in detail. Extensive research was carried out on the flora and fauna, the weather conditions as well as the soil and water conditions to evaluate the quality of the site.

The decisive factor for the design concept was a targeted intervention in the natural conditions to achieve a significant improvement of the conditions on site in the architectural implementation.

The possible negative effects of the building on the structures of the building site should be reduced to a minimum. Due to the elevated construction of the building, it is possible to touch the ground only selectively and to keep the paths on the ground free for animals. The excavation work and thus the invasive, constructionally necessary interventions in the soil are reduced by a pile foundation. The building materials are largely limited to renewable raw materials such as wood and natural insulation materials. In addition, care was taken in the design to integrate existing trees into the architectural design and to preserve them. Based on these parameters, the building develops along the contours of its surroundings. The shape of the building is a result of the analysis of the conditions on the building site as well as the needs of the animals and plants of the Wienerberg. The building is oriented in all four cardinal directions along the edges of the riverbank to meet the different requirements of various animal and plant species.

In the walls of the building, variously dimensioned openings are generated, which can provide a habitat for a variety of animals. Depending on the orientation to the sky, the position in the terrain and the surrounding environment, the building manages to provide a heterogeneous range of retreats, nesting sites and winter quarters. The wall thickness can vary flexibly, as the supporting or insulating level is decoupled from the habitat level. The walls are located at different heights in relation to the surrounding terrain and are partly directly connected to the ground, to also provide a refuge in the façade for animals that live close to the ground. Two of the habitat walls have a slight forward slope, which provides a nesting site for kingfishers and sand martins, which otherwise like to nest in overhanging bank slopes.

Several habitats for plants and animals are integrated into the wooden platforms, some of which also benefit humans. Large earth troughs embedded in the platforms provide sufficient space for wildflowers and perennials to settle, creating new habitats for insects and microorganisms. The platforms closer to the water or the ground are filled with sand and gravel, as there is a lack of free sand or gravel areas on the Wienerberg. These areas are used for sand bathing by birds, egg laying by amphibians, but the coarse sand is also an ideal place for wasps to lay their eggs.

Since many different animals and plants are integrated into the design and some of them come into very close contact with people, the aim of the building is to create an awareness among people for the correct, mindful treatment of living creatures and plants. In the course of the work, new questions have arisen again and again. How can humans and animals live together? What limits may or may not be crossed in order not to restrict the well-being of the protagonists?

The basic idea is that the reaction of the animals to, for example, too much noise or hectic movements on the part of the humans will lead to an intuitive change in behaviour on the part of the museum visitor. However, it is questionable whether this change in behaviour develops quickly enough so that the animals do not feel permanently disturbed by humans and thus do not settle in the building.

The museum building is divided into four parts and is connected to each other via a common platform. Along the wooden platform, visitors can experience the different natural spaces of the Vienna Wienerberg up close and feel a natural connection with the surroundings. This experience is also to be continued in the interior spaces, which is why large openings to the surroundings are integrated at certain points in the building and nature thus becomes part of the exhibition spaces. The result is a flowing transition from the exterior to the interior. The exhibited sculptures and works of art enter into a close dialogue with nature and human. The museum deliberately works with textures and the contextualisation of the environment in the interior to create a unique exhibition experience in which nature plays just as great a role as the works of art on display. Art is by no means intended to compete with nature, but rather to merge the two.

The design strives for a harmonious relationship between man, nature, and the exhibited art, and attempts to strengthen man's awareness of his environment through the deliberately created proximity.

It remains to be seen to what extent the conceptual considerations are tenable and which animals and plants would settle in and around the building. Although the project creates a broad range of nesting sites, habitats and green spaces for various animals and plants, the development of the building over several years can only be guessed at the present time. The actual processes should be documented in a further analysis, which will generate information for future Ecolopes projects to develop increasingly attractive and functional habitat facades.

6

APENDIX

Bibliography

Gottfired HAUBENBERGER, Vom Wienerberg: Ziegelweide - Ziegelgrube - Lustlandschaft, Wien 2009, S. 35ff.

Felix CZEIKE, Historisches Lexikon Wien, Wien 1992-2004, S. 632ff.

Hans Wolfgang HOFFMANN, Handbuch und Planungshilfe Museumsbauten, Berlin 2016, S.9ff.

Elena Filipovic, Der globale White Cube, in: John, Jennifer u.a.: Re-Visionen des Displays. Ausstellungs-Szenarien, ihre Lektüren und ihr Publikum, Zürich 2008, S. 30ff..

Brian O´Doherty, Inside the White Cube. The Ideology of the Gallery Space, San Francisco 1986, S.14ff.

Karen van der Berg, Das ausgestellte Museum. Von Abu Dhabi nach Teshima, Schwarte, Lutger (Hg.): Paragrana. Internationale Zeitschrift für Historische Anthropologie, Bd. 26, Berlin 2017, S. 64ff.

Hanno Rautenberg, MOCAA. Hier geht es in die Höhe, in: Zeit Online, Hamburg 13.09.2017

Peter Schneemann, Wenn Kunst stattfindet! Über die Ausstellung als Ort und Ereignis der Kunst, Köln 2007, S. 75ff.

Markus Brüderlin, Die Transformation des White Cube. In: Brian O´Doherty, Inside the White Cube. The Ideology of the Gallery Space, Berlin 1996 S.139-166

Christian Teckert, Display als Dispositiv. Die Ideologie der Ausstellung als Thema zeitgenössischer Architektur, Köln 2007, S.187ff.

Maike WAGNER, No way out. (Kein) Ausweg aus dem White Cube, Bochum, 2018, S.11

Tomas ALTROGGE, Michael HORMANN, Jen KREWEDL, Kimbell Art Museum - Louis Kahn / Licht & Architektur, 2001, S.1-3

Gisela BAUERMANN, Dia:Beacon - Kunsthalle am Hudson River, Artikel aus der Bauwelt 39, 2004, S. 28-33

Areti MARKOUPOULOU, Responsive Cities: Design with Nature - Symposium Proceedings 2021, S.370

Web Pages

https://www.tagesspiegel.de/wissen/mehrfamilienhauser-sind-sinnvoller-als-singlewohnungen-6598321.html

https://www.wien.gv.at/umwelt/wald/erholung/wienerberg/ , Accessed 10.08.2022

https://www.biotopecity.wien/ueber_die_biotope_city_wien, Accessed 10.08.2022

https://www.wien.gv.at/stadtentwicklung/strategien/step/, Accessed 10.08.2022

https://www.wien.gv.at/stadtentwicklung/strategien/step/step2035/index.html, Accessed 10.08.2022

https://www.biotopecity.wien/ueber_die_biotope_city_wien, Accessed 11.08.2022

https://www.sueddeutsche.de/kultur/richard-rogers-architekt-nachruf-city-of-london-centre-pompidou-1.5491215, Accessed 14.08.2022

https://www.tate.org.uk/art/art-terms/w/white-cube, Accessed 21.08.2022

https://www.baunetzwissen.de/licht/fachwissen/tageslichtanwendungen/tageslicht-in-museen-752089, Accessed 22.08.2022

https://deu.archinform.net/projekte/2657.htm, Accessed 22.08.2022

https://www.baunetzwissen.de/licht/objekte/kultur-bildung/museum-folkwang-in-ess,
Accessed 22.08.2022

https://arthist.net/archive/7946,
Accessed 23.08.2022

https://sculpture-network.org/de/Entwicklung-zeitgenossischen-Skulptur,
Accessed 23.08.2022

https://de.wikipedia.org/wiki/Alfred_Hrdlicka,
Accessed 23.08.2022

https://de.wikipedia.org/wiki/Franz_West_(K%C3%BCnstler),
Accessed 23.08.2022

https://www.ulriketruger.at/biografie,
Accessed 23.08.2022

https://www.ulriketruger.at/texte,
Accessed 23.08.2022

https://de.wikipedia.org/wiki/Erwin_Wurm,
Accessed 23.08.2022

https://de.wikipedia.org/wiki/Brigitte_Kowanz,
Accessed 23.08.2022

https://www.co-vienna.com/de/leute/die-gelatins,
Accessed 23.08.2022

https://de.wikipedia.org/wiki/Yayoi_Kusama,
Accessed 24.08.2022

https://de.wikipedia.org/wiki/%C3%93lafur_El%C3%ADasson,
Accessed 23.08.2022

https://www.srf.ch/kultur/kunst/olafur-eliasson-in-basel-die-fondation-beyeler-steht-unter-wasser-fuer-die-kunst,
Accessed 24.08.2022

https://www.ecolopes.org/about-ecolopes/,
Accessed 25.08.2022

https://www3.ls.tum.de/fileadmin/w00bds/toek/pics/Figure1.jpg,
Accessed 25.08.2022

https://wien.orf.at/stories/3162607/, Zugriff, am 29.08.2022
https://www.wien.gv.at/umwelt/wald/erholung/wienerberg/,
Accessed 29.08.2022

https://www.baunetzwissen.de/licht/fachwissen/tageslichtanwendungen/tageslicht-in-museen-752089,
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The increasing density of cities in recent decades has had a strong negative impact on people. Due to the rising temperatures, summers in the city are becoming progressively unbearable due to the lack of temperature-regulating greenery.

The heavy sealing of the soil and the constantly decimating green spaces also have a negative impact on animals. They continue to lose much-needed urban habitat, which has reduced the populations of certain animal species to alarmingly low levels. Therefore, new innovative approaches and solutions are needed in architecture to integrate habitats for animals, plants and microbes into building structures in order to generate new unique habitats, which would improve the microclimate in cities and reduce the impact of climate change.

The aim of the work is to explore the possibilities of merging architecture and nature, and to generate possible solutions for a future architectural economy. The design possibilities are examined on the basis of a sculpture museum on the Wienerberg. The guiding idea of the design is based on the Australian architect Glen Murcutt whose principle was to “touch the earth lightly”, which is why the focus is not only on the creation of habitat for plants and animals, but also to only intervene minimally in the existing natural spaces on the Wienerberg.

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