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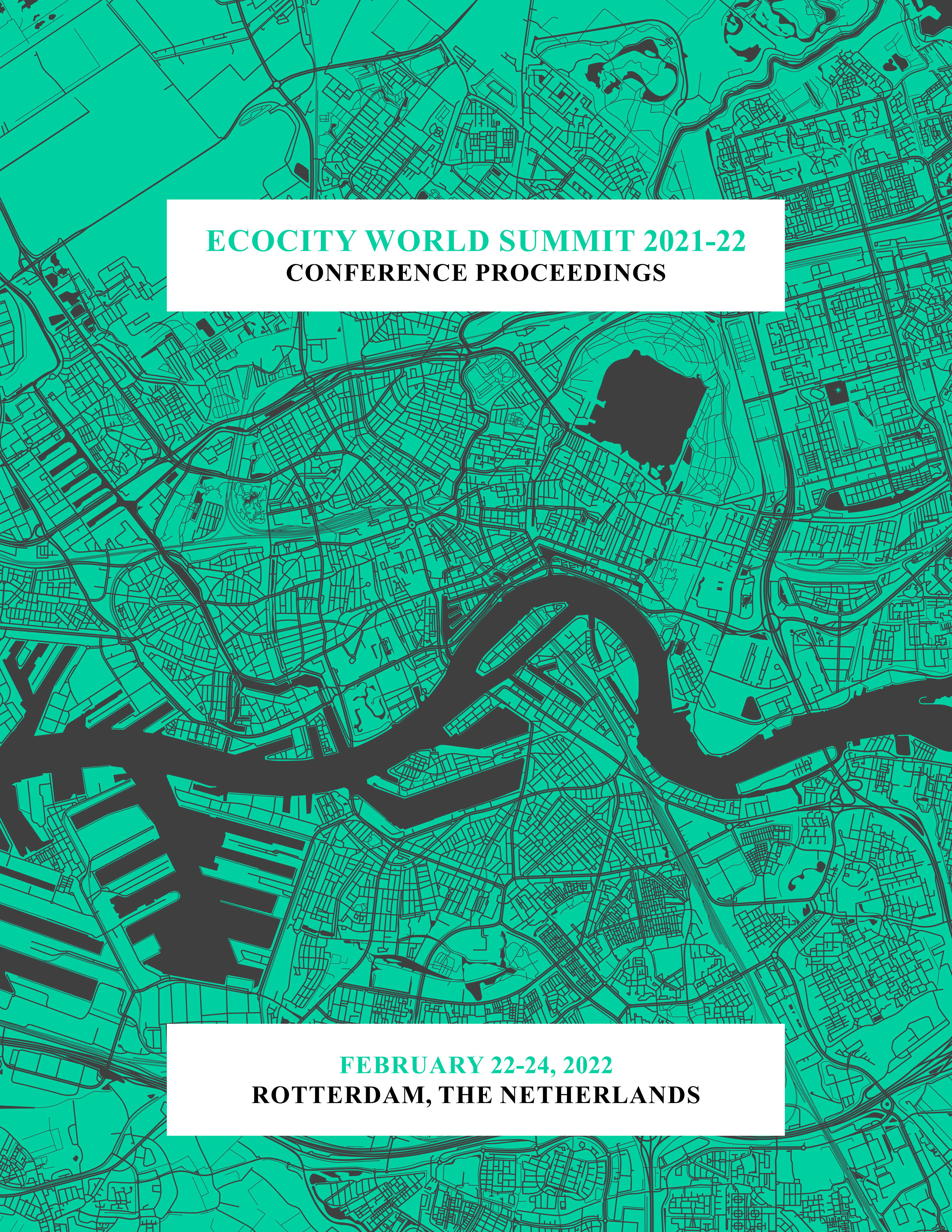

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DESIGNING FOR BIODIVERSITY - CONCEPTUALIZATION OF A SUSTAINABLE BUILDING ENVELOPE FOR A SINGLE-FAMILY HOUSE IN SWITZERLAND

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ABSTRACT

In urban areas, the promotion of biodiversity is gaining importance. On the one hand, biodiversity is dwindling due to intensive agriculture and the loss of habitats; on the other, cities offer a variety of suitable microclimatic conditions for plant communities and animals, which can be implemented through sustainable planning. This work aimed to develop a feasible concept for a building envelope to promote biodiversity, considering the surrounding habitats while addressing the specific needs of target animal species. This required a close cooperation between architects and environmental engineers. The study case selected was a family house in Gattikon (Zurich, Switzerland), belonging to the Swiss architectural office VBAU and subjected to renovation.

First, a site analysis was run to map local habitats, animal species occurrence and wildlife barriers, and simulate the time exposure to sunlight/ shadows on the building envelope. Second, the criteria to rule out habitats and species was identified following an exclusion procedure. As a result, three habitats and six animal species were selected. Last, a concept for the design of the facade on the base of the ecological analysis results was developed. Bricks were used as suitable material to create a structured green facade that mimics the selected habitats while meeting the ecological requirements of the selected target plant and animal species.

In conclusion, considering both the habitats as a model and the life cycle of the target animal species enabled the selection of plant species to green the facades without missing the survival needs of animal species.

KEYWORDS

Animal-Aided Design, biodiversity, building envelope, bricks, ecological design, facade, green architecture, urban habitat

INTRODUCTION

The sixth mass extinction in world history is already underway [1]. In 2018, 35% of the animal and plant species recorded in Switzerland were considered endangered, missing or extinct [2]. For this reason, promoting and preserving biodiversity in construction and urban planning is becoming critical to fulfil nature conservation aims defined by the Aichi biodiversity targets [3]. Due to the increase of intensive agriculture and the sprawl of urban areas, built environments need to be considered when planning for the conservation of natural and semi-natural habitats. Therefore, planners can use near-natural landscaping, green roofs, and facade greening [4] not only to promote biodiversity, but also to provide benefits to people well-being, protect the buildings from weathering and UV radiation, as well as cooling the air, binding carbon dioxide and filtering pollutants and fine dust [5]. Nevertheless, to successfully incorporate biodiversity features into the building and to make it part of the whole design/ planning/ monitoring phases [6], the cooperation between construction planners and ecologists or environmental engineers through the whole project is crucial [7].

Species-based concept

A method used commonly to integrate biodiversity in designing practice is the *species-based* concept. In particular, considering that finances, time and, in some cases, knowledge are insufficient to develop measures for all threatened animal and plant species, it is common to privilege umbrella species, namely those whose protection would ensure that of many others [8]. For example, the protection of the capercaillie (*Tetrao urogallus*) has significantly increased the species diversity of endangered mountain birds with similar habitat requirements in the Swiss Pre-Alps [9]. In the urban context, the universities of Freisingen and Kassel in Germany have further developed the Animal-Aided Design (hereafter AAD) © method [10, 11]. In a nutshell, the AAD concept aims to integrate the requirements and characteristics of the target species into architectural and landscape design. To this end, AAD uses *species portraits* which contain the information necessary to the construction planner about the needs of the species across their life cycles [10, 11]. Nevertheless, it was shown that the use of this method might be not sufficient in terms of number of promoted species [12]. In fact, only few species genuinely benefit from it, and therefore the created habitat may not be as biodiverse as wished [8]. Instead, it might be more efficient to look at entire habitats [13].

Habitat-based concept

Another complementary approach was developed by Chartier Dalix Architects and applied in their project in Boulogne-Billancourt (Paris, France) in 2014. In this case, instead of explicitly integrating some animal's needs into their design, they designed a school building to imitate entire habitats: the facade was inspired by an old structurally rich stone wall with crevices and holes, providing space for vegetation, insects and small birds. On the green roof, plants were introduced so to resemble an oak-hornbeam forest typical to the French region of Ile-de-France near Paris, surrounded by a mesophilic herbaceous edge and a meadow [14]. The hope was, that the ecosystem would be able to develop independently. As a result, 70 new plants were recorded in 2016 in addition to those planted [15]. Even though this *habitat-based* concept encompasses several plant and animal species, a pure consideration of ecosystems might be too broad to protect certain target species [16].

Aim of the study

Combining the *species-* and *habitat-based* concepts, this study aims to overcome the identified gaps and explicitly embed biodiversity features on the building's envelope. Therefore, we intended to develop a method being 1) space- specific and able to select the habitats to replicate on the facade hosting target animal and plant species, 2) flexible enough to be implemented in other projects, fulfilling different requirements in other social and ecological contexts.

MATERIALS AND METHOD

The method itself is divided into three phases (Fig. 1): 1) the site analysis, 2) the selection of animal and plant species and 3) the design of a concept of the facade. The first two phases consisted of an analytical process based on collecting and interpreting the spatial data (species and habitat distribution). The third phase integrated the needs of the stakeholders (architectural firm involved) thanks to workshops and discussions facilitated by the selection of inspiring examples already planned or build.

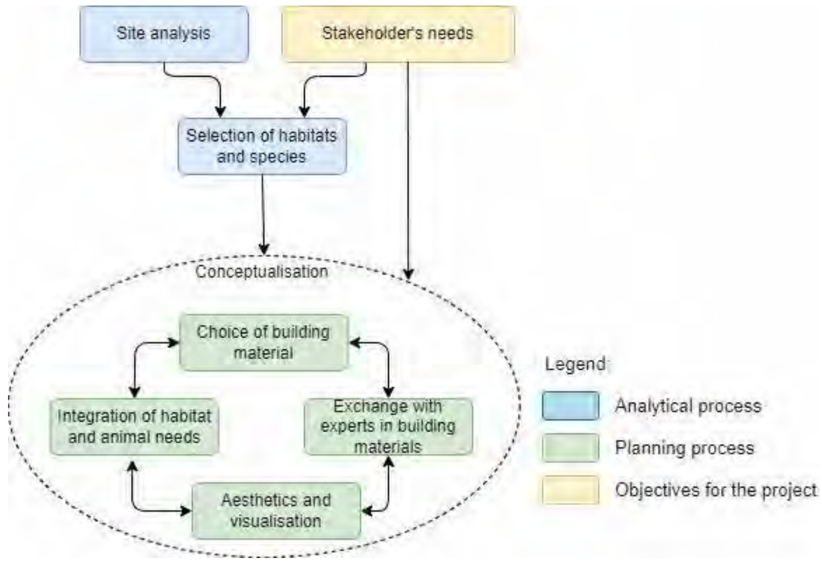

Figure 1: Overview of the work procedure

The study object was a single-family house (Fig. 3) owned by the architectural office VBAU Architektur AG, located in a small village of 2615 inhabitants within the municipality of Thalwil in Switzerland (Adress: Waldstrasse 12, 8136 Gattikon ZH; Coordinates LV95 2693965.2E/ 1237350.04N) [17].

Figure 2: The study area (1.2 km^2): green = forest, blue = ponds, red circle = house location (GIS Canton Zurich)

Figure 3: West side of the building with access to the street (photo: myHausverkauf)

Site Analysis

The first step was to analyse the surroundings of the house, namely the habitats and animals occurring in the nearbies. For this, a study area of approximately 1.2 km^2 around the house was investigated (Fig. 2). Impenetrable barriers for terrestrial animals, like the highway, were selected as the borders [18].

To retrieve the animal species occurrence, the following open-source data repositories were screened: "https://opendata.swiss/de", "https://www.bafu.admin.ch/bafu/de/home.html", "https://www.geolion.zh.ch" and "https://www.geocat.admin.ch". Moreover, the citizen science platform "https://www.inaturalist.org" and the Swiss Data centre Info Fauna (SZKF) – the data of the latter not shown in this paper - was used to retrieve animal and plant observations. All the data collected, including the surrounding habitats such as forests, ponds, settlements, barriers for animals (e.g., fences, walls, roads, and rivers) and access points to the building proximity were mapped and further analysed by means of the programme ArcGIS (ArcGIS pro advanced/2020/3.1). The satellite aerial view was retrieved from *swisstopo* "https://www.swisstopo.admin.ch/de/home/meta/angebot/online-tools.html". Existing data from the local ecological network showing the barriers and the corridors for ground-based animals was added too [19].

Finally, the number of shading hours of the longest and shortest day of the year (December 22, 2020 and June 22, 2020) on each facade side of the building was simulated with the shadow analysis tool (Shadow analysis for Sketch Up/2020/2.1, Deltacode) on a 3D model of the building.

Habitat and target species selection

In the second step, the habitats to be replicated and the target animal species, to be promoted as part of this project, were selected. As for the target species, only those who were already observed in the area or whose occurrence was documented in other local initiatives were considered [18, 19]. The following criteria were used for a further selection of the target species:

a. promotion requirements (at least one criteria must be fulfilled):
   i. The species was one of national priority according to the Swiss red list [20, 21]
   ii. The species was a relevant umbrella or flagship species.
   iii. The species was already included in local biodiversity conservation measures, actions or plans from organisations or the municipality.
b. compatibility between animals and humans (all criteria must be fulfilled):
   i. Humans would not be drastically disturbed by the species (e.g., with noises or hazards or damaging the building with nesting).
   ii. The species was observed living in the urban context.
c. feasibility in the project (all criteria must be fulfilled):
   i. The species was compatible with the other selected target species.
   ii. The implementation of measures needed to support the species (e.g., food, breeding, shelter) was feasible and affordable.

A species profile for each target species was created following the AAD method and contained: 1) the description of the species most critical needs over the entire life cycle (e.g., pairing, raising cubs, adult phase and wintering), 2) species affiliation (e.g. related species), 3) the occurrence in Switzerland, 4) the preferred habitats and shelters, 5) social behaviour (e.g. live in colonies or as individuals), activity (i.e. nocturnal or diurnal), action radius or hunting ground, and 6) status (e.g. threatened). The information needed to build each species profile was based on scientific literature and on data published by recognised organisations such as the Swiss Society for the Protection of Animals (STS), the German Society for Nature Conservation (NABU) and local ornithological stations.

Habitats from the literature *Habitats of Switzerland* [22] and that are surrounding the study area or could be easily integrated on a facade (e.g., not habitats requiring a large amount of water) were considered for the project. Moreover, a benefits analysis was carried as a decision-making aid for complex problems. In the process, the potential solutions are broken down into different main- and subcategories, and their importance is assessed by using a semi-quantitative scale. Thus, aspects of different types (quantitative and qualitative) can be compared [23]. The habitats were assessed and evaluated in the following categories and subcategories in which habitat could score up to 100 points:

- The correspondence of the habitats with the temperature, soil acidity and nutrient content, precipitation and the shading of the site [24].
- The status (e.g., endangered, locally threatened) as well as the spatial distribution in Switzerland [22]. A higher score prioritised the habitats on the red list. In addition, the correspondence of the climatic zone of the habitat was also rated.
- The aesthetic potential value of the plant species. The habitats characterised by valuable plants for the residents got higher points.
- The feasibility of each habitat considering the initial and the maintenance costs.

The assessments were based on values taken from Landolt et al. [24] and Delarze et al. [22] as well as on the results of the shadow analysis. Due to the different shading, each side of the facade, the eaves and the ground was assessed individually. The habitats with the highest scores were selected and applied in the third and final exclusion procedure. Finally, the Landolt indicator values [24] of the plant species characterising each habitat [22] and the plants growing on sight were compared. The indicator values indicate various site conditions suitable for the plant growth on a scale of one to five and include parametres such as: soil moisture (M), soil reaction (R), soil nutrient (N), light (L), temperature (T). This made it possible to exclude habitats whose indicator values hardly matched those of the existing plant species. The values of the temperature and light were particularly decisive for the exclusion procedure.

Design of a concept of the facade

To develop the concept of the new facade, a suitable building material was selected. The building material itself should consist of a natural raw material, be frost-proof and moisture-resistant, and minimise the impact on the environment. In addition, the material had to be adaptable to different design solutions. The whole process was carried out taking into account the advice of producers of different building materials and the VBAU architectural office.

Once the material was selected, similar projects like the structured facade of the Project in Boulogne-Billancourt from ChartierDalix served to inspire the design of the facade. The site analysis, the needs of the selected habitats and target species helped to determine the structure of the facades and the composition and thickness of the substrate. Finally, possible individual facade structures, the so-called *modules,* were created with the programme SketchUp (SketchUp/2020/2.1). Each element should provide either a shelter for the target species or allow the planting of the recommended plant species on the selected habitats. The next step was to determine which habitats and species were the most suitable for each side of the building and, thus, which *modules* should be used. The shadow analysis provided the basic clues to address this process. Plant species were divided into three categories based on their estimated growth: small (maximum height up to 50 cm), medium (maximum height between 50 and 100 cm) and large (maximum height more than 100 cm). Based on these size categories and the Landolt values for light (L), the habitat suitability for each vegetation type was estimated.

Finally, the elements were included in the 3D-model of the building and illustrations were created with Photoshop (Adobe Photoshop/2020/21.1.2).

RESULTS

Site analysis

The shadow analysis allowed to quantify to what extent the shading time on the north-facing facade (Fig. 4) is longer with respect to the south-facing facade (Fig. 5). As expected, the facades on the east and the west side are partly sunlit and shaded throughout the year.

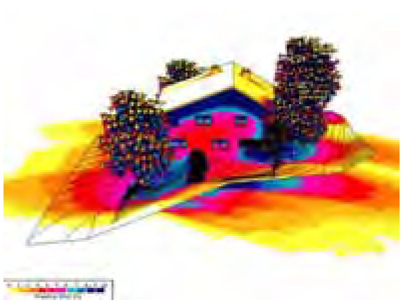

Figure 4: Shading duration on north-facing side (June 22 2020) is between 4 to 10 hours/day

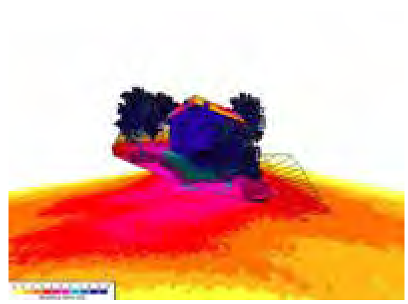

Figure 5: Shading duration on south-facing side (June 22 2020) is between 4 to 10 hours/day

Figure 6 shows the different habitat types and plant communities that have been surveyed for the site analysis . The forest covers 54% of the area on the map, whilst 4.2% of the considered surface is made of wetlands and 4.8% corresponds to agricultural zones. According to the site analysis, the following six habitats were relevant (habitat definition follows Mucina et al. 2016): Meadows on temporarily wet soils (*Molinion*), Reed swamp vegetation (*Phragmition*), Sedge-bed marsh vegetation (*Magnocaricion*), Basiphilous beech forest of temperate Europe (*Galio- Fagenion*), Acidophilous beech forest of Central Europe (*Luzulo-Fagenion*), Mesic mown meadow (*Arrhenatherion*). According to the Swiss Data centre Info Fauna (SZKF), more than 180 animal species were observed in the region within the last twenty years. The building is close to a conservation area with high biodiversity (in particular the pond named "Gattikerweiher") where several corridors for terrestrial and flying animals are leading to the building (Fig. 7).

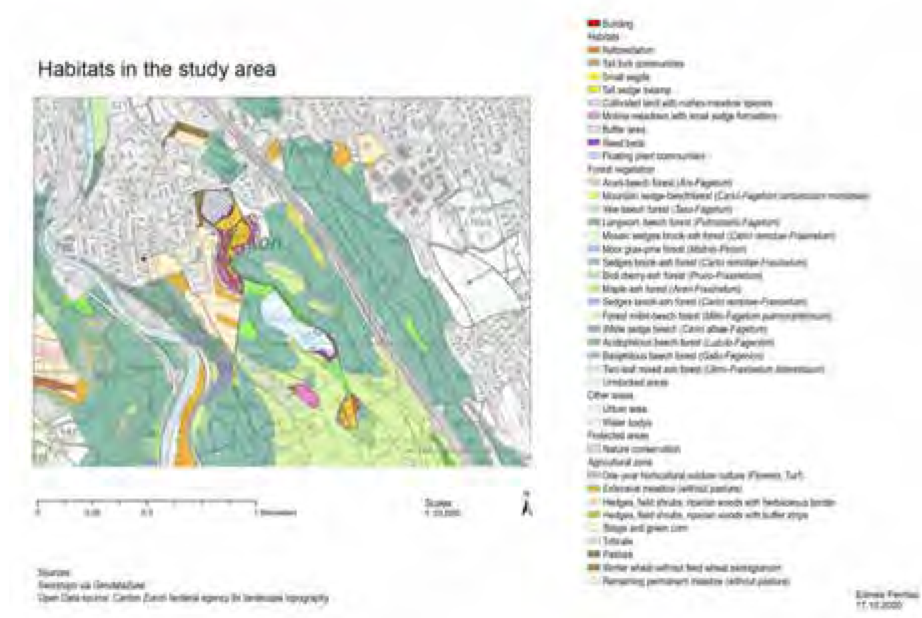

Figure 6: The habitat mapping of the study area in Gattikon shows more than 20 habitats and their plant communities (Data from Zurich federal agency for landscape topography, 2017)

Figure 7: Barrier map created via ArcGIS; green lines show the access to the building available for ground- based animals, the purple lines the access for flying animals (Data from Zurich federal agency for landscape topography, 2017; municipality thalwil, 2017)

Selection of the target species and habitats

Of the observed animal species in the study area, the following six target animal species were selected based on the declared criteria (promotion requirements, compatibility between animals and humans and feasibility in the project): greater mouse-eared bat (*Myotis myotis*), common redstart (*Phoenicurus phoenicurus*), common hedgehog (*Erinaceus europaeus*), common house Martin (*Delichon urbicum*), masked bee (*Hylaeus* sp.), and sand lizard (*Lacerta agilis*).

The sand lizard, for example, was selected because it was observed several times in the study area, it is considered vulnerable [20], and it is also an umbrella species [25]. Other animal species, such as the sand bees (*Andrena* sp.) and natterjack toads (*Epidalea calamita*) benefit from implementing the needs of the sand lizard, as they live in similar site conditions. In addition, the sand lizard does not cause any damage to the building, it adapts to settle in urban areas, and it needs specific site conditions that are feasible to apply in the project.

For each selected animal, a species profile was created. The crucial information – namely the critical location factors by life stage – from the sand lizard`s profile is shown below as an example:

- ***Egg-laying and hatching:*** A suitable site for oviposition is characterized by low vegetation and requires a substrate that is loose and aerated such as sand, gravel, or lava rock. This area should be around 1-2 m^2 large, 0.3 m deep, and be in a south-westerly exposition [10, 26].
- ***Adult:*** The sand lizard depends on wide temperature ranges in their environment. Therefore, habitats hosting patchy vegetation including shady and sunny areas are suitable. On the one hand, the sand lizard needs vegetation-dense structures to hide from predators such as bushes or tall grasses; on the other hand, they prefer low vegetation ground for hunting and foraging. Materials that heat up quickly are needed in the habitat, such as dead wood, stones, or dry vegetation. At night, sand lizards retreat into crevices or underground tunnels. The predators of adult sand lizards are the smooth snake, various mammals such as cats or martens, magpies, birds of prey, or crows [10, 26, 27].
- ***Winter quarters:*** From the end of September to April, sand lizards go into hibernation. For this purpose, cavities and tunnels are dug, or crevices are used. The hibernation site must be sufficiently insulated and frost-free. A south-facing slope is usually suitable [10, 26].
- ***Territories and pairing:*** Young lizards need to find their territory to stay for their whole lives. The males defend their territory against other sand lizards, whereas the females sometimes share their location. The sand lizards mate from mid-April to mid-May [10, 26].

Of the assessed habitats, the three following habitats were selected based on the declared criteria (the correspondence of the habitats with the on-site factors, the status of the habitat, the aesthetic potential values, the feasibility): *Centrantho-Parietarion* for the south-facing side, *Trifolion medii* for the west/east-facing side and the herbaceous layer of *Galio-Fagenion* for the north-facing side. The process to get this result is explained in the following paragraph: First, two out of the six habitats in the study area (*Phragmition* and *Magnocaricion*) were excluded because of the high amount of water required. The remaining four habitats were: *Molinion*, *Galio-Fagenion*, *Luzulo-Fagenion* and *Arrhenaterion.* Second, the following habitats were also considered, because they were judged to be compatible with the climatic conditions of the building envelope or because they already occur in urban areas: *Geranion sanguinei*, *Berberidion*, *Galeopsion segetum* and *Centrantho-Parietarion* for the south-facing side; *Trifolion medii* for east/west- facing side, *Cystopteridion* for the north-facing side. Third, the habitats were scored for each side of the building in each category as listed in the method. For the selection process of the habitat, the results concerning the south-facing side are shown as an example in Table 1.

The scale went from 1 to 100, whereas the highest scores point out that the habitats were more suitable for the facades. Last, the Landolt values of the plants on site were compared with the ones occurring in the most suitable habitats (Table 2). The habitats with the most overriding numbers were finally selected.

Table 1: Final results of the benefit analysis of each selected habitat for the south-facing side of the facade.

Name	*Eaves*	*Facade*	*Ground*
Geranion sanguinei	53.1	56.3	45.1
Berberidion	48.2	63.8	63.2
Galeopsion segetum	46.9	61.1	55.3
Centrantho-Parietarion	51	82.2	72.2
Selected	***Geranion sanguinei***	***Centrantho-Parietarion***	***Centrantho-Parietarion***

Table 2: The Landolt values of the plant species compared with the reference plants on the south-facade [22].

Name/ Index	**Moisture**	**Reaction**	**Nutrient**	**Light**	**Temperature**
Centrantho-Parietarion	1 to 3 +	4 to 5	2 to 3	3 to 4	4+ to 5
Geranion sanguinei	1 to s 3	3 to 5	2 to 4	3 to 4	3 to 5
Reference Value	2+ to 3	3	3 to 4	2 to 4	3 to 4+

The compatibility between habitats and animal species was verified throughout the whole process. In Table 3, the target animal species are listed in their suitable habitats.

Table 3: Compatibility between selected habitats and target animal species [21, 20].

Habitat Type	**Animal species**
Galio-Fagenion	*Myotis myotis, Lacerta agilis* (only in forest edges), *Erinaceus europaeus*
Trifolium medii	*Phoenicurus phoenicurus, Lacerta agilis, Hylaeus* sp.
Centrantho-Parietarion	*Lacerta agilis, Hylaeus* sp.

Designing and conceptualization

While selecting the materials to be used in the design of the facade, only those with a low environmental impact were considered. In a study by KBOB, rammed earth, wood, sand-lime and bricks were found to have a lower impact on the environment [28]. Bricks were finally chosen as the most suitable material because they are widely used in architecture and they are available in several shapes and sizes. The 'structural liberty' offers a wide range of possibilities to realize facade greening and nesting sites as part of the architecture. The chosen brick type was frost- resistant and contained some holes able to host some substrate to favour plant establishment and growth [29]. To seal the exposed bricks, a plate or mortar would prevent the substrate from falling out. The bigger grip hole of the bricks (88×33×135 mm) gives enough space for plants to grow on lightweight substrate mixtures. The smaller holes provide space for smaller organisms like mosses. Near-natural soil conditions are mimicked by creating a complex combination of depths and layers of the substrate as it is commonly done for green roofs [30]. Every facade side (Fig. 14, Fig. 15) was designed according to the selected habitat and needs of the target animal species. Therefore, each side had different *modules* (some examples Figure 8 -13).

Figure 8: The oversized grip hole in the center provides space for medium-sized plants. This design leans to more structure in the facade with small crevices.
Possible animals present: insects
Substrate depth: 14-20 cm

Figure 9: The exposed bricks are placed on top of each other, therefore doubling the substrate thickness. This element is particularly suitable for larger plants or plants that prefer wetter soils.
Possible animals present: insects, spiders, snails, butterflies, small birds, sand lizards.
Substrate depth: 27 cm.

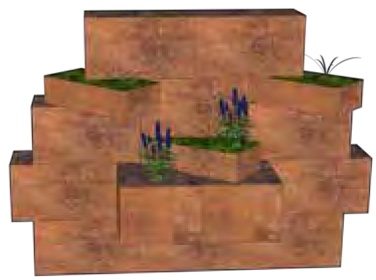

Figure 10: Some bricks lie diagonally above the bigger bricks. This creates an even more complex structure with varying substrate depths.
Possible Animals: insects
Substrate depth: 14-20 cm

Figure 11: Two thin exposed bricks are clamped between two rows of bricks. In this case, these are custom-made (300×120×50 mm). Alternatively, a wooden board can be used. House martins use this board for their nests.
Possible animals: House martins

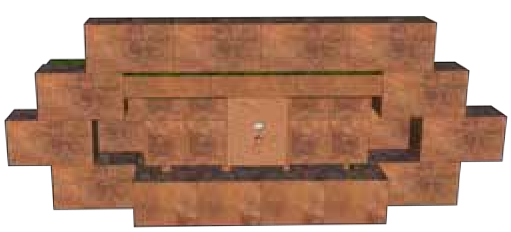

Figure 12: The element contains a nesting box (180×240×200 mm) for the redstart. The nest is protected by a cut wooden board and offers access by means of an oval entrance hole (200×32 mm).
Possible animals: Redstart, other birds

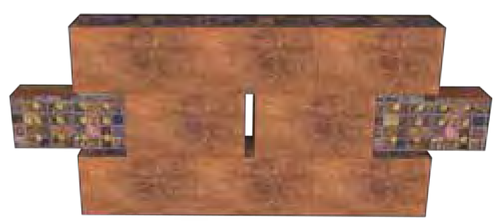

Figure 13: The module provides a gap that can be used by bats. In addition, two exposed stones are turned upside down and serve as an insect hotel. For this purpose, small plant stems are placed in the holes of the exposed stone.
Possible animals present: insects, spiders, wild bees, bats

Figure 14: On the west-facing side, several brick beds are attached to columns so that larger plant species characteristic of the habitats Trifolion medii and Galio-Fagenion. are integrated into the building envelope. Among others: the blackberry (Rubus fruticosus), the hairy sedge (Carex hirta) and the spiky rapunzel (Phyteuma spicatum). The containers shade the facade behind them, which provides a semi-shaded and sheltered niche for the redstart. Plants of the Trifolion medii occur also in the modules near the balcony. On the upper edge of the facade, there are built-in structures on which house martins build their nests.

Figure 15: On the south-facing side of the facade, the habitat Centrantho-Parietarion is imitated. Apiaceae, such as the wild carrot (e.g. Daucus carota), are planted to provide food for the masked bees. The spars in the modules can be used as summer roosts by smaller bat species such as the common pipistrelle. On the top floor, an entrance is built into the attic for the greater mouse-eared bat, separated from the space occupied by humans.

DISCUSSION

The aim of this study was to develop a method for incorporating biodiversity into the design of a building from the outset, using a real study case. The method was inspired by the basic idea of not only *design with nature,* as the Scottish landscape architect McHarg [31] described in his ecological planning methods, but to go further and *design for nature* [32]. The base of *design with nature* is that the designer needs to understand the area through analysis of environmental factors such as soil, climate, hydrology, etc., then decide where and how the urbanization should be implemented to reduce the influence on the most vulnerable ecosystems [31]. *Design for nature* builds on and expands this concept by using ecological digital models and combining them with *sustainability criteria, socioeconomic development goals* and *conservation targets* [32]. In this framework, technologies such as GeoBIM (in which BIM is integrated with GIS) have become a tool that can perform accurate urban analysis and lead to sustainable development [32]. Tackling sustainability, urban development can aim to meet both the SDGs and the Aichi Targets.

The interdisciplinary knowledge required to implement the goals of *design for nature* and the complexity of biodiversity makes practical implementation difficult for planners, architects and biologists. Therefore, trying to combine the *species-based* concept and the *habitat-based* concept represents a promising way of implementing part of the *design for nature* idea into practice without GeoBIM computer models, because they balance their weaknesses out and fill knowledge gaps.

Data collection and site analysis

The building of our case study is located near a nature reserve of national biological importance. In addition, the different shading conditions allow for a variety of dry and wet microclimates on the building. Despite the favourable conditions, the risk of misinterpret data or neglect factors remains real. For example, certain species may not settle in one area because of underestimated disturbance factors such as loud noises or pets. Also, only the shadow analysis and the indicator values analysis of the existing plant species served as information on the location. Furthermore, the data of the animal observations are taken in a range of 20 years. Therefore, it can be assumed that the species which were observed several times in the last 20 years, such as the sand lizard (*Lacerta agilis*), have a stable population. However, it is unclear if birds observed only once, such as that of the grey woodpecker (*Picus canus*, observed in 2008) or the cirl bunting (*Emberiza circlus*, observed in 2013), will occur again in the future.

Selection of animal species and habitats

The site analysis revealed a large range of animal and plant species that could have been eligible in this project. The difficulty, therefore, laid in defining the most effective and objective selection criteria possible for promoting biodiversity on the facade. Other projects/concepts, such as AAD and Projects from Chartier Dalix, helped to form these criteria as they already had monitoring data that allow to demonstrate their success. A main difference from these was that the selection process for the target animal species and the habitats ran parallel, therefore the two methods were mutually dependent and supportive. The fact that target animal species were supposed to occur in the selected habitats simplified and accelerated the exclusion process.

Designing and conceptualization

The design concept has proven to be flexible and rich in structure. The assessment of whether the building material was suitable for a structurally rich, densely greened facade was mostly based on the advice of experts for the respective building material. The design concept can also be applied to other projects and extended with additional *modules*. In addition to flexibility, the environmental compatibility of the material was crucial. Therefore, the UBP value was used as an approximate guideline to compare ecological building materials, even if it is not an exact value [33].

To minimize uncertainty regarding waterlogging and frost damage, water absorption capacity and frost resistance were considered in the selection of bricks. When creating the modules for the facade, care was taken to ensure that the requirements of the species issuing from the species profiles were met on the facade and in the garden (e.g., entrance holes in the nesting box), but it cannot be guaranteed that the desired target species will settle there. In further studies, the focus could be on the optimal size of the holes containing the appropriate substrate thickness to host the target plant species. In this work we assumed that a plant up to 50 cm height could be planted in the brick hole area of 88×33mm. An irrigation system and the maintenance of the facade has to be tested in further studies.

CONCLUSIONS

This study aimed to successfully design a biodiversity-friendly facade using a combination of the *species-based concept* and the *habitat-based concept*. In the considered project in Gattikon (ZH, Switzerland), it has proven advantageous that a broad spectrum of animal and plant species was covered in the planning by imitating the habitats and important promotion measures for the target animal species were planned at the same time. The advantage of combining these methods became clear when promoting target species for which there was less knowledge about their life cycle needs. In this case, promotion using only the *species-based concept* is more demanding when the information on certain target species was difficult to find. By mimicking the three habitats of *Trifolion medii*, *Galio-Fagenion* and *Centrantho-Parietarion*, which have a variety of suitable flowers for wild bees, the facade became more attractive for wild bees and therefore increasing the chance that the bump-masked bee would also settle there. The *habitat-based concept* in turn benefited from the *species-based concept* in that more details could be planned.

In the next step, to scientifically consolidate the findings of this work, the facade concept needs to be tested and monitored experimentally, as well as plant species growth and dynamics, and material behaviour.

AUTHORS` CONTRIBUTION

CC and Pascal Geiger (PG) arranged the thesis initial framework (topic, generic aims and identification of the study case). BD and EP run the literature review, developed the method, run the analysis, and ideated the design solutions under the supervision of CC and PG. EP and BD wrote the first draft of the manuscript. BD, EP and CC carried out the final revision. All the authors shared the final version of the manuscript.

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