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Data use and interoperability for ecological and spatial oriented design

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Master's Thesis

by

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Abstract:
Fragmentation, degradation, and loss of habitats have caused serious loss of biodiversity. Urbanization especially is exerting an increased social, health, infrastructural and environmental pressure on urban ecosystems. In fact, the ecological footprint of urban areas is set to increase in the coming decades, additionally exacerbated by the effects of climate change. While urbanization and the expansion of the built environment have currently a negative impact on biodiversity, they also represent the greatest opportunity to integrate the promotion of biodiversity into development projects. This is an opportunity to be grasped by the AEC industry to design integrated eco-services and to eco-retrofit our cities, as well as to actively integrate biodiversity conservation into urban planning processes. At the same time, there is still uncertainty on what could be the drivers and incentives for planners and architects to implement such ecological and spatial oriented designs. There is a need of a new way of integrating ecological knowledge early in the design processes, that is focused more on interdisciplinary cooperation and on the integration in the built environment of biodiversity and wildlife inclusive sensitive designs. This thesis investigates the interdisciplinary cooperation and the ecological data interoperability, by seeking opinions of the AEC sector workers, teachers and students, through an online questionnaire about the awareness and readiness towards adopting sustainable and most importantly ecological and biodiversity improving project designs. Furthermore, it investigates the feasibility of developing, through parametric design, a façade integrated target species promoting BIM element. The modeling and parametrization were developed using Revit Architecture, a popular BIM software, whereas Dynamo, a visual programming environment, was used to test the interaction capabilities of such element in relation with its parameters and the ecological information. This thesis is intended, on one hand to improve the interdisciplinary exchange and understanding of ecological information and on the other to explore a way of creating a façade integrated BIM element, that can be adapted and modified in real time in correlation with the dimensions of a selected target species. Thereby providing ecologists, architects and planners with the knowledge and tools to maximize cooperation and the biodiversity potential of their designs.

Keywords: sustainable development; sustainable building; urban ecology; biodiversity; holistic design; Design with Nature; ecological oriented design; Revit; parametric design; integrated biodiversity measure design

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1. Introduction

It has been proven, that the human population has dramatically shifted to urban centers in recent centuries. In effect, only 10 % of the world's population lived in urban areas in 1900, while now this proportion exceeds 50 % and is expected to increase further in the next 50 years [1]. As a result, there has been an increase in social, health, infrastructural and environmental pressure on urban ecosystems.

To cope with the influx of people into cities, these are becoming increasingly densely built-up, and at the same time the agglomerations are becoming more widespread. As a result, in growing cities, internal development and the demand for building land often exert strong pressure on green and open spaces [2]. In fact, the ecological footprint of urban areas is set to increase in the coming decades, additionally exacerbated by the effects of climate change, like extreme weather events, increased heat island effect, worsening air quality and the loss of biological communities and their associated ecosystem services in and around cities [3].

In turn, the increase in urbanization and urban density, can decrease the ecosystem services as Tratalos et al.[4] showed, and also pose dangers for the relationship between humans and nature: on one side, urbanization often goes hand in hand with a loss of biodiversity [5], and on the other, humans are thereby increasingly losing contact with nature [6, 7].

As a response, the diverse functions of urban green spaces are gaining in importance, tackling current challenges such as adaptation to climate change, environmental justice, and the protection of biodiversity. In this context, becomes relevant advancing biophilic urban design and redefining cities as places of restorative nature and understanding them as places that already host nature, as Beatley [8] stresses. The concept of reconciliation ecology described by Francis & Lorimer [9], by which the anthropogenic environment can be modified to promote non-human use and biodiversity conservation without compromising social use, is of relevance as well.

Thus, to design integrated eco-services and to eco-retrofit our cities [10], as well as to actively integrate nature conservation into urban planning processes, become of key importance. This way as stated in the eco-positive design approach, the built environment shall give back to nature more than what it consumes [11], followed by a change in perspective from ecosystem services to urban eco-services [12], aimed at regenerating local habitats by overcompensating the negative impact of the construction.

This concept is also expressed by the net-positive design approach[13], that “Buildings must not only become eco-productive, but must reverse the impacts of previous development and expand indigenous ecosystems and ecosystem service in absolute terms”. For this to happen, the future of biodiverse cities has to be directly dependent on the cooperation of different experts and stakeholders, like engineers, landscape architects, ecologists, architects and urban planners [14]. Collaboration, that needs to incorporate existing ecological knowledge for biodiversity conservation in decision-making processes [15]. Therefore, ecologists and conservation biologists will have to be involved from the beginning of the projects [16], and vice versa, designers shall be incorporated into applied ecology frameworks [17].

1.1. Current state of research

In the last decades there has been the transition in urban design from traditional analogue methods, to computer aided tools. In fact, Computer Aided Design (CAD), Building Information Modelling (BIM) and Geographic Information Systems (GIS) have become increasingly important in architectural and engineering design and in spatial planning. While the transition is far from being completed, the digital innovation in design and planning shows how central the collaboration between design professionals and geographical and environmental sciences experts is, and how it may offer with the support of Information Communication and geo-spatial Technologies powerful tools for earning insights to develop better project designs [18].

In this framework, the “GeoDesign” concept, referred by Omusotsi [19] as an evolutionary step in the GIS field, borrowing concepts from landscape architecture, environmental studies, geography, planning, and integrative studies, can also be applied. As Carl Steinitz [20] says in his book, “designing for change cannot be a solitary activity, rather, it inevitably is a team endeavor with many participants (from the design professions and geographic sciences)”.

In fact, GeoDesign takes an interdisciplinary and synergistic approach to solving critical problems and optimizing projects both on a local and a global scale. The advantage of it, is that it makes the problem solving and the project design optimization an integral part of the workflow, both shortening the cycle time of the design process, by moving the analysis to an earlier stage in the design process and improving the quality of the results [21].

Within this context of collaboration and synergies between different stakeholders, more specifically correlated to the topic of this thesis, different methods or approaches have already been developed to aid and enhance the integration of ecological based project designs.

For one there is the "Animal Aided Design" from Apfelbeck et al. [2, 22], focused on the interaction between landscape architects and ecologists. It is a methodology for the design of urban open spaces, to integrate Fauna biodiversity conservation into open space planning. The basic idea is to include the presence of animals in the planning process, such that they become an integral part of the design. Basically, after choosing in the beginning a target species, a species portrait is developed, listing all the species critical needs, which is then integrated with supplementary planning aids that translate the critical needs into designed features. The requirements of the target species, thus, not only set boundary conditions for the design, but also serve as an inspiration for the design itself. The same authors developed a conceptual framework for choosing target species for "Wildlife-Inclusive Urban Design" by using participative processes to involve different stakeholders. This selection process, suggested to be key for successful wildlife management in urban areas, relies on close cooperation of developers, architects, landscape architects, and ecologists, who should form part of the design team and analyze the project area with respect to human and target species needs. In the selection procedure, participation is based on a pre-selection of species that ensures that potential target species are ecologically and socially sensible and feasible. There is also the concept proposed by Apfelbeck et al. [23] of including wildlife-inclusive city design, that support human-animal coexistence, into the different steps of the urban planning cycle. As successful principles for wildlife-inclusive urban design are proposed: involving ecologists early on in interdisciplinary design teams, taking in consideration the entire target species life cycle, stakeholder involvement and participatory approaches and conducting an active post-occupancy monitoring and evaluation with feedback for communication.

Garrard et al. [15, 24] developed the "Biodiversity Sensitive Urban Design" (BSUD) based on principles ranging from creating habitat and promoting dispersal to facilitating community stewardship. It's a framework aimed at delivering onsite benefits to biodiversity, and that is applicable across a range of urban development types and densities. BSUD proceeds in 6 steps, of which step 5 is optional, it allows a quantitative assessment of the contribution of the built environment to biodiversity: 1) identify and map ecological values, 2) define ecological objectives, 3) identify development objectives, 4) identify actions required to achieve objectives, 5) quantitative assessment of contribution to biodiversity (optional), 6) identify the actions that best meet ecological objectives (Step 2), while also accommodating development objectives (Step 3) for the area.

Finally, it is worth to mention the technical guide developed by Gunnel et al. [25] "Designing for biodiversity", focused mainly on the UK, but collecting valuable knowledge and strategies spendable in an international context as well. This book reviews the needs of UK's building reliant species, while at the same time taking in consideration the build types that are likely to be in use over the next decade and the building regulations, for the enhancement of biodiversity in both new and existing low or zero carbon buildings. Although this guide concentrates particularly on birds and bats, it is recognized that buildings and developments, like e.g., green roofs and green facades, are an opportunity for a greater range of wildlife.

As stated, computer aided tools have gained a prominent spot in the AEC industry. In this context, Building Information Modelling (BIM) enables the digital modelling of complex buildings with accurate geometry and information for the design process and decision-making [26]. BIM can be considered as a digital representation of the physical and functional characteristics of a building. As such, it can be described as a working methodology, which makes it possible to manage the project's 3D-model and data in a digital format during the building's lifecycle[27].

Moreover, this digital representation serves as a shared source of information about the construction, allowing the Architecture Engineering and Construction (AEC) stakeholders to have a reliable basis for decisions during the building's life cycle, from design to end of service life/demolition. Through the BIM methodology, one or more accurate virtual models of a construction, whether it is a building, an infrastructure, or a single element can be digitally constructed. These models can then support the project in its conception phases, allowing improved analysis and control of processes. The models generated in the BIM environment contain the geometry and the data required to support the entire construction process, manufacturing, and activities through which the construction is carried out.

To exploit the most benefits of BIM in each stage, a certain level of accuracy and actuality of the underlying data is needed to describe the information richness of BIM objects. BIM practitioners in the AEC industry use the Level of Development (LOD) as a reference to clearly describe the content and specifications of BIM models for communication among the project teams at different stages of building design and construction processes [28].

The data and software interoperability problem between Architecture, Engineering, and Construction (AEC) teams is on one hand currently being tackled by the ArcGIS GeoBIM software, developed by Autodesk and ESRI (said to be coming 2021). This software, as declared on the homepage [29], should deliver an innovative, easy-to-use web-based experience for teams to explore and collaborate on BIM projects and issues, using data from multiple systems in a geo-spatial context, simplifying the communication and collaboration with teams and different stakeholders.

In Switzerland, the Swiss BIM LOIN definition (LOD)[30], which aims to describe the state and finished state of models, enables those involved in the project, both during planning and realization and subsequently during operation, to understand and use the information.

The abbreviation LOD is sometimes used as the level of detail rather than the level of development. The difference in definition is that the Level of Development describes the output to a BIM level, whereas the Level of Detail describes the input of how detailed a model element needs to be to reach the required level of development (depth of information, visualization). Level of Detail can thus be described as the required input into the element, while Level of Development is the reliable output (state of knowledge, state of planning).

1.2. *Gaps in the field of research*

There is still uncertainty and is still not clear, what could be the incentives for planners and architects to implement ecological /target species data in the project design, as it is not yet become common practice and often depends either on the project contest or on the design team philosophy. As previously addressed, there is a need of including ecological spatial analysis early on in the design processes, but there is also a need for the integration of biodiversity and wildlife inclusive sensitive designs in the building envelope.

For that to happen, the main decision holders, architects and planners, should be on board and motivated for collaborating and be compelled in utilizing the provided information for shaping their vision and design. The improvement of this step could range from changing the format (digital/interactive/PDF-Sheet/3D/) or the platform in which the ecological information is conveyed, to adding additional information, that could be crucial for developing the design from an architectural and engineering point of view. Should also be taken in consideration communication difficulties between different stakeholders, depending on the different expert lingo used. There is also the lack of ready to use 3D Libraries (e.g., for Autodesk Revit, Trimble Sketchup and McNeel Rhino) of ecological 3D BIM models, which, if developed through a parametric design, could facilitate and expedite not only the visualization but the render as well, of different visions and scenarios. These are the main potential leverage points, on which this thesis will focus.

1.3. *Hypotheses and Research questions*

This master thesis is built partly upon my previous semester project about "Implementing ecological site analysis with GIS tools for architecture"[31], in which a methodological framework was assessed, by means of which georeferenced ecological information about habitat suitability of specific target species can be produced, which afterwards should be incorporated early on in the project development.

This work was conducted within the international project "Design and Modelling of Urban Ecosystems: A spatial-based approach to integrate habitats in constructed ecosystems" (hereafter: DeMo) [32], a multidisciplinary framework and design approach tackling the issue of biodiversity loss and habitat fragmentation at landscape, urban and building scale. The DeMo framework aims at enabling ecologists and designers to cooperate from the early stage of a project, in order to integrate habitats and facilitate species colonization and movement in and of built areas. This cooperation is conveyed through digital technologies, such as GIS, BIM, and ecological modelling.

At this juncture, where different stakeholders must collaborate, in order to incorporate a project specific ecological context in the decision-making processes for biodiversity conservation, there is still a need of refining the analysis workflows, as well as tackling data interoperability and accessibility challenges among these different field of applications.

The problematic presented by data interoperability and information use between different stakeholders should be considered on a deeper level. Taking in consideration the prominent role architects and planners often take in shaping and developing project designs, when the ecologists or environmental engineers prepare target species ecological information for the other stakeholders, different questions rise:

For example, if architects and planners find the information, in its content and format, compelling and useful to use, to develop the project design. There is also the question, how deeply they can comprehend the information provided and therefore integrate it in their workflow, or if there are aspects which can be better tuned so to increase the potential translation of information in the project.

In this context, the hypothesis would be, that by elucidating and better understanding the exchange process of ecological information from the perspective of architects, planners and other stakeholders, the collaboration as well the information transfer could be enhanced and improved, therefore increasingly enable architects and planners to integrate such information early in the design.

Thus, with a better understanding of the geographical, ecological, and environmental context of a project, planners, architects, engineers, and landscape architects should then ideally develop the project design based on the analyzed data. In this way, the potential ecological impacts, effects and critical factors of a proposed project could be analyzed up front rather than after the design phase.

The following research questions were therefore developed:

- Which are the most suitable pathways for sharing the results of the ecological analysis with architects and planners, so that it can be implemented in the design process?
- What are the Architects' needs, requirements and hurdles for ecological data exchange, interoperability, and implementation?
- With which data format can they work with?
- Which information should be delivered?
- Can dynamo be used to competently shape and adapt a parametric family based on parameters extrapolated from the ecological information provided?
- Can parametric designed families (Revit) interact in a BIM environment with ecological information (raster Image)?

2. Materials and Methods

The research questions can be divided into two main subsections, each with a different methodology and output. While both subsections are referencing the same case study, the first one is dedicated to collecting qualitative and quantitative data from selected target audiences belonging to the AEC industry through a questionnaire. The second subsection is instead dedicated on creating and testing a 3D BIM model and its interactability with the modeling software Revit and visual scripting interface Dynamo within the case study BIM model.

2.1. Data collection (questionnaire)

Questionnaires can be used for descriptive, explanatory, and exploratory research. The quantitative method is traditionally based on positivist approach used to scientifically explore a certain phenomenon. On the other hand, the qualitative method can provide the intricate details of phenomena, which cannot be derived through quantitative methods [33].

For this thesis was implemented a Web-based questionnaire, deemed the most appropriate for this type of research, as the main advantages are its potential global reach, consumer appeal, flexibility, speed and timeliness, convenience, and ease of data entry. "One of major strengths is that due to the fact that most societies now have internet access and are internet savvy, the basic drawback of online survey research – lack off representativeness" [34].

The questionnaire titled "Data interoperability for ecological and spatial oriented design in AEC", was defined based on the objectives of the research questions and was used as a recognized survey research instrument toward seeking opinions of the AEC sector workers, teachers and students about the awareness and readiness towards adopting sustainable and most importantly ecological and biodiversity improving project designs.

It was prepared in "Google Forms" and was distributed to respondents through a google form link mainly via e-mail, in which clear introduction of the purpose of the study and instructions, how to fill the questionnaire, were provided. The link was also published on LinkedIn on the author's personal page in a later moment.

The questionnaire, which can be found in the attached documents, has 44 items (questions) sectioned 1 to 6, where Section 1 introduces the aim and the scope of the questionnaire, Section 2 is solely dedicated to the privacy statement and GDPR compliance, Section 3 consists of demographic information [Category, role in the field of work etc.], Section 4 is dedicated to assessing the awareness and perception about the topic of biodiversity and ecological based designs, Section 5 is dedicated to evaluating perception and acceptance of "Integrated solutions for Biodiversity", while Section 6 is dedicated to the evaluation of the relevance and importance of different ecological maps applied to the GA Grüental case study from the DeMo project. The questions from section 3 to 6 can be found in Table A1 in Appendix A.

The questions aimed at evaluating the user perception were designed based on a five-point Likert scale rating, with assigned weights of 1, 2, 3, 4, 5 respectively. For example, from [1] "Strongly disagree" to [5] "Strongly agree".

Specific respondents' strata were selected because they are more closely related to the stakeholders involved in AEC project design and development.

The questionnaire was distributed in 4 different instances:

1. Target audience selected from personal/professional contact pool based on geographic region and main field of activity in the AEC sector.
   [36 e-mails sent].
2. Pool of contacts selected because listed as field experts in the Swiss Sustainable Building Association (NNBS) under the category ("Umwelt"; "Nachhaltigkeit").
   [52 e-mails sent].
3. Link posted on LinkedIn with personal account.
   [22 reactions to the post and 838 visualizations]
4. Questionnaire submitted to a class of students during a lecture of the module "Landscape Architecture" of the University of Palermo.
   [submitted to entire class]

The structure of respondents based on respondent's type, category and working experience of respondents can be found in Table 1.

Table 1 Questionnaire – General information: Multiple choice questions about respondent's demographics

Question about	Multiple Choice options
Professional category	Architect
	Landscape Architect
	Ecologist
	Environmental engineer
	Agronomist
	Planner/Urbanist
Professional typology	Government employees
	Private sector
	Self employed
	Teacher Higher education
	Researcher
	Student
Working experience	less than 5 years
	6 - 10 years
	11 - 15 years
	16 - 20 years
	more than 20 years

The names of the participants were coded, according to the respondent's pool and in chronological order as follow [e.g., A12; C2]. The respondents were grouped based on the six main category types. The qualitative study's focus is to explore the magnitude with which the ecological information provided by professionals should be tuned in the view of a professional audience such as architects, landscape architects, environmental engineers, and urban planners to respond to the respondent's requirements for integrating such information from an early point in the project and design development.

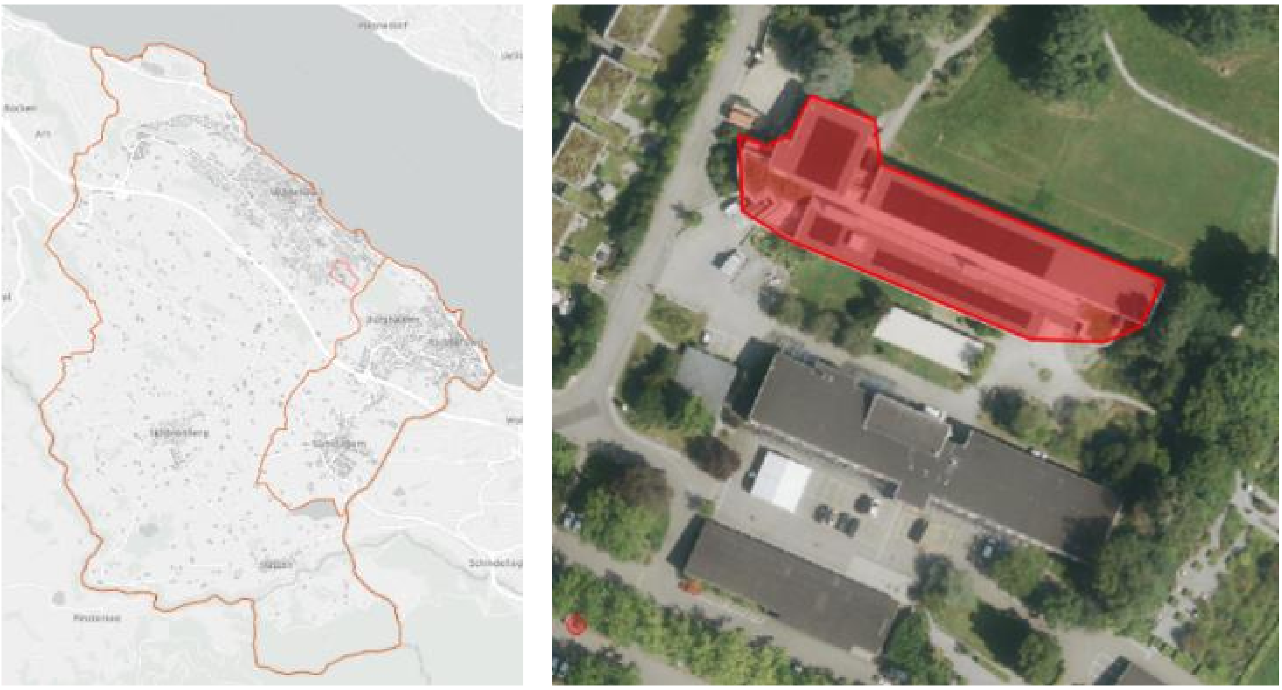
The quantitative study focus is to explore trends about the respondent's awareness and readiness to implement ecological information, also correlated to the respondent's categories (Tab. 1). Due to the overall low response rate across the four respondents' pools, the decision was taken to combine the responses and to analyze them together in Excel (Build 13801.21092). Therefore, must be considered, that due to lack of randomization, there is an overrepresentation of some categories, e.g., architects, within the results, and these become therefore less representative. Some results of the multiple-choice questions and Likert scale questions were expressed as percentage values, without decimal digits to improve readability and usability.

2.2. *Ecological data collection and BIM Model implementation*

This thesis questionnaire and parametric modeling were developed partly based on a case study conducted within the DeMo project, which involved the development of a concept for the renovation of the building "GA" on the "Campus Gruental", while implementing an ecological site analysis with GIS tools in architectural design processes. The aim was to develop an ecological driven design, as well as at creating a collaborative environment and workflow, enabling architects and ecologists to share and modify data so to adapt the design step by step.

In fact, the mentioned concept was to be developed considering from an early stage the ecological and environmental context. For example, looking at ecological corridors present in the municipality, land cover categories, fauna sightings, list of trees and so on. The overall objective of the case study being, developing a building merged in the surrounding ecosystems, by integrating biodiversity measures in the design of the building envelope, so to make the building itself part of the ecosystem.

My second project work in research unit (hereafter: PWRU2) [31], executed within the context of the DeMo project, was focused on an ecological site analysis of 6 avifauna target species (see Table 2), within the spatial system boundary of the joint boundaries of Wädenswil and Richterswil municipalities in the Canton Zurich (Figure 1).



(a) (b)

Figure 1. (a) 2D view of joint boundaries, Case Study perimeter [scale 1:50'000]; (b) GA Building highlight on Campus Gruental [scale 1:1'250] (Orthophoto, https://map.geo.admin.ch/).

Table 2: Target species for the PWRU2 case study Campus Grüental

Taxon	Trivial name_EN	Trivial name_De
Cyanistes caeruleus	Eurasian Blue Tit	Blaumeise
Parus major	Great Tit	Kohlmeise
Hirundo rustica	Barn Swallow	Rauchschwalbe
Phoenicurus ochruros	Black redstart	Hausrotschwanz
Passer domesticus	House Sparrow	Haussperling
Passer montanus	Eurasian Tree Sparrow	Feldsperling

The ecological analysis, executed for the target species in the PWRU2, considered all three scales, landscape, urban and building scale. The analysis was the basis for the development of the workflow represented in Figure 2.

Thanks to GIS, the values of a series of suitability factors were stored in numerical form. The individual suitability maps were then analyzed and combined to obtain an overall target species suitability map. In this workflow came into play the GIS-based Multi Criteria Decision Analysis and various standard GIS tools, used to overlay the reclassified raster and to assign them a specific weight factor. For example, for the DeMo project the case study building GA was of relevance, therefore the GA building footprint was weighted with a factor of 2.

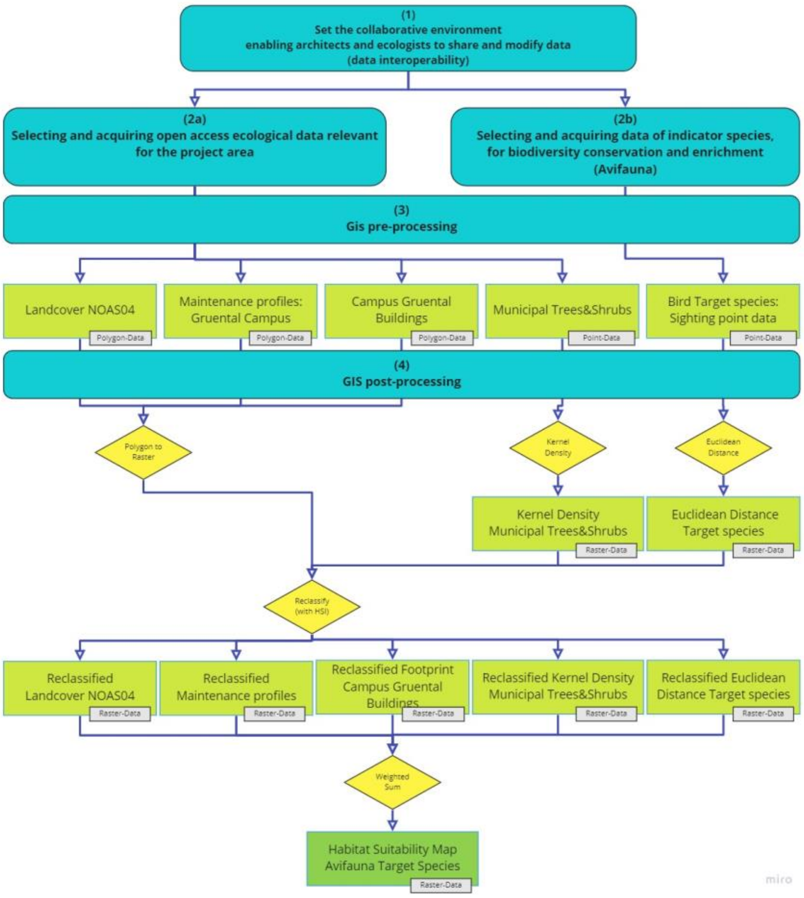
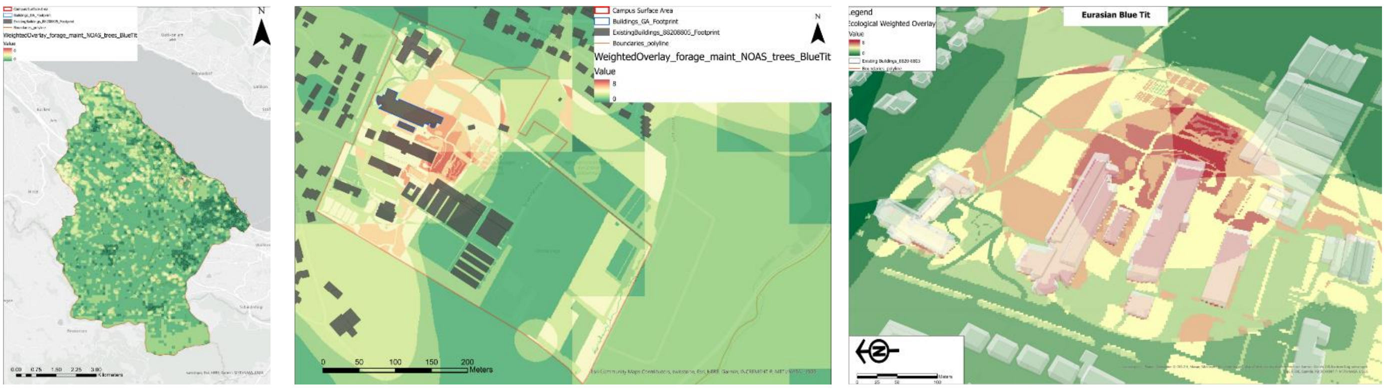


Figure 2: Ecological GIS based Analysis Flowchart[31]

In Figure 3a,3b and 3c can be seen an example of the workflow suitability map output for one of the bird target species (Eurasian blue tit), represented on different scales, combining the foraging range, the landcover categories suitability, the distance to trees-clusters and the campus maintenance profile suitability. The color coding represents the level of habitat suitability for the target species from green (low) to red (high).



(a) (b) (c)

Figure 3. Eurasian Blue Tit suitability maps[31]: (a) Landscape scale [1:50’000]; (b) Urban scale, Detail Campus – 2D View; (c) Building scale, Detail Campus – 3D View .

2.3. *Revit*

The importance of a geometric model with high quality in BIM may require the development of new objects, capable of translating intended construction elements and that once created can be used on other projects. In the Autodesk Revit, there are the so called "Revit Families". Within Revit families, there are several categories for the conception of different types of objects. There are ones dedicated to architectural, structural, mechanical construction elements as well as those with generic capabilities.

In this case study, the objective was to model a simplified bird nesting aid element, to be developed then in a further study in a building envelope integrated element (in this document referred hereafter to as "BNA"). The following steps were completed: (1) creation of an excel table with the BNA parameters based on the properties given by the guide for bird nesting boxes[35]; (2) creating a new Revit family; (3) choose metric wall based model; (4) reference the design to the wall exterior face reference plane for the implementation of the element; (5); development of parameters and constraints based on the excel table and document [35]; (6) upload of the BNA family in the case study BIM model; (7) placement of an instance of the BNA family on the wall. The BIM Model of the GA building was kindly given by fsp Architekten AG[36], who were engaged in the renovation of the GA building envelope in 2020.

2.4. *Dynamo for Revit: A Visual Scripting Interface*

Autodesk Revit allows users to add features to the software and create custom tools and plugins. Dynamo is such a tool, under development by users as a plugin to Revit using the Revit API. It is designed to extend Revit's parametric modeling capabilities by adding a level of associativity that does not exist in the off-the-shelf application. One can visually map the appropriate parameters and dynamically change each value with a value derived from the input source [37].

The elements, with which users interact in Dynamo, are referred to as "nodes". Each node can have a number of "ports", which enable communication between nodes along "connectors". Ports can only be connected to other ports whose output type matches the port's input type, or to any port whose output type is further up the inheritance hierarchy of the port's input type. Together these connected elements create the "workflow".

In this case study was developed a new Dynamo script, which can select one BNA element and change its parameters and dimensions in real time depending on the target species specific dimensions provided in the excel table. Moreover, by defining in Dynamo certain nodes as input and output, the script can be then executed in a more user-friendly interface with the Dynamo player.

2.5. Parametric Design

In this thesis the parametric design study for developing a biodiversity improving element for the case study target species was conducted with two software. On the one hand the modeling and parametrization of the 3D BIM element was executed in the Autodesk Revit API (Application Programming Interface), whereas the interaction capabilities of such element in relation with its own parameters and the ecological information was tested in the Revit plug-in Dynamo.

At the beginning of the study the following main steps were laid down.

- Step 1: Creation of a parametric "Bird Nesting Aid" Family in Revit [wall based]
- Step 2: Dynamo Script for shifting "Bird Nesting Aid" Family parameters based on excel listed bird target species information (Revit Family Instance shaped depending on bird species)
- Step 3: Development of environmental and spatial parameters/constraints for the "Bird Nesting Aid" Family (Distance to floor; Distance to Wall edge; etc.)
- Step 4: Dynamo Script for importing and reading GIS exported raster images (HSI; Species Absence/presence)
- Step 5: Dynamo Script for interaction between parametric "Bird Nesting Aid" Family and imported raster images.

These steps can also be seen graphically represented in Figure 4 as a flowchart.

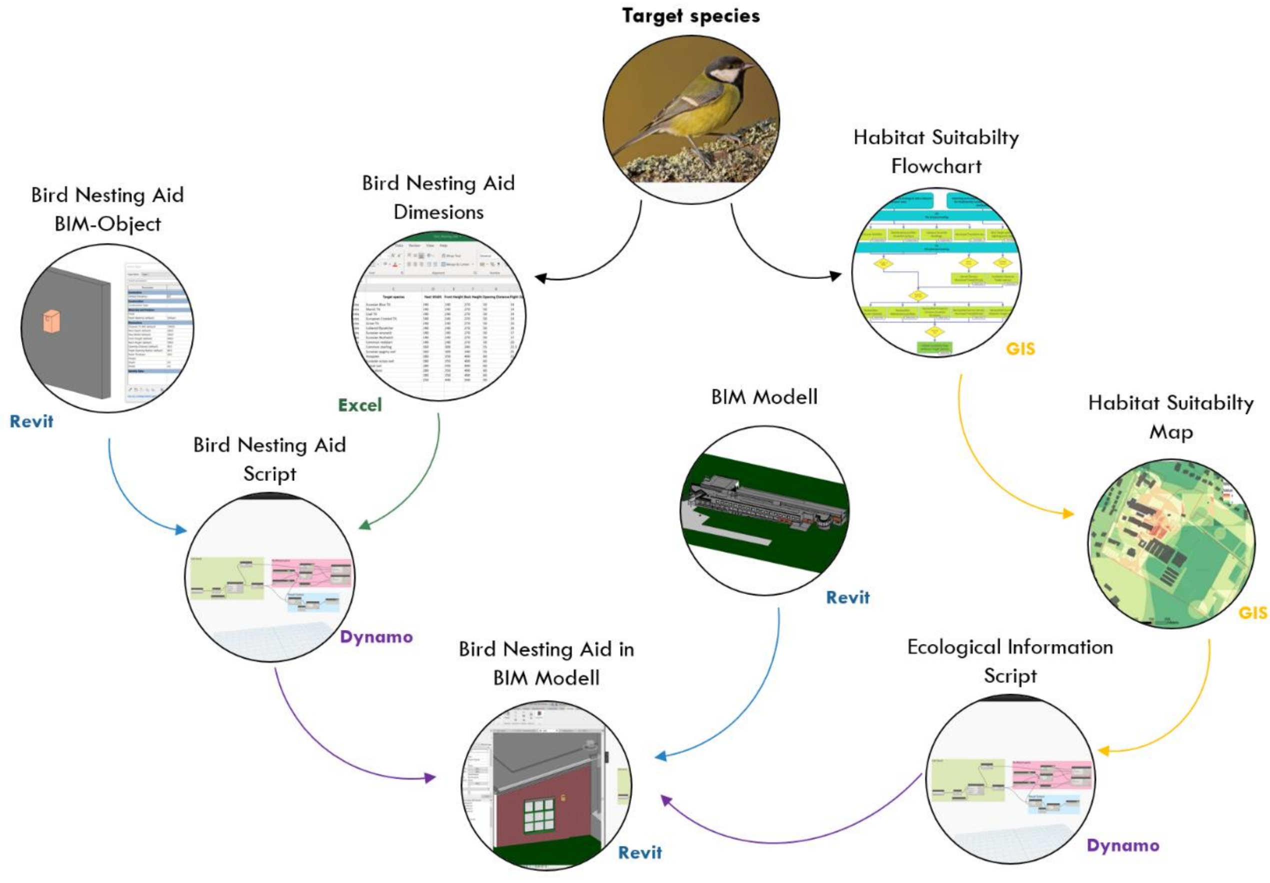


Figure 4 Workflow Excel+GIS+Revit+Dynamo

3. Results and Discussion

3.1. Questionnaire

From the four different target audiences, to which the questionnaire was submitted, came not a lot of responses and had quite different response rates, as can be seen in Table 3.

Table 3 Summary of the questionnaire's target audiences and response rate

Code	Target audience	Nr. of email sent	Nr. of responses	Response rate
A	Professional contact pool based on geographic region and AEC sector	36	19	53%
B	Experts listed in the Swiss Sustainable Building Association (NNBS)	52	4	8%
			Nr. of responses	**Response rate**
C	Link posted on LinkedIn	22 reactions, 838 visualizations	3	14%
D	Class of the "Landscape Architecture" module of the University of Palermo	/	34	100%

While the first and second section of the questionnaire were solely dedicated to introducing the topic and collecting the privacy agreements, the third section of the questionnaire was dedicated to assessing the geographical and demographic distribution of the respondents. In the fourth section the respondents were asked to what extent they agreed with statements about biodiversity and ecological based designs, while the fifth section was aimed at evaluating the respondent's acceptance towards different categories of building envelope integrated solutions for biodiversity improvement. The sixth and last section of the questionnaire was specifically dedicated to the evaluation by the respondents of different types of ecological information.

Section 3: General Information

From a total of 60 respondents, as can be seen in Table 4, half is composed by architects, followed then by landscape architects making 21% and 8% composed by respondents with a multidisciplinary profile. As the question was multiple choice and some respondents had a multidisciplinary profile, the new category "Multidisciplinar" was then added retrospectively.

Table 4: Professional category of questionnaire respondents

Professional category	Frequency	Percentage
Agronomist	1	1.7%
Architect	31	51.7%
Consultant for Sustainability	1	1.7%
Ecobau	1	1.7%
Environmental engineer	3	5.0%
Environmental planner	1	1.7%
Landscape Architect	13	21.7%
Planner/Urbanist	3	5.0%
Spatial data science	1	1.7%
Multidisciplinar	5	8.3%
Grand Total	**60**	**100.0%**

The respondent's strata were mainly composed by students for 56.7 %, followed by 20% from the private sector and 5% researchers, as can be seen in Table 5. In Table A2 in Appendix A can be found the respondents typology grouped by category.

Table 5: Professional typology of questionnaire respondents

Professional typology	Frequency	Percentage
Government employees	1	1.7%
Teacher Higher education, Researcher	1	1.7%
Government employees, Teacher Higher education, Researcher	1	1.7%
Self-employed, Teacher Higher education	1	1.7%
NGO	1	1.7%
Private sector, Self employed	1	1.7%
Self-employed, Researcher	1	1.7%
Researcher, Student	2	3.3%
Teacher Higher education	2	3.3%
Researcher	3	5.0%
Private sector	12	20.0%
Student	34	56.7%
Grand Total	**60**	**100.0%**

In Figure 5 can be seen the geographical distribution of the respondents. It should be taken in consideration, that almost half of the respondents, where from the university class in Palermo, namely all from Italy and almost all architecture students. This had an effect on the relevance of the results divided per category, as there was an overrepresentation of the architect's category.

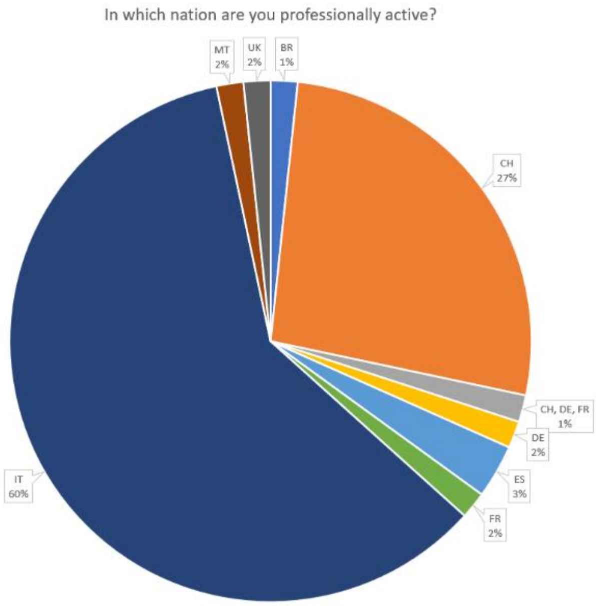


Figure 5 Percentage of questionnaire respondents by geographical distribution

In Table 6 instead, has been reported the percentage and number of respondents according to their working experience.

Table 6: Working experience of questionnaire respondents

Working experience	Frequency	Percentage
0-5	34	57%
11 - 15 years	6	10%
16 - 20 years	5	8%
6 - 10 years	6	10%
more than 20 years	9	15%
Grand Total	**60**	**100.00%**

Section 4 Biodiversity and ecological based design: Awareness and perception

The main points covered were about the promotion of ecological and nature-based solutions and biodiversity conservation actions and their incorporation into urban planning, as well as involving ecologists early on in interdisciplinary teams to implement target species in urban development to create new habitats in both built-up and open spaces, along with using target species as inspiration for developing the project design. The questions and statements of this section were formulated, in order to on one hand asses the awareness and perception of the respondents toward biodiversity and ecological based designs, and on the other to indirectly introduce and prepare them to the topic, so that the respondents could then conduct an informed evaluation of the ecological information in section 5 and 6.

As can be seen in Table 7, there was an overall positive response to the statements from this section, having most of the respondents either "agreed" or "strongly agreed" to the different statements. Thus, demonstrating an overall good awareness of the respondents related to ecological based designs and biodiversity.

Table 7 Responses Section 4 of the questionnaire; Likert scale: 1[Strongly disagree]- 5[Strongly agree]

	1	2	3	4	5	Total
To what extent do you agree that in the age of sustainable development, climate change and biodiversity loss, architects, planners and engineers should promote and implement ecological and nature-based solutions?						
Q5	0%	0%	3%	12%	85%	100%
To what extent do you agree that cities should respond to the biodiversity extinction crisis by incorporating biodiversity conservation actions into strategic planning?						
Q6	0%	0%	0%	30%	70%	100%
To what extent would you agree with involving ecologists early on in interdisciplinary teams to make wildlife an integral part of urban development and thereby create new habitats in built-up and open spaces?						
Q7	0%	0.%	12%	20%	68%	100%
To what extent do you agree with the statement that the anthropogenic environment can be modified to promote biodiversity, without compromising social use and human comfort?						
Q8	0%	0%	15%	32%	53%	100%
To what extent would you agree with implementing target species for wildlife-inclusive urban design/planning, taking in consideration their entire life cycle, not only for the design phase but also for the building operations/ maintenance?						
Q9	0%	2%	20%	20%	58%	100%
To what extent would you consider the integration of target species as a useful tool and as an inspiration for developing the project design?						
Q10	0%	0%	13%	30%	57%	100%

With question 11 (Q11) the respondent's understanding of the definition "Biodiversity Oriented and Ecological Based Design" was asked. While 40% of the respondents didn't answer, 56% gave an appropriate answer, entailing one or several elements which were aligned with the topic meaning. For example, shifting from an anthropocentric view to a more inclusive and holistic one, taking in consideration the ecological context in the project development and design early on, not only in the open spaces, but integrated in the building envelope as well, so to improve biodiversity, sustainability, social use and life quality.

There were a couple of answers which were not wrong, but unaligned with the definition. In fact, some uncertainty often arises in terms of definition, when dealing with sustainable city or urban sustainability[38]. What should be of common understanding is that a sustainable city must fulfil the balance between social equity, economic development and environmental protection[39, 40]. Instead, both answers mentioned almost exclusively sustainability, one referred to renewable materials and the other one to sustainable design.

Though not meant with a negative connotation, often sustainability is not necessarily used as a synonymous of biodiversity friendly, but instead it is often used in this kind of context exclusively referred to energy efficiency and material sustainability, leaving out the aspect of sustainable and regenerative ecosystems and biodiversity improvement. Furthermore, a proper evaluation of biotope quality or biodiversity status is often neglected or poorly considered in city assessments[32].

Therefore, to achieve sustainability, work on all its three dimensions is required, economy, society and environment, also known as the Three Sustainability Pillars.

To overcome this discrepancy between smart and sustainable approaches, in the last decade, though still at an early stage of conceptualization, emerged the term sustainable smart city [41–43] , which is defined as a city that [43]: "[…] meets the needs of its present inhabitants, without compromising the ability for other people or future generations to meet their needs, and thus, does not exceed local or planetary environmental limitation, and where this is supported by Information and Communication Technology".

The last question of this section (Q12) was multiple choice and dedicated on assessing how many of the respondents already came in contact or heard about some of the approaches that were introduced in the state of research.

Table 8 Responses to Question 12

Approaches	Percentage
Natural Based Solutions (NBS)	28%
Biodiversity Sensitive Urban Design (BSUD)	16%
Wildlife-Inclusive Urban Design	12%
Animal Aided Design	11%
City Biodiversity Index (or Singapore Index)	11%
Geodesign	10%
Property-specific biodiversity index (© DGNB GmbH)	3%
None of the above	9%
Grand Total	**100.0%**

As it can be seen in Table 8, where the number of times each approach was chosen is reported, Natural Based Solutions[44] is the best-known approach among the respondents followed by the BSUD and the Singapore Index[45, 46]. Both approaches were chosen from almost all the respondent's categories, whereas the 8.6 % of those, which knew none the approaches, was composed by five architects, two landscape architects, one planner and one environmental engineer.

It was also asked, if they would have considered implementing target species and ecological based design in future projects even without explicitly defined requirements laid out by the contracting authority or in the technical specification (Q13). To this question 67% responded yes, 33% "Maybe" and 0% "No". The respondents were subsequently asked the reasons for no implementation. One responded that it would depend on the specific building requirements and location, the second showed uncertainty about the selection process of the target species.

There is an interesting study conducted by Ofori e Kien [47] , about the level of environmental awareness in Singapore's construction industry, which showed an opposite trend, that the awareness is rising, but is being mainly driven by the presence of regulations. The responding architects indicated that they were aware of the impact of construction activity on the environment, however, most of them (58%) rated the level of awareness within Singapore's construction industry as low, while the study also confirmed that architects in Singapore, though claiming to have a high level of awareness, do not reflect this in their practices.

Section 5 Integrated Solutions for Biodiversity Evaluation

The integrated solutions categories, divided in four main categories based on the dissertation from Stokes & Chitrakar [48], were not meant to set a standard, but as a guide tool for the respondents to grasp the different typologies of integrated solutions, which are and can be used in the AEC field.

But first, the respondents were asked to assess the level of impact, which the cost perception of construction and maintenance, derived by the integration of integrated solutions in the building envelope, would have had on their choice of implementing them (Q15). A similar question was posed about the impact on their influence of implementing such solutions, derived by the lack of specific legislation and standards, demanding biodiversity inclusive measures (Q16).

Table 9 Responses from Q15 and Q16; [1-Low Impact, 5-High Impact]

	1	**2**	**3**	**4**	**5**	**Total**
To what extent would the perception of the cost of construction and maintenance, derived by the integration of biodiversity features in the building envelope, influence your choice?						
Q15	7%	17%	43%	25%	8%	100%
To what extent would the lack of specific legislation and standards, demanding biodiversity inclusive measures, influence your choice?						
Q16	13%	22%	28%	18%	18%	100%

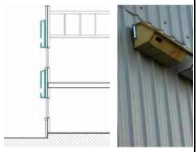
As can be observed in Table 9, the results are in this case more even and widespread, and there is not a unified consensus among the respondents. Indeed, the cost perception of measures, as well as what is mandated and requested by the project, are two important factors. Regarding the cost perception only one fourth perceived it as a lower impact, while almost half of the respondents perceived it as medium impact. These results confirm, that more often than not, stakeholders are already discouraged from their perception of what the cost could be, rather than the actual short-term and long-term cost.

Regarding the lack of legislation, the results were more evenly distributed on the Likert scale, as the majority of the respondents (28.3%) perceived it having a medium impact. These results are more aligned with the ones from the study in Singapore, where the awareness and readiness is being driven by the presence of legislations.

As previously mentioned, the respondents were asked, for each of the four typologies of strategies connected to the building envelope to enhance biodiversity, which option would they have considered (Q17, Q19, Q21, Q23). Moreover, they were given the chance to add a motivation or a comment for their decision. In the following table the results of each categories are going to be shown separately. The questions were multiple-choice, whereas the results are represented as the amount, that each option had been chosen, as well as the results divided per each respondent's category. The respondents were also advised that the different pictures presented, were not meant as specific examples but only as representations of broader typologies.

The Self-contained typology was described as follows:
"Spaces intended for wildlife occupation are evident as independent constructions, either as free-standing assemblies or as external building attachments. Often, they are visibly differentiated in materials or aesthetics from the host structure or landscape. This approach allows ease of relocation or modification as needs arise. Common exemplars include artificial nesting boxes, beehives, lizard slabs, roosting platforms and feeding structures"[48].

Table 10 "Self-contained" Strategies – Multiple Choice;
Sources: Option 1(© 2017 Associazione Apicoltori Mantovani); Option 2 (Philippe Maupetit); Option 3 (dustygedge.co.uk); Option 4 (Stokes & Chitrakar, 2012; Filcris Ltd.,2011)

					
	None	Option 1	Option 2	Option 3	Option 4
Q17	2%	26%	28%	26%	18%

In Table 10 can be seen that Option 2, 3 and 1 were respectively the most favored. By the respondents was mentioned how this type of solutions would not yet be satisfying, and that would have to be more aesthetically developed. A designer mentioned it's preference for integrating the strategies into the building envelope, type of strategy which is being proposed by the inserted- and envelope-habitat in the next questions.

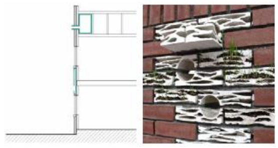
In Table 11 can be seen for each respondent's category, which were the preferred Options.

Table 11: "Self-contained" Strategies, Option preferences

Category	None	Option 1	Option 2	Option 3	Option 4	Category total
Agronomist	0%	50%	0%	0%	50%	**2%**
Architect	5%	23%	33%	23%	16%	**47%**
Consultant for Sustainability	0%	50%	0%	50%	0%	**2%**
Ecobau	0%	33%	0%	33%	33%	**2%**
Environmental engineer	0%	40%	40%	0%	20%	**4%**
Environmental planner	0%	33%	0%	33%	33%	**2%**
Landscape Architect	0%	23%	26%	32%	19%	**24%**
Planner/Urbanist	0%	38%	13%	25%	25%	**6%**
Spatial data science	0%	0%	0%	100%	0%	**1%**
Multidisciplinar	0%	23%	38%	31%	8%	**10%**
Option Total	**2%**	**26%**	**28%**	**26%**	**18%**	**100%**

The Inserted-Habitat typology was described as follows:
"Inserted habitats display similar elements to self-contained habitats, excepting that the habitat space is physically integrated into the building as distinct component. Although availability and range are currently limited, prefabricated modular construction elements providing habitat are growing in popularity, particularly for bird nesting, insect hotels and plant hosting modules. Alternatively, more complex bespoke solutions may be required, e.g. access and accommodation for bats roosting in large ceiling cavities"[48].

Table 12 "Inserted-Habitat" Strategies – Multiple Choice;
Sources: Option 1(Studio Fanny Hofstra); Option 2 (Stefano-Boeri-Architetti-Il-Bosco_Egypt);
Option 3 (Andy Scott, 2019); Option 4 (Stokes & Chitrakar, 2012; Fabrikaat, 2012)

					
	None	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Q19	2%	18%	36%	21%	23%

In Table 12 can be seen that Option 2, 4 and 3 were respectively the most favored. By the respondents was mentioned how such strategies are mostly project specific, while was also expressed the preference for elements not aesthetically distinct from the envelope. The specificity of such strategies is indeed intrinsic, as these are aesthetically distinct from the facades, and therefore for each project the stakeholders would probably look for a bespoken solution in line with the project design.

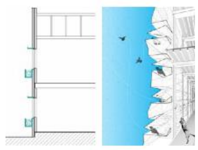
In Table 13 can be seen for each respondent's category, which were the preferred options.

Table 13: "Inserted-Habitat" Strategies, Option preference grouped by category

Category	None	Option 1	Option 2	Option 3	Option 4	Category total
Agronomist	0%	0%	100%	0%	0%	1%
Architect	2%	15%	37%	19%	27%	46%
Consultant for Sustainability	0%	0%	100%	0%	0%	1%
Ecobau	100%	0%	0%	0%	0%	1%
Environmental engineer	0%	0%	75%	0%	25%	4%
Environmental planner	0%	0%	0%	100%	0%	1%
Landscape Architect	0%	21%	39%	21%	18%	25%
Planner/Urbanist	0%	25%	25%	25%	25%	7%
Spatial data science	0%	0%	100%	0%	0%	1%
Multidisciplinar	0%	25%	19%	31%	25%	14%
Option Total	**2%**	**18%**	**36%**	**21%**	**23%**	100.0%

The Envelope-Habitat typology was described as follows:
"Wildlife habitat features are created through integrated design elements across a façade or surface, so that the primary identification is a whole building. Envelope habitats often arise through incidental analogue design e.g., green walls encouraging foraging, or ornamentation that function as perches. Intentional incorporation allows for creative design solutions. Envelope habitats may encourage transient wildlife rather than permanent occupation or nesting activity"[48].

Table 14 "Envelope-Habitat" Strategies – Multiple Choice ;
Sources: Option 1 & Option 4 (terreform.org/monarch-sanctuary); Option 2 (Boulogne Billancourt, ChartierDalix); Option 3 (Husos Architects); Option 5 (ChartierDalix); Option 6 (Stokes & Chitrakar, 2012; Lamphier, 2011)

							
	None	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**
Q21	3%	14%	15%	20%	15%	20%	13%

In Table 14 can be seen that Option 5, 3, 4 and 2 were respectively the most favored. By the respondents was expressed interest on how much the design is determined by the function and to what extent these elements can be then adapted to different specific projects. Moreover, was expressed the importance of knowing how these elements would technically function and what would their requirements be. A point about the embedded grey energy, as well as the economical sustainability of these solutions was brought up as well.

Indeed, such type of strategies are predominantly bespoken solutions, tailored to a specific project. While this could entail higher costs, as such strategies, their requirements and function would have to be developed from the ground up, it also entails having complete design freedom and develop solutions tailored not only to the concept design, but also to the ecological context.

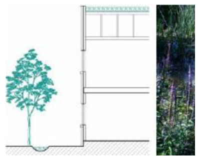
In Table 15 can be seen for each respondent's category, which were the preferred options.

Table 15: "Envelope-Habitat" Strategies, Option preference grouped by category

Category	**None**	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Category total**
Agronomist	0%	50%	0%	50%	0%	0%	0%	**1%**
Architect	5%	17%	9%	20%	14%	17%	20%	**43%**
Consultant for Sustainability	0%	0%	50%	0%	0%	50%	0%	**1%**
Ecobau	100%	0%	0%	0%	0%	0%	0%	**1%**
Environmental engineer	0%	33%	17%	0%	17%	33%	0%	**4%**
Environmental planner	0%	0%	50%	0%	0%	50%	0%	**1%**
Landscape Architect	0%	8%	22%	25%	19%	19%	6%	**24%**
Planner/Urbanist	0%	9%	18%	18%	18%	27%	9%	**7%**
Spatial data science	0%	20%	20%	20%	20%	20%	0%	**3%**
Multidisciplinar	0%	10%	14%	19%	14%	24%	19%	**14%**
Option Total	**3%**	**14%**	**15%**	**20%**	**15%**	**20%**	**13%**	**100%**

The Green infrastructure typology was described as follows:
"It has significant crossovers between architecture, landscape and urban design. Green infrastructure is intended towards adequate provision of urban ecosystem services and is often, but not exclusively, concentrated in streets/movement corridors or coupled with recreational areas. As such it may contain a high degree of man-made structures and hard-scape elements. Green infrastructure serves a primary function for urban wildlife in habitat connectivity and foraging and is often coupled with storm water, soil and air quality management processes. Green infrastructure is a good candidate for either revelatory or wildscape aesthetic approaches" [48].

Table 16 "Green infrastructure" Strategies – Multiple Choice;
Sources: Option 1(Chartier Dalix); Option 2 (Lars Gitz Architects); Option 3 (Sasaki Associates);
Option 4 (©Ali García y José Miguel Cano); Option 5 (Stokes & Chitrakar, 2012; Vision Division, 2010)

						
	None	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Q23	2%	22%	20%	21%	18%	17%

In Table 16 can be seen that Option 1, 3 and 2 were respectively the most favored. By the respondents was mentioned, that these examples and solution strategy is not clear, as well as how such examples could be mistaken for technological solutions without actual green infrastructures. In insight, a picture choice better representing this strategy typology, could have been made, none the less it seemed clear from the presented pictures, that this typology can comprehends vegetation and green infrastructures around a building, but also vegetation developed on terraces, balconies, containers and facades.

In the Table 17 can be seen for each respondent's category, which were the preferred options.

Table 17: Green infrastructure" Strategies, Option preference grouped by category

Category	**None**	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Category total**
Agronomist	0%	33%	33%	33%	0%	0%	**2%**
Architect	1%	24%	21%	24%	18%	13%	**49%**
Consultant for Sustainability	0%	0%	0%	50%	50%	0%	**1%**
Ecobau	100%	0%	0%	0%	0%	0%	**1%**
Environmental engineer	0%	33%	33%	17%	17%	0%	**4%**
Environmental planner	0%	0%	0%	0%	0%	100%	**1%**
Landscape Architect	0%	21%	21%	14%	17%	28%	**21%**
Planner/Urbanist	10%	20%	10%	20%	20%	20%	**7%**
Spatial data science	0%	20%	20%	20%	20%	20%	**4%**
Multidisciplinar	0%	23%	15%	23%	23%	15%	**9%**
Option Total	**2%**	**22%**	**20%**	**21%**	**18%**	**17%**	**100%**

As a conclusion of this section the respondents were asked, if they'd already had the chance to work on a project, where the forementioned approaches and strategies were implemented, and in that case if it was realized. In the case they didn't yet have had a chance of implementing such strategies, they were asked, if they could give an explanation.

As can be seen in Figure 6, half of the respondents didn't yet work on a project where such strategies were implemented, while 28% did, but in that case the project wasn't realized, while only 18% did the implementation and the project was realized as well.

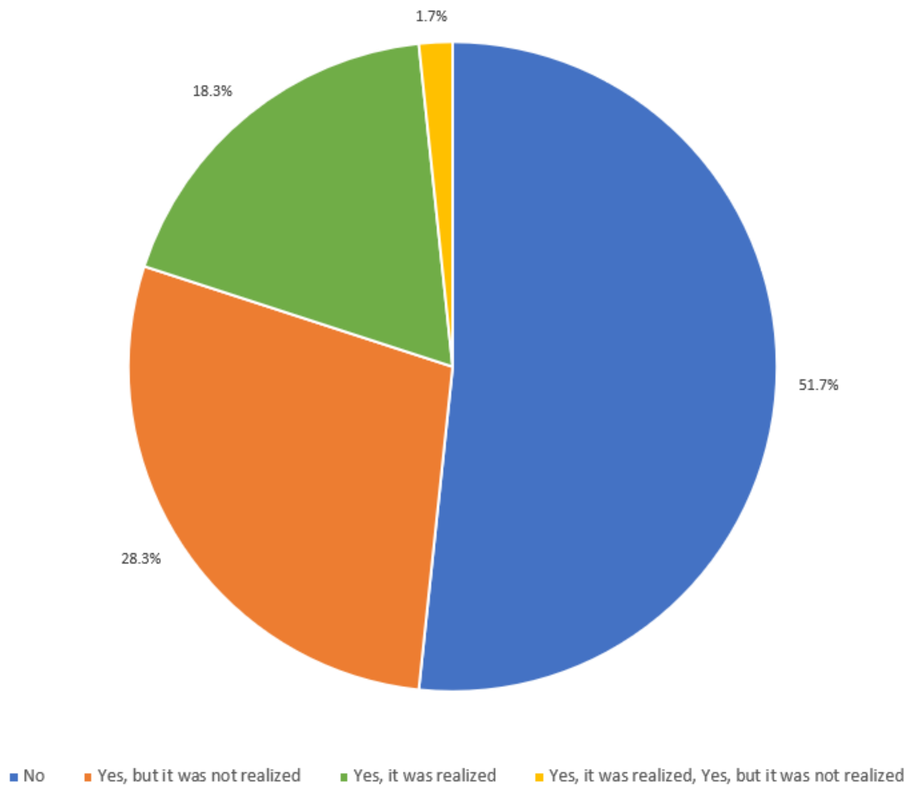


Figure 6 Q25 Realization of projects related to envelope strategies.

The main motivations, being cited for not realizing a project, were related to the fact that the projects were only for conceptual planning studies without implementation. Others motivated, that they had not enough budget, another cited the lack of consideration and money dedicated to nature-based solutions in Switzerland, while another explained how biodiversity measure were mainly elaborated in connection with open and green spaces and not with the built environment.

These motivations, also partly connected with each other, seem to fall in line with the common trends in the AEC industry. For one, often the built environment is seen as a separate entity from nature, thus, if measures are taken for improving biodiversity, they are often exclusively related to the surrounding green spaces, these often being developed in the last phases of the project. Therefore, if these measures are being taken, if not planned from the early project stages, are mostly perceived as an added cost and are often lacked consideration or even discouraged.

The study conducted by Opoku[49], aimed at examining the link between the sustainable built environment and biodiversity conservation strategies, did state, that there should be a smooth interaction between the built and the natural environment. On one hand because humanity and nature are the usual victims of loss of biodiversity and on the other, though the built environment has currently a negative impact on biodiversity, it also has the greatest opportunity to integrate biodiversity into development projects. In this context, is important to again stress the importance of considering the ecological context and developing such strategies from the early project development phases.

Section 6 Ecological Information Evaluation

This last section of the questionnaire, as forementioned, was specifically dedicated to the evaluation by the respondents of different types of ecological information, which would realistically be provided by the environmental engineers to the other project stakeholders.

The respondents were asked:
"Would you consider the following "…." map type useful to shape your project? "

To give a frame of reference for the evaluation, the questions regarding the ecological map types were related to the DeMo GA Building case study, as can be seen in Figure 7. The respondents were asked to imagine as if they were asked to integrate habitats for plants and animals on a building envelope.

Figure 7 GA building, photo credit ZHAW

As map types examples, were used some of the ecological maps, which were produced during the DeMo project[31]. These can be found in Appendix B [Fig. B2, B4, B6, B8, B10, B12, B14, B16, B18, B20]. In Table 18 are reported the Likert scale results.

Table 18 Ecological map types evaluation – Likert scale 1[Not Useful] – 5[Highly Useful]. Two highest values in Bold

Q	Ecological Map Type	1	2	3	4	5
Q30	Land Use	2%	2%	17%	**42%**	**38%**
Q31	Population Viability	2%	5%	17%	**47%**	**30%**
Q32	Presence Density	5%	7%	22%	**32%**	**35%**
Q33	Movement Ability	5%	5%	22%	**40%**	**28%**
Q34	Land Use Suitability	3%	5%	13%	**33%**	**45%**
Q35	Site Vegetation Profiles	2%	2%	15%	**35%**	**47%**
Q36	Site Vegetation Profiles Suitability	2%	8%	22%	**32%**	**37%**
Q37	Habitat Suitability	5%	2%	22%	**38%**	**33%**
Q38	3D-Habitat Suitability	8%	10%	20%	**30%**	**32%**
Q39	habitat structures and target species specific design elements	2%	0%	10%	**32%**	**57%**

Overall, all the ecological map types were either found useful and highly useful, especially the habitat structures and target species specific design elements were found most useful for integrating habitat structures in the envelope for flora and fauna. The results represented graphically can be found in Appendix B [Fig. B1, B3, B5, B7, B9, B11, B13, B15, B17, B19]. Such a positive response is reassuring and a valuable feedback for ecologists, that these types of ecological maps are considered mostly useful. The response could also be correlated with the high awareness and perception tested in section 3.

After the multiple-choice questions, the respondents were also asked in Q40 and Q41, what additional information or different data/ visualization format (*.shp, *.dwg, *.dxf, *.ifc, *.pdf, etc.) would they have needed for the presented ecological maps, as well as more generally what components should the ecological information have, to be compelling for them to be integrated in their design workflow. The results were divided in open answers (qualitative evaluation) and short answers regarding the data format (quantitative evaluation), which were then used to create a world cloud and summarize the main take home messages.

The main take home messages from the open answers were on one side, that scale and scalability of the ecological information are regarded as important factors, on another that an expert summary of the target species (Flora & Fauna) would be considered also most useful as well as a pdf report with the interpretation and evaluation of the most important ecological maps. This type of feedback acquires more relevance, as a couple of respondents answered, that they were not able to understand or interpret the ecological information.

Moreover, was stressed the importance of having 3D maps and 3D models, possibly in format .ifc, .dwg, .3dm, .skp, .rvt, .obj, of not only habitat structures and possible ecological solutions, but also of high impact infrastructures and barriers to species movement and dispersal, as several species move and colonize not only on ground level but also in the sky and develop in the verticality as well. Finally, there were some remarks made about the relevance of the land use map type related to target species, as this type of map is principally related to the anthropogenic environment. Therefore, was requested additional information about the land use categories serving as habitats for the target species.

Regarding what formats the map types should be outputted, a word cloud was created to visually represent, which formats were mentioned the most, visualized in Figure 8.

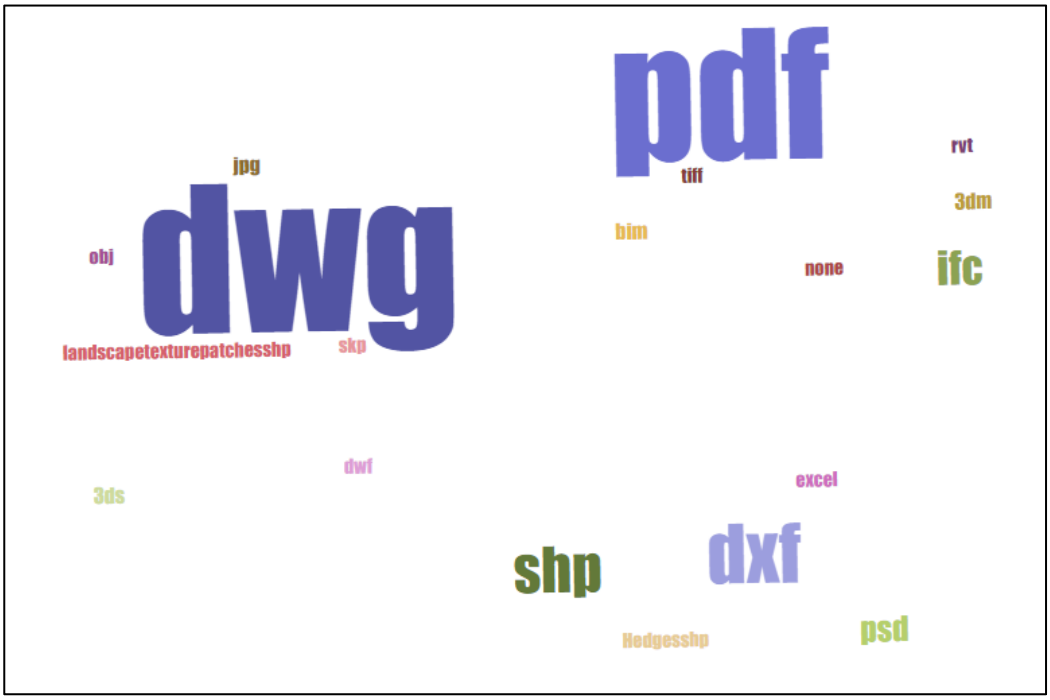


Figure 8 Short answers of Q40 & Q41 quantitative results evaluated as a Word cloud

Clearly the data format .dwg, pdf, .dxf, were the most favored options, while .shp and .ifc were respectively in fourth and fifth place. It is noteworthy to observe, how the standard industry foundation class format (.ifc) wasn't between the three most chosen data options.

In the end the respondents were also asked two optional questions (Q42&Q43), namely which skills respectively architects and planners on one side and environmental engineers and ecologists on the other, should add to their curricula for improving the interdisciplinary cooperation.

There were some answers, which were shared between the two categories, namely for both was remarked the importance of having a common vocabulary and an understanding of systemic design as well as landscape planning based on botanical and ecological knowledge. Moreover, knowing how to use digital tools for enhancing collaboration, was also mentioned.

About which skills architects and planners should add to their curricula, there was a consensus on them having a basic knowledge and understanding of ecology, more specifically urban ecology, and biodiversity, related also to species and their habitats, as well as the connections with other ecosystems.

This trend, of integrating this knowledge in the curricula of architects, has already being studied and applied. For example Cisek e Jaglarz [50] have studied the methodology of implementing ecology and sustainability in practice in academic teaching, while Ofori e Kien[47] stated, that in order for green designs to take firm root in Singapore, further education of professionals on environmental issues is necessary. Moreover, the department of Life Sciences at the ZHAW Zurich University of applied sciences, has begun collaboration with the department of architecture, creating an interdisciplinary module [51]for both architects and environmental engineers within the bachelor's degree.

In this context also understanding the relevance of landscape processes and ecosystem services, defined as the benefits human populations derive, directly or indirectly, from ecosystem functions[52], was appointed as a crucial skill. A basic understanding of landscape architecture and climate change was also suggested.

Openness and consciousness of biodiversity in urban environments as well as understanding the value of ecological networks and steppingstones were also indicated as important skills to be added. In this regard was also mentioned, understanding the built environment and nature not as separate entities, but as part of one ecosystem.

Furthermore, the respondents also mentioned the importance of being able to understand and evaluate the input of other experts as well as promoting interdisciplinary cooperation from the beginning of a project. For example, in Singapore was observed that designers required relevant information to guide them in making appropriate choices, while the absence of it was considered by respondents as one of the obstacles to their adoption of green design principles[47]. Moreover, Poon [53] stated, that AEC practitioners need to promote stronger sustainability visions for solutions purposed for the urban buildings of tomorrow, where sustainable urban design is challenged to change social perceptions, that sustainable architecture is a way of experiencing nature in environmental design.

Regarding the curricula of ecologists and environmental engineers the main take home messages were, that they should acquire knowledge about planning and building processes as well as construction procedures. Also gaining a better understanding of design and landscape architecture, so to be able to better integrate biodiversity solutions in those contexts, was mentioned. As Dorney [54] stated, is vital for ecologists understanding the philosophy, methodology, and goals of the design- and engineering-oriented professions.

Adding to that, knowing how to architecturally integrate or minimize the design of ecological choices was also appointed. It is for example suggested, that in order to achieve in urban landscapes sustainable, multi-service ecosystem design, within applied ecology, ecological knowledge will inherently be required. That, therefore, over the long term, design and programs in professional environmental management should be a component of ecological education, for academic ecologists[17].

Some respondents mentioned the relevance of integrating social sciences as well, in order to better understand anthropological behaviors and improve interdisciplinary cooperation.

Some arguments were also made about developing a deeper knowledge of the relation between climate change and the future development of species habitats as well as habitat connectivity. In fact, connectivity conservation, defined as coordinated efforts to achieve metapopulation viability across a range of spatial scales, plays an important role for biodiversity conservation and can be applied to increase the resilience of species populations to the variety of threats caused by or intensified by climate change, especially in areas of high environmental heterogeneity, like urban ecosystems[55].

Finally, an observation was made about enhancing decision making and the integration of biodiversity solutions through a better marketing and branding by linking them not exclusively to ecological arguments but also to ecosystem services and their benefits for the anthropogenic environment, as well as from a financial point of view to the long-term effects and reduced maintenance costs over time.

3.2. Parametric Design

Bird Nesting Aid Excel Table

As forementioned in the methodology, an excel table with the dimension parameters was created for the avifauna category of cavity-nesting birds, based on the document provided by the BirdLife Svizzera [35], which also provided a base design for the element [see Figure 9].

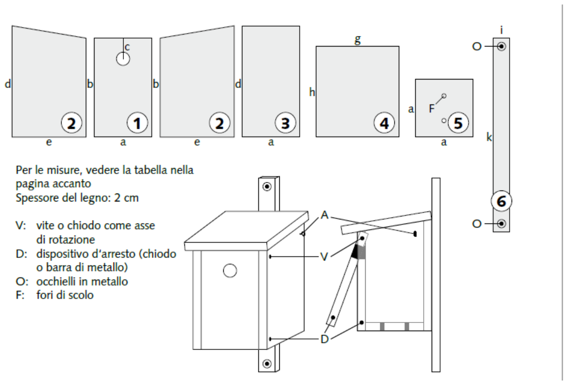


Figure 9 Base design of bird nesting box[35]

As the focus of the thesis was to test the interaction capabilities of a wall-based BIM element with Dynamo, though the element was still created based on the target species category from the PWRU2 (avifauna) of the DeMo Project, the dimensions were taken for other bird species as well, for testing purposes [see Table 19].

Table 19 Dimensions for BNA for cavity-nesting Birds in mm [35].

ID	Comments	Mark	Nest Width	Front Height	Back Height	Opening Distance	Flight Opening Radius
B-1.1	Bird Target Species	Eurasian Blue Tit	140	240	270	50	14
B-1.2	Bird Target Species	Marsh Tit	140	240	270	50	14
B-1.3	Bird Target Species	Coal Tit	140	240	270	50	14
B-1.4	Bird Target Species	European Crested Tit	140	240	270	50	14
B-2.1	Bird Target Species	Great Tit	140	240	270	50	16
B-2.2	Bird Target Species	Collared flycatcher	140	240	270	50	16
B-2.3	Bird Target Species	Eurasian wryneck	140	240	270	50	17
B-2.4	Bird Target Species	Eurasian Nuthatch	140	240	270	50	17
B-3	Bird Target Species	Common redstart	140	240	270	50	20
B-4.1	Bird Target Species	Common starling	160	300	340	55	22.5
B-4.2	Bird Target Species	Eurasian pygmy owl	160	300	340	55	25
B-5.1	Bird Target Species	Hoopoes	180	350	400	60	32.5
B-5.2	Bird Target Species	Eurasian scops owl	180	350	400	60	35
B-6.1	Bird Target Species	Boreal owl	180	350	400	60	42.5
B-6.2	Bird Target Species	Stock dove	180	350	400	60	42.5
B-6.3	Bird Target Species	Jackdaw	180	350	400	60	42.5
B-7	Bird Target Species	Tawny owl	250	440	500	90	60

The second and third columns headers were named after default parameters of Revit families, in order to facilitate the information upload and visualization via Dynamo. The type and structure, as well as the value unit of the excel table must be maintained in order to work with the Dynamo script.

Revit

The BNA model, created in the Revit wall-based family modeler, visually matched a simple nesting box, as can be seen in Figure 10.a to 10.d. As previously stated, the parameters were named after the excel table headers, so to assure data-source compatibility between the different software and the right execution of the Dynamo script. If the nomenclature of the BIM element is modified or adapted, so must be the headers of the excel table as well. Several reference planes and lines were created to then lock in the "alignment" of the element's boundaries, thus creating constraints and new parameters.

In this case study was developed a BIM element raging between a LOD 100 and 200. Level 100 describes the lowest level of information, 500 the highest:

- Level 100: Conceptual representations and study
- Level 200: Information on dimension and size of significant construction elements and their relationship to each other

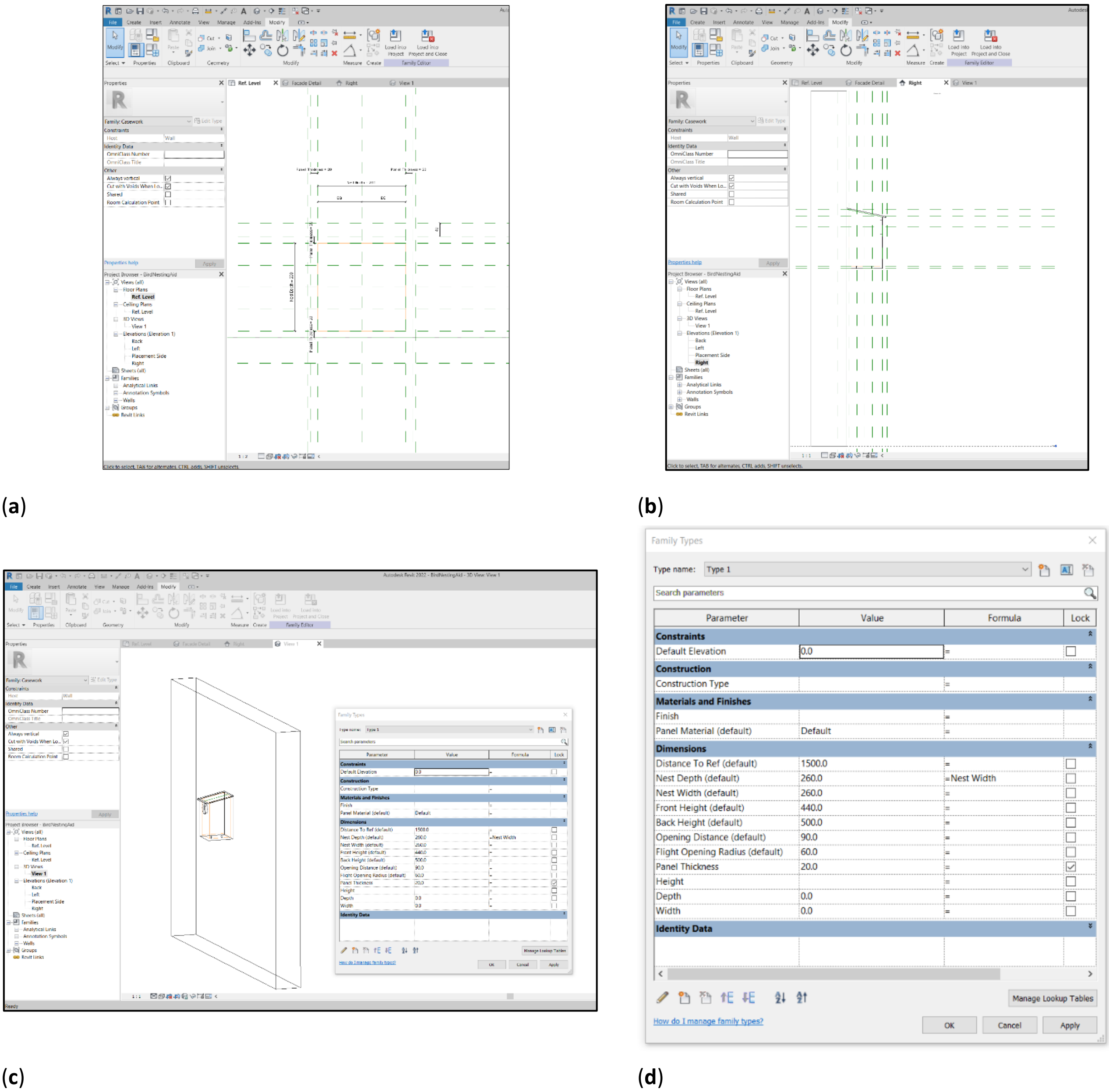


Figure 10: Revit Family model: (a) Reference level; (b)Right-View; (c)3D-View; (d)Family Parameters

All parameters, but the "Panel Thickness", which was set as a "Type" parameter, were set as "Instance" parameters, as these will be the ones, that will be able to be changed for each instance, namely for each BNA element placed in project model. Whereas the panel thickness depending on the construction material of the BNA, can be still changed, but will remain persistent. This model could be classified as a LOG 200 and LOI 100, as cost per element and other information have still to be added.

Dynamo

The Dynamo script was developed in order to select any BNA element in the BIM model, to then source the information provided by the BNA excel table and to finally modify accordingly the BIM element dimensions. As can be seen in Figure 11, the script was in fact divided into three main sections. The first one named "Get Excel" is dedicated to read in the excel file and extrapolate on one hand the information and on the other the parameter names (headers). The second section, named "BirdNestingAid" enables the selection of a BIM element and the modification of its dimensions according to the element parameter names and to the values provided by the first section. Finally, the third section named "Visual Output" is used as an additional aid to make the dynamo player more user friendly by displaying the target species "id" and "name" on the user interface.

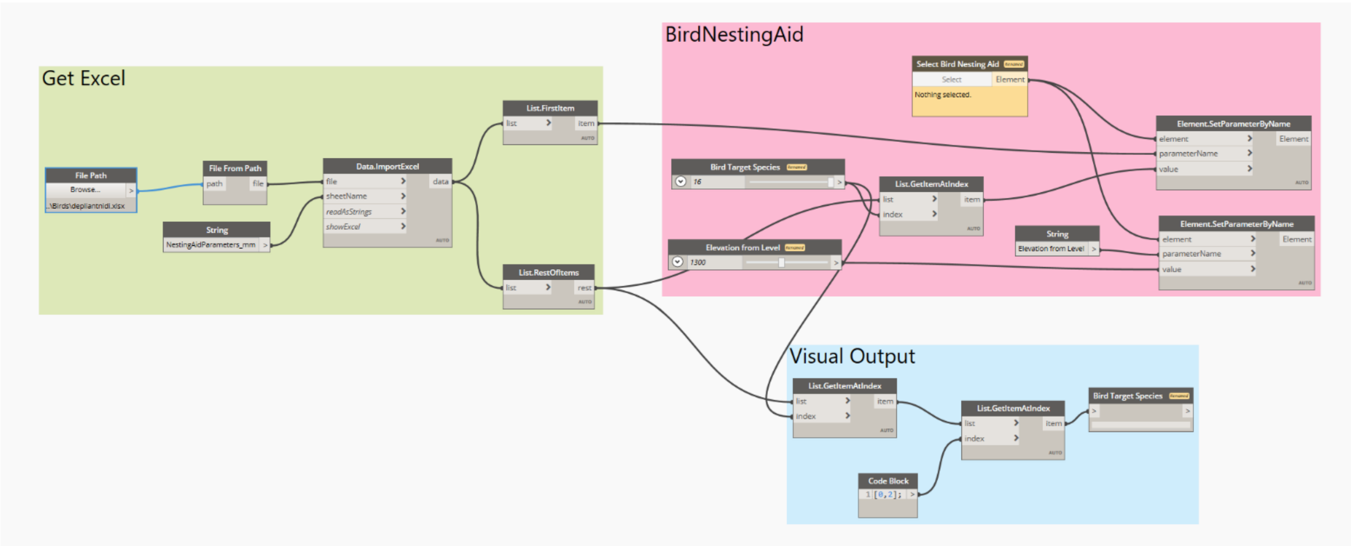


Figure 11 Bird Nesting Aid Dynamo Script

In order for the script to be run by the dynamo player, some of the nodes had to be set as input and others as output, as reported in Table 20. The dynamo player interface would then look as represented in Figure 12.

Table 20 Input and Output Nodes of the Dynamo script

Input/Output	**Section**	**Node**
Input	Get Excel	File Path
Input	BirdNestingAid	Select Bird Nesting Aid
Input	BirdNestingAid	Bird Target Species-Slider
Input	BirdNestingAid	Elevation from Level-Slider
Output	Visual Output	Bird Target Species-Watch

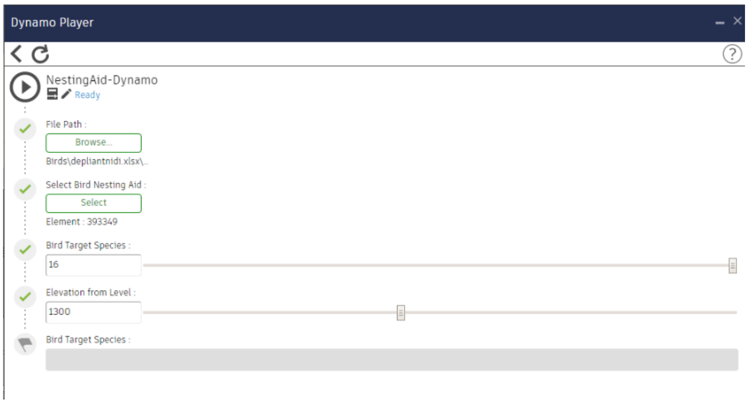
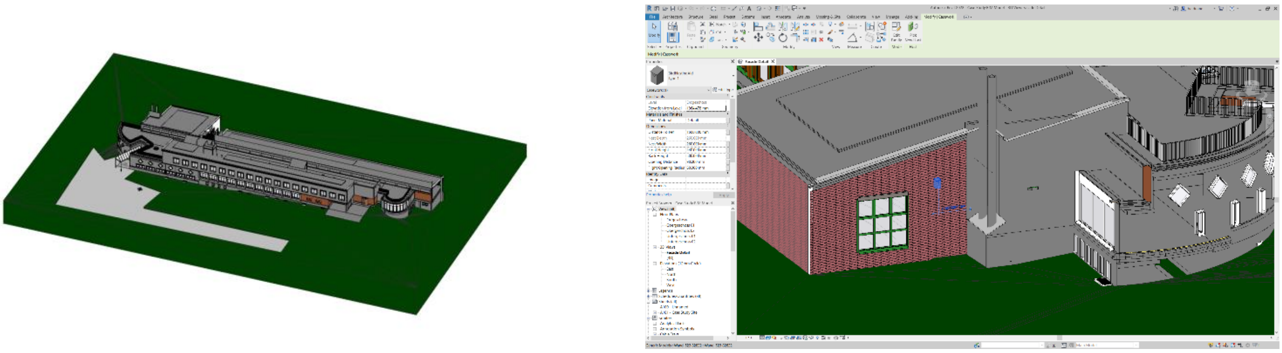


Figure 12 BNA Dynamo player user interface

Revit + Dynamo + Excel

The three results presented separately above [excel table, Revit element, Dynamo script] have to be prepared separately, but once completed can interact together and give form to the end result, which would be a façade integrated target species promoting 3D BIM element, which thanks to the dynamo player, can be adapted and modified in real time in correlation with the dimensions of the selected target species. This way a BIM element must not be modelled and parametrized for each species, but instead an "Umbrella model" can be created, which can cover the dimensions needs of entire target species categories.

As can be seen in Figure 13.a the first step would be to upload the project building model, then, based on the ecologist consultancy together with the information provided by the suitability maps, the BNA instance could be placed on the suited façade (13.b), which after the Dynamo player could be activated and the BNA dynamo script executed. In this iteration the BNA instance was placed on the west façade only for visualization purposes, and not yet based on a specific target species ecological map, as no specific bird species was chosen for the visualization.



(a) (b)

Figure 13: (a) Case Study GA Building BIM model [Source: fsp Architekten AG];
(b) West Façade detail of the Aula with placed BNA element

In Figure 14 are shown the subsequent steps of selecting the element, selecting the excel table and then through the toolbars choosing the target species, based on which the BNA dimensions will then be automatically updated. Though not represented here, there is also a version of the script, with which multiple BIM elements placed on the building can be selected and modified.

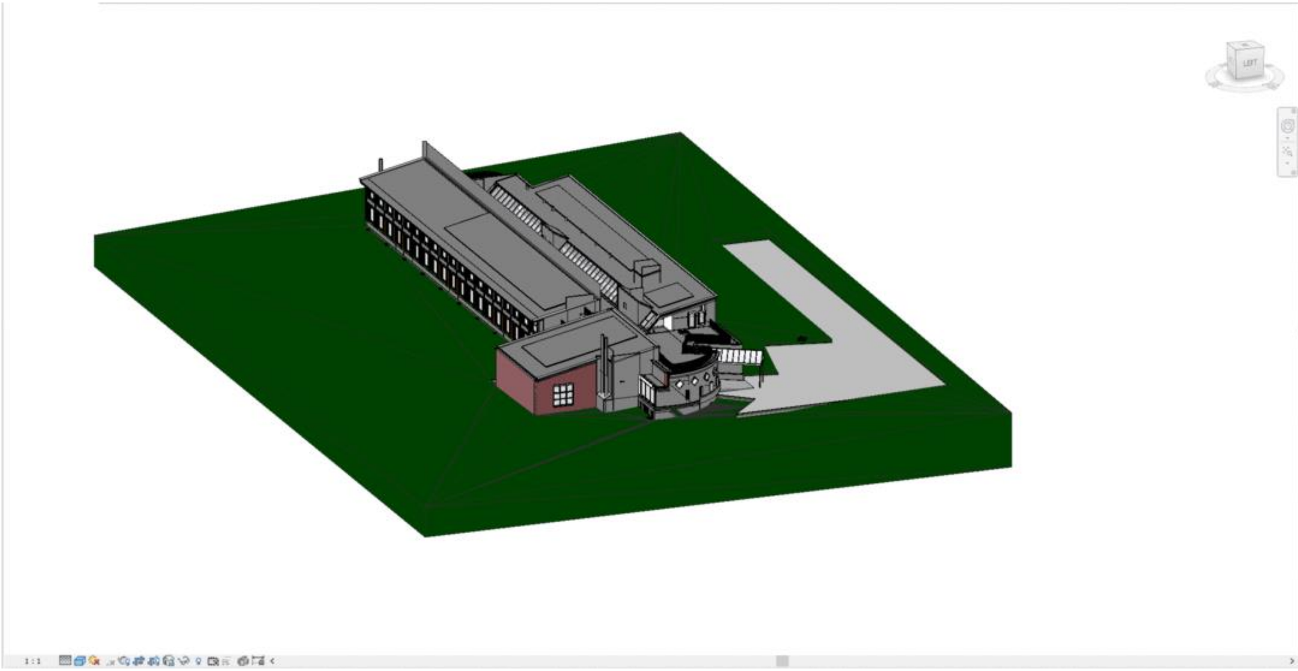


Figure 14 Animated GIF Dynamo player BNA modification steps

As Zanni et al. [56] states, to make a step change towards sustainable development, assisted by the new technological improvements (software, hardware and networks), there is the need to specify the components and processes within BIM collaboration. In our case the BNA model could represent such a component, with defined parameters and native information, would represent for stakeholders a tool, to not only visualize but integrate sustainable building solutions in BIM projects. The challenge that this incorporation faces is the coordination and the availability of all such BIM elements, which are necessary to achieve optimum results. In addition, for BIM integration traditional roles like architect, structural engineer, environmental engineer ecologist etc.), could either gain a new range of expertise or add new experts to the project team. For example, BIM manager, BIM information manager, BIM coordinator, and Sustainability Consultant.

Moreover, as stated by Lim [28], the integration in BIM of sustainable design decision making and establishing relevant BIM-based guidelines and frameworks for ecological based modeling should expedite the usage of BIM in the early stages of building design by the main decision makers in sustainable building design projects (designers, architects, environmental and ecological consultants). However, it’s deemed possible only if the stakeholders are well informed and dispose, at every level of the design, of information based on the BIM Level of Development.

In this context, as stated by Turrin et al. [57] ,parametric modeling could, if combined with performance simulation software and with a database to store and retrieve the solutions for subsequent exploration, enhance the design exploration by means of the interaction of the designer with the process, thus facilitating knowledge extraction from the generated solutions.

4. Conclusions

The questionnaire results gave a valuable feedback on how ecological maps can be perceived by stakeholders other than ecologist and env. engineers, and how these could be improved in order to optimize the ecological information exchange. All the presented types were evaluated positively, whereas some observations were made. For example, some felt that a summary explaining the content provided in the ecological maps could be helpful, as well as identifying potential barriers for the target species. Of course, the map types presented didn't cover the whole range of additional information which would be provided along with them, as section 6 of the questionnaire covered only typologies of ecological maps and not the specific information about the life cycle and requirements of the target species. It was also interesting to see that from the respondents dwg and pdf formats where the formats most requested, though the industry is going more in direction of using the BIM environment and standard IFC.

Although the Bird Nesting Aid BIM element was modelled after a nesting box and is simple in its construction and design, it proves that these three distinct workflows, redacting an excel table with the target species specific dimensions, the use of Revit to parametrize and model target species aid elements and the use of Dynamo as a visual scripting language, were successful in interacting with one another. This thesis is trying to lay the foundations or at least inspire, what in the future could become a BIM library of façade integrated biodiversity promoting 3D elements, which should then not only assure that these are being developed with the needs and requirements of target species in mind, but also ease the visualization and design considerations of architects and planners in the early project phases. Thanks to a faster visualization and integration of such elements in the project BIM model, hopefully this type of strategies will convince and win over more stakeholders and be implemented more often.

As beautifully expressed by Von Richthofen et al.[58], parametric modeling can lead the way to explicit, logical and replicable urban design approaches. It renders the urban design process transparent, leading to a better understanding of the design process and providing insight to the design. It further increases the accountability of designers or design-decisionmakers, while by identifying processes and parameters influencing the design process, it increases control, and it helps managing the expectations concerning possible urban design outcomes. Furthermore, it assures its applicability to other settings, and makes it possible to incorporate and communicate urban design processes to other disciplines.

The authors hope is that thanks to parametric modeling more and more façade integrated solutions will be implemented, as also from the questionnaire was expressed the preference for habitat structures provided as 3D models at scale. It was also noted, how among the four different element strategies, one which is in line with the building materialization, design and concept would be preferred. On the other hand, it was considered, that the cost and sustainability of such solutions could be a problem. Indeed, an ad-hoc solution could be more expensive, than a conventional one to develop and realize, none the less there would be the added value derived from the ecosystem services provided. Moreover, if taken in consideration from the early phases, from a budget point of view, is the author's opinion that the readiness of the project stakeholders to implement such strategies would be rather higher, than in a classic situation in which these are considered later on and only seen as an added expense.

This vision for the future seems to be more feasible after looking at the questionnaire results, especially as the author didn't expect such a positive response in the biodiversity and ecological based design awareness and perception assessment. Of course, the questionnaire had a limited number of responses, meaning that to further confirm these results, supplementary data should be sourced and analyzed. None the less these preliminary trends and results are reassuring that the AEC stakeholders are developing a deeper sensibility towards this topic and rising awareness.

Still should be again stressed, how easily in this context, even if indirectly and not consciously, the term sustainable building and sustainable design is used without keeping the ecological aspect in consideration, thus almost becoming a sort of green washing, as we as producers as well as consumers in our minds, if we hear the term sustainable, we are readily convinced that we did our part for the environment. Indeed as also mentioned by Gunnel et al [25], we often forget that when sustainable building is being considered, there has been a tendency to focus solely on energy, carbon and material related issues, while biodiversity is being given limited consideration. However, buildings can only be truly sustainable if they enhance and sustain life as well.

4.1. Future Work

There are two major foreseeable next steps for the advancement of this case study.

The first is focused on the interaction between the BIM element and the environmental parameters and information carried by Dynamo to be able either to select the suitable target species dimensions based, among others, on species habitat suitability raster maps, or to automate the placement of the BIM element on a suited façade based on ecological maps and other environmental parameters derived from the project BIM model. For example, the sun/shadow analysis, noise analysis, etc., could also be taken into consideration. One known challenge to this, is that raster can only be imported in Revit in the 2D Floor plan of the project as image instances. These are therefore not recognized as geometries; a requirement needed to program and register interactions in dynamo between the BNA BIM model and the raster image.

During this thesis a possible pathway was attempted. Namely to first breakdown the image in pixels, then to translate it to a geometry to which the pixel information/coloring would have been assigned again. While this part was successfully executed in Dynamo, some difficulties were encountered, when trying to export the dynamo modeled raster geometries to the Revit project environment. Partly due to lack of time, as the thesis was executed parallel to the questionnaire in three months, and partly to lacking a deeper knowledge of the software Revit and Dynamo, it was not possible to further explore this workaround. None the less, it would seem a feasible pathway to explore, at least until the GeoBim software from ESRI and Autodesk will be available, thus then being able to combine different files format from different software in the same environment. There could also be the chance that this workaround would work in Rhino and Grasshopper, but the original author's intension was to execute such a workflow in a BIM environment within the same software.

The second step would be to remodel the BNA as a façade integrated element (like the windows categories) and add information so to reach LOI 200 (e.g., an estimate of the price depending on the material could be integrated).

Finally, the long-term goal would be on one hand to model additional BIM parametrized elements for other target species groups, like reptiles, insects and plants, on the other hand to optimize the Dynamo script so that these elements can interact with both the imported and native environmental information in BIM, as well as with environmental sensors as shown by Kensek [37] in his study about the integration in BIM of sensors.

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Appendix A

Table A 1 Questionnaire questions from section 3 to 6

Q	Questionnaire Questions
Section 3: General Information	
1	To which category do you identify with?
2	Respondent's type
3	In which nation are you professionally active? (initials will suffice)
4	Working experience
Section 4: Biodiversity and ecological based design: Awareness and perception	
5	To what extent do you agree that in the age of sustainable development, climate change and biodiversity loss, architects, planners and engineers should promote and implement ecological and nature-based solutions?
6	To what extent do you agree that cities should respond to the biodiversity extinction crisis by incorporating biodiversity conservation actions into strategic planning?
7	To what extent would you agree with involving ecologists early on in interdisciplinary teams to make wildlife an integral part of urban development and thereby create new habitats in built-up and open spaces?
8	To what extent do you agree with the statement that the anthropogenic environment can be modified to promote biodiversity, without compromising social use and human comfort?
9	To what extent would you agree with implementing target species (i.e. keystone, umbrella, flagship and indicator species) for wildlife-inclusive urban design/planning, taking in consideration their entire life cycle (e.g. foraging, nesting, brooding), not only for the design phase but also for the building operations/ maintenance?
10	To what extent would you consider the integration of target species as a useful tool and as an inspiration for developing the project design?
11	What do you understand under the definition of "Biodiversity Oriented and Ecological Based Design"?
12	Have you already encountered, heard about one of the following approaches?
Section 5: Integrated Solutions for Biodiversity Evaluation	
13	Would you consider implementing target species and ecological based design in future projects even if there are not explicitly defined requirements neither laid out by the contracting authority nor in the technical specification?
14	If no, could you please explain why?
15	To what extent would the perception of the cost of construction and maintenance, derived by the integration of biodiversity features in the building envelope, influence your choice?
16	To what extent would the lack of specific legislation and standards, demanding biodiversity inclusive measures, influence your choice?
17	Which typology of the following "Self-contained" strategies connected to the building envelope to enhance biodiversity would you consider?
18	If you answered "none" to the previous question, could you please explain why.
19	Which typology of the following "Inserted habitat" envelope strategies to enhance biodiversity enhancement would you consider?
20	If you answered "none" to the previous question, could you please explain why?
21	Which typology of the following "Envelope Habitat" strategies to enhance biodiversity would you consider?
22	If you answered "none" to the previous question, could you please explain why?

23	Which typology of the following urban "Green infrastructure" strategies connected to the building envelope would you consider to enhance biodiversity?
24	If you answered "none" to the previous question, could you please explain why?
25	Have you already had the chance to work on a project, where the forementioned approaches and strategies were implemented? If yes, was it realized?
26	If no, could you please explain why?
27	[Optional] If yes, would you be willing to share some information about the project to collect best practice examples? NOTE: With the submission of the following optional information, you agree that you may be contacted via email by the ZHAW to gather further detail. Your personal data will be stored till December 2022.
28	[Optional] Name and Surname
29	[Optional] Project name; Location; Partners; Year
Section 6; Ecological Information Evaluation	
30	Would you consider the following "Land Use" map type useful to shape your project?
31	Would you consider the following "Population Viability" map type of selected target species useful to shape your project?
32	Would you consider the following "Presence Density" map type of selected target species useful to shape your project?
33	Would you consider the following "Movement Ability" map type of selected target species useful to shape your project?
34	Would you consider the following "Land Use Suitability" map type of selected target species useful to shape your project?
35	Would you consider the following "Site Vegetation Profiles " map type useful to shape your project?
36	Would you consider the following "Site Vegetation Profiles Suitability" map type of selected target species useful to shape your project?
37	Would you consider the following "Habitat Suitability" map type of selected target species useful to shape your project?
38	Would you consider the following "3D-Habitat Suitability" map type of selected target species useful to shape your project?
39	Would you consider information about habitat structures and target species specific design elements useful to shape your project?
40	Of those ecological map typologies you didn't find useful, what additional information or different data/ visualization format (*.shp, *.dwg, *.dxf, *.ifc, *.pdf, etc.) would you have needed?
41	What components should the ecological information have, to be compelling for you to be integrated in your design workflow, and in which format (*.shp, *.dwg, *.dxf, *.ifc, *.pdf, etc.)?
42	[Optional] Which skills in your opinion should architects and planners add to their curricula for improving the interdisciplinary cooperation?
43	[Optional] Which skills in your opinion should environmental engineers and ecologists add to their curricula for improving the interdisciplinary cooperation?

Table A 2 Respondent's demographics: Typology grouped by category

Respondent's typology by category	
Agronomist	**2%**
Student	100%
Architect	**52%**
Researcher	3%
Researcher, Student	3%
Private sector, Self employed	3%
Self employed, Teacher Higher education	3%
Private sector	13%
Student	74%
Consultant for Sustainability	**2%**
Teacher Higher education	100%
Ecobau	**2%**
NGO	100%
Environmental engineer	**5%**
Student	33%
Researcher	33%
Teacher Higher education	33%
Environmental planner	**2%**
Private sector	100%
Landscape Architect	**22%**
Researcher, Student	8%
Government employees	8%
Private sector	23%
Student	62%
Multidisciplinar	**8%**
Self employed, Researcher	20%
Government employees, Teacher Higher education, Researcher	20%
Student	20%
Researcher	20%
Teacher Higher education, Researcher	20%
Planner/Urbanist	**5%**
Private sector	100%
Spatial data science	**2%**
Private sector	100%
Grand Total	**100.00%**

Appendix B Questionnaire Section 6 - Ecological Information Evaluation

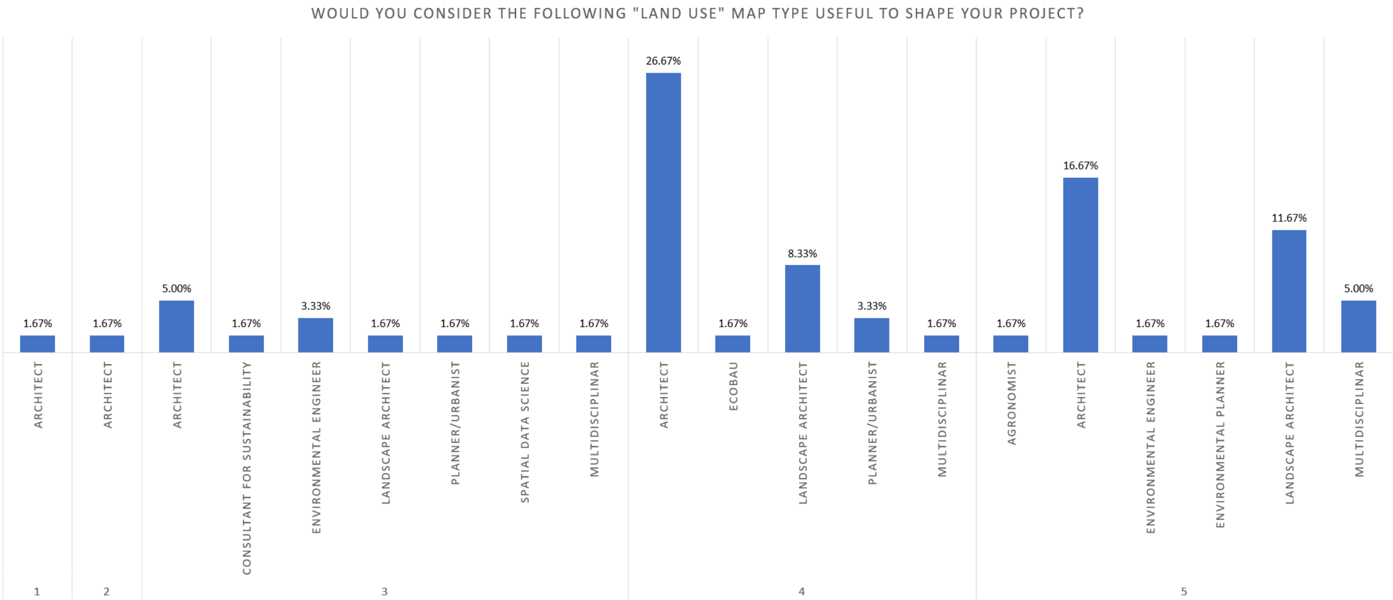

Figure B 1 Q30 Results divided per category; Land use

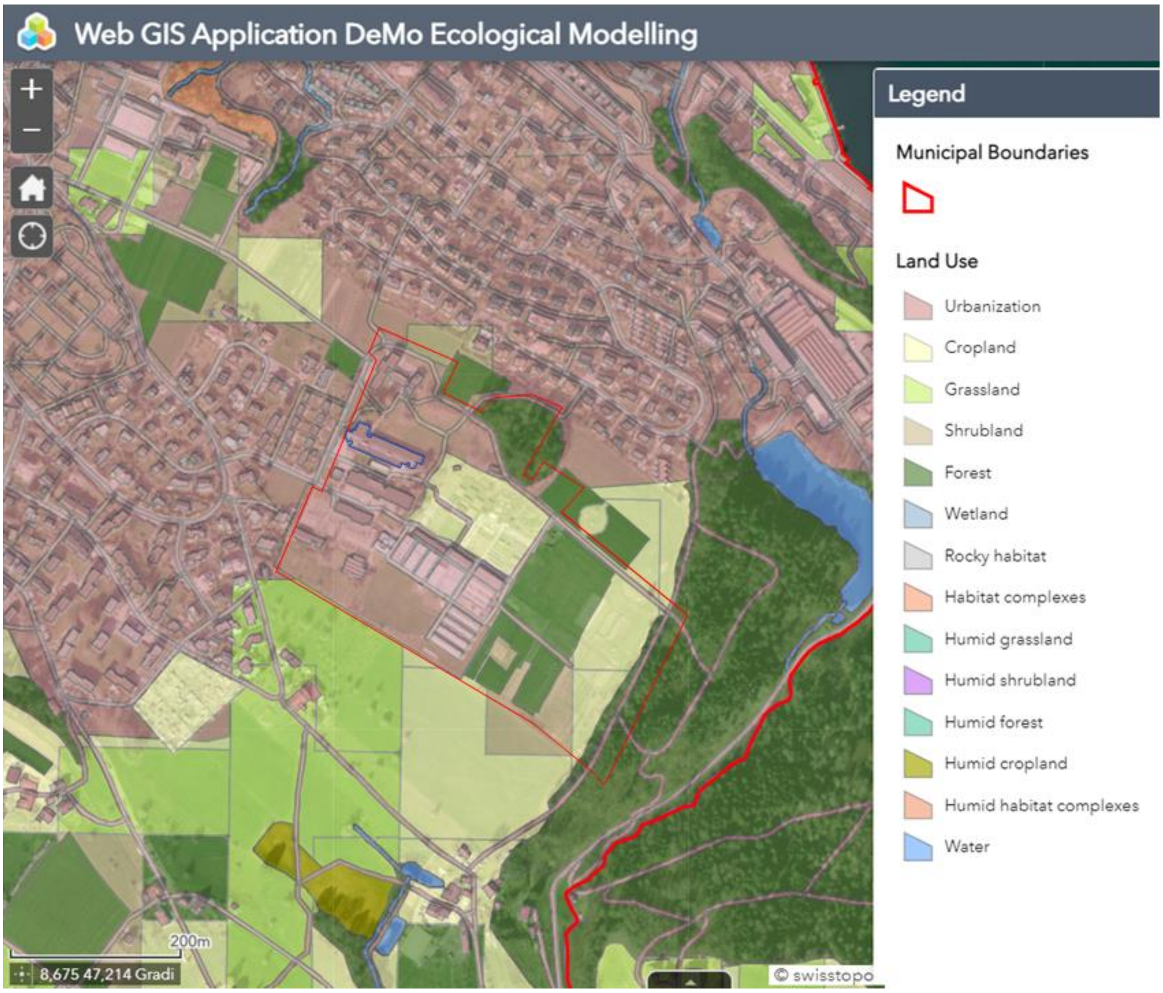

Figure B 2 Q30, Ecological map type: Land use (Source: TerrOïko; swisstopo)

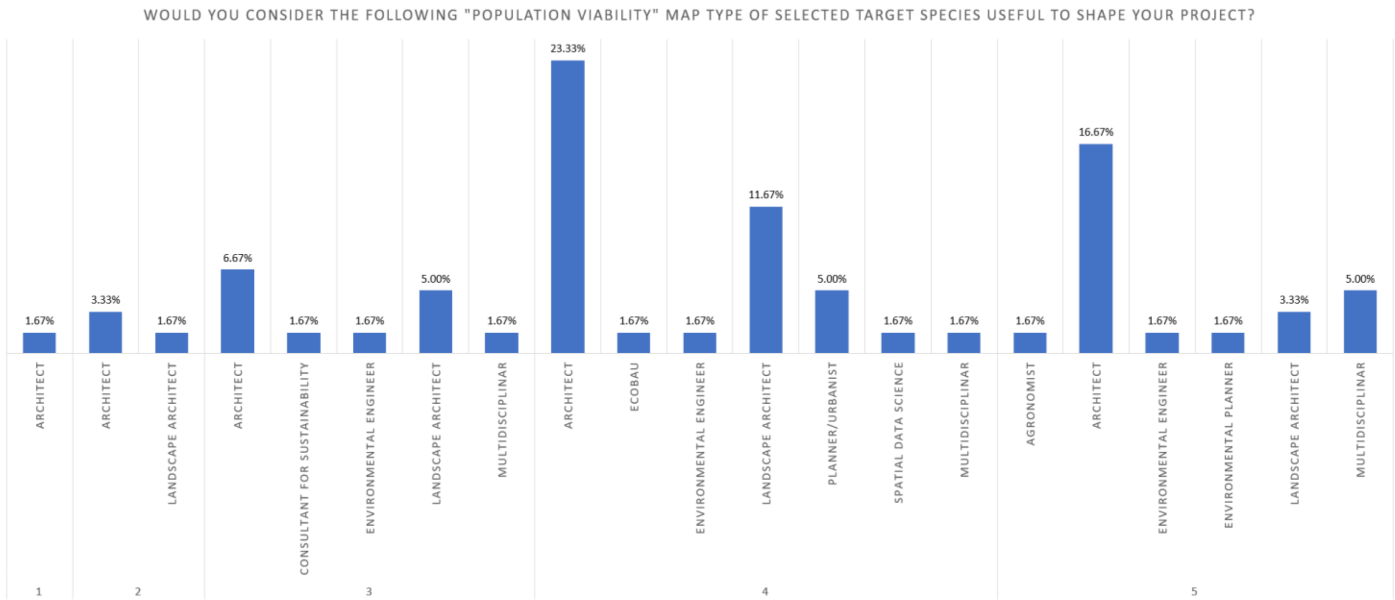

Figure B 3 Q31 Results divided per category; Population viability

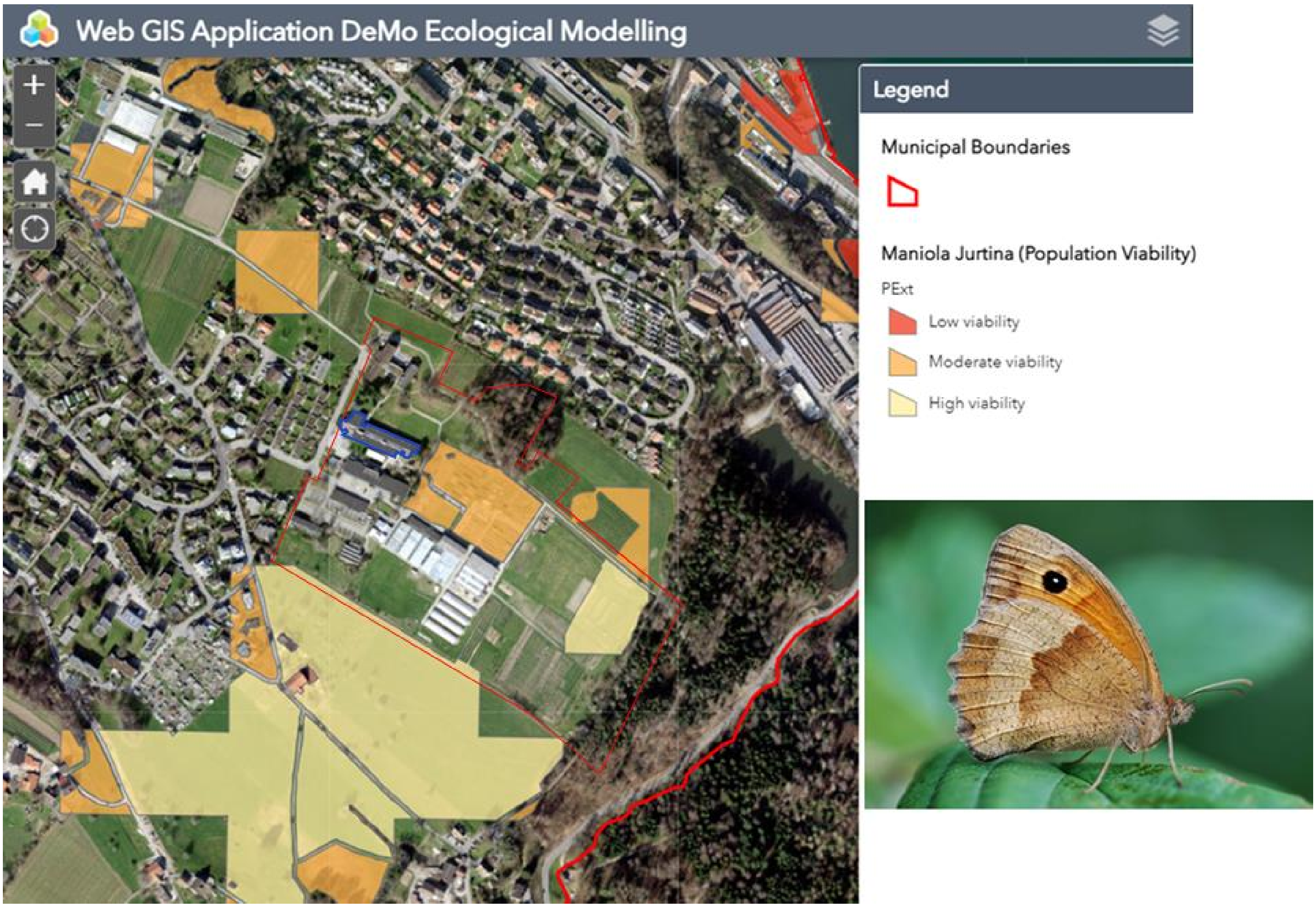

Figure B 4 Q31, Ecological map type: Population viability: the probability that a population will go extinct within a given number of years (Source: TerrOïko)

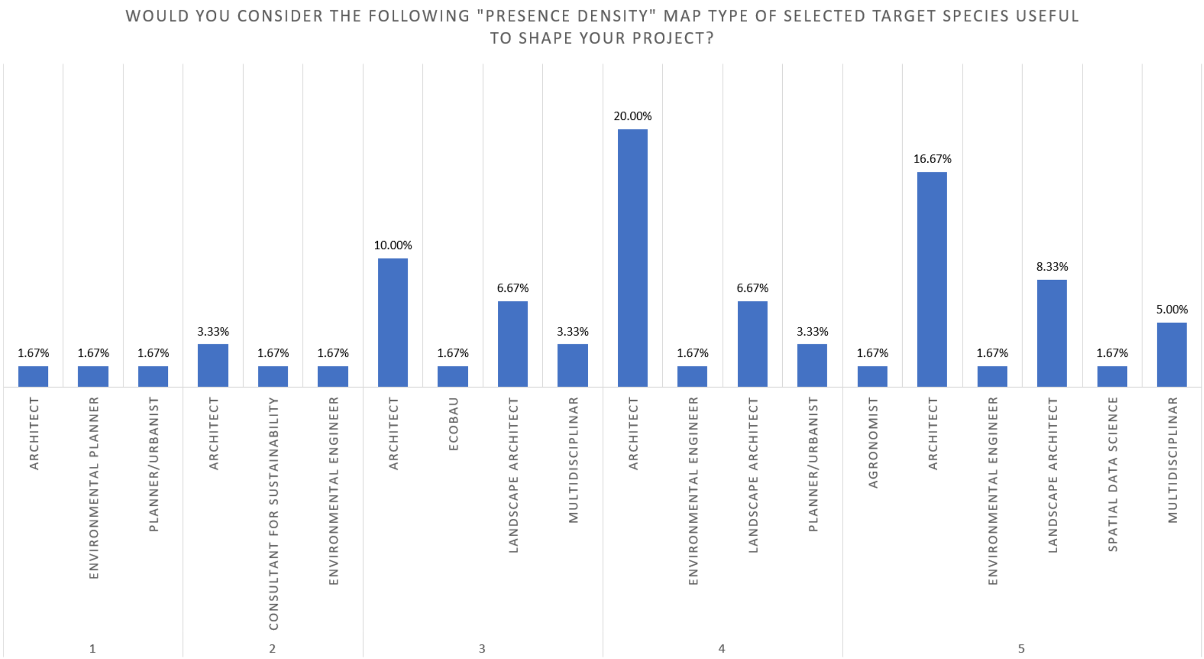

Figure B 5 Q32 Results divided per category; Presence density

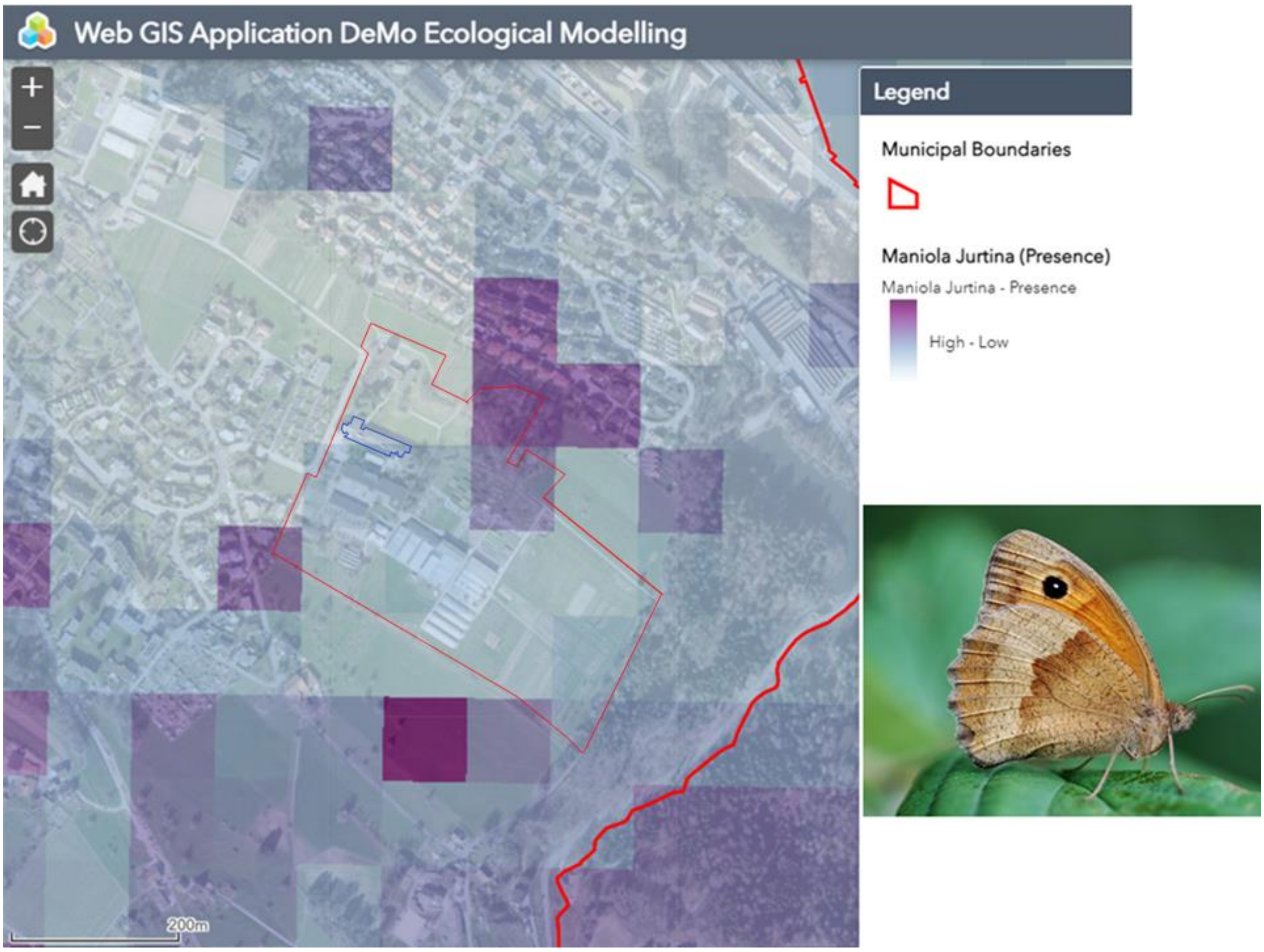

Figure B 6 Q32, Ecological map type: Presence density (Source: TerrOïko)

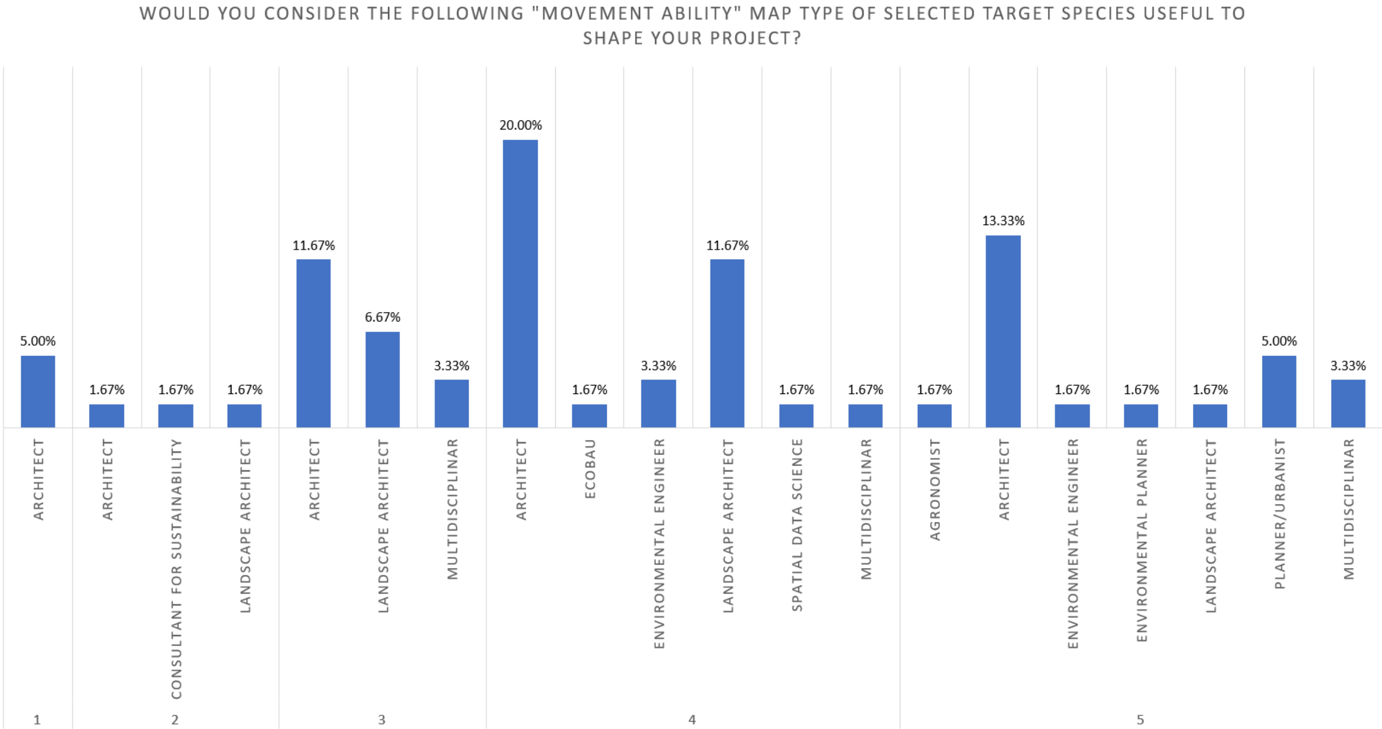

Figure B 7 Q33 Results divided per category; Movement Ability

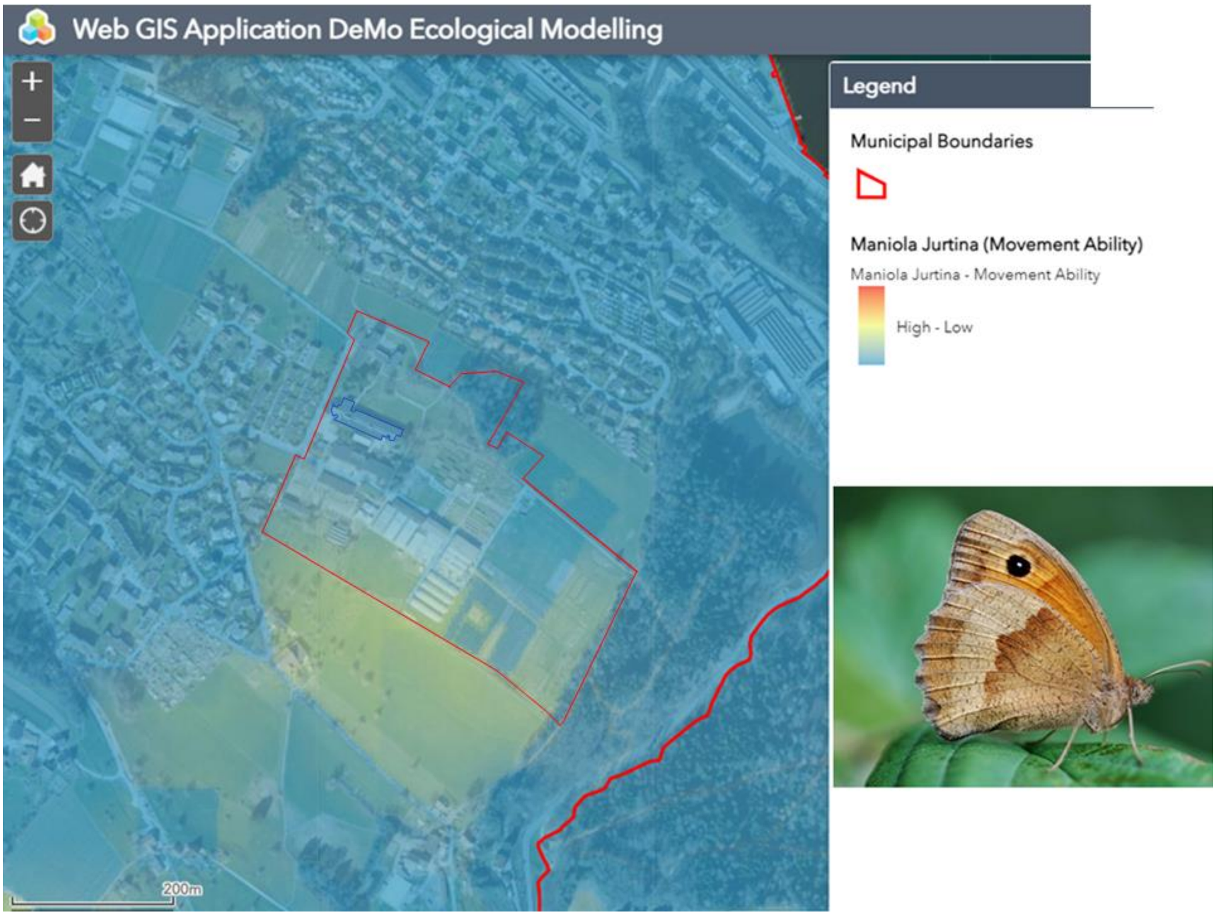

Figure B 8 Q33, Ecological map type: Movement Ability (Source: TerrOïko)

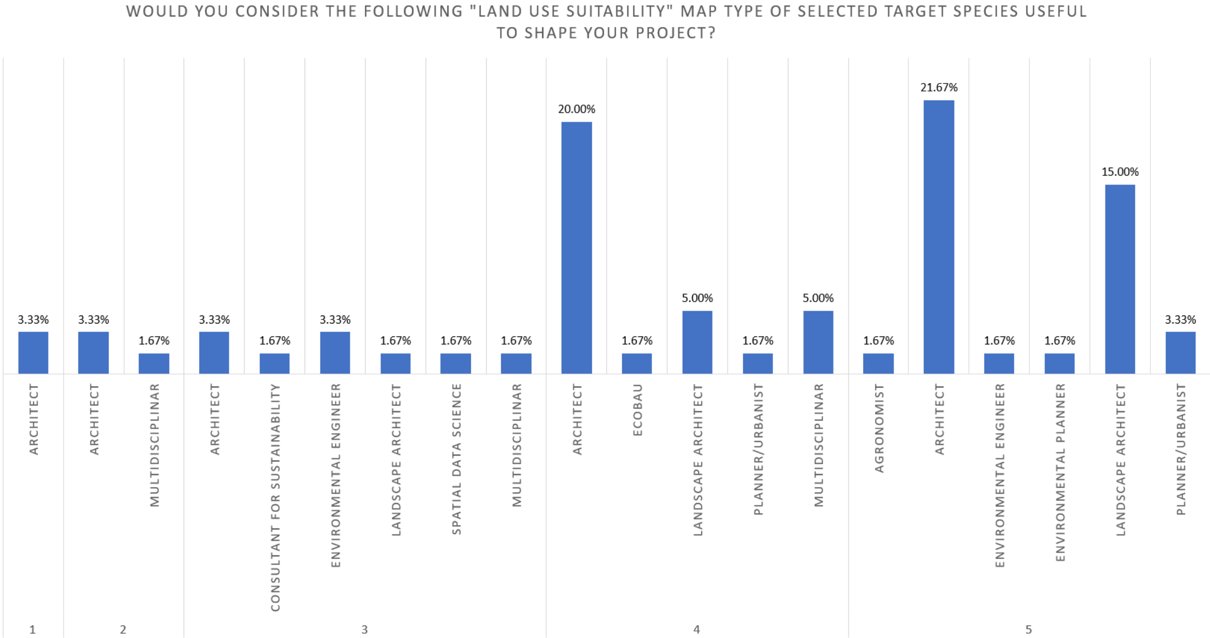

Figure B 9 Q34 Results divided per category; Land use suitability

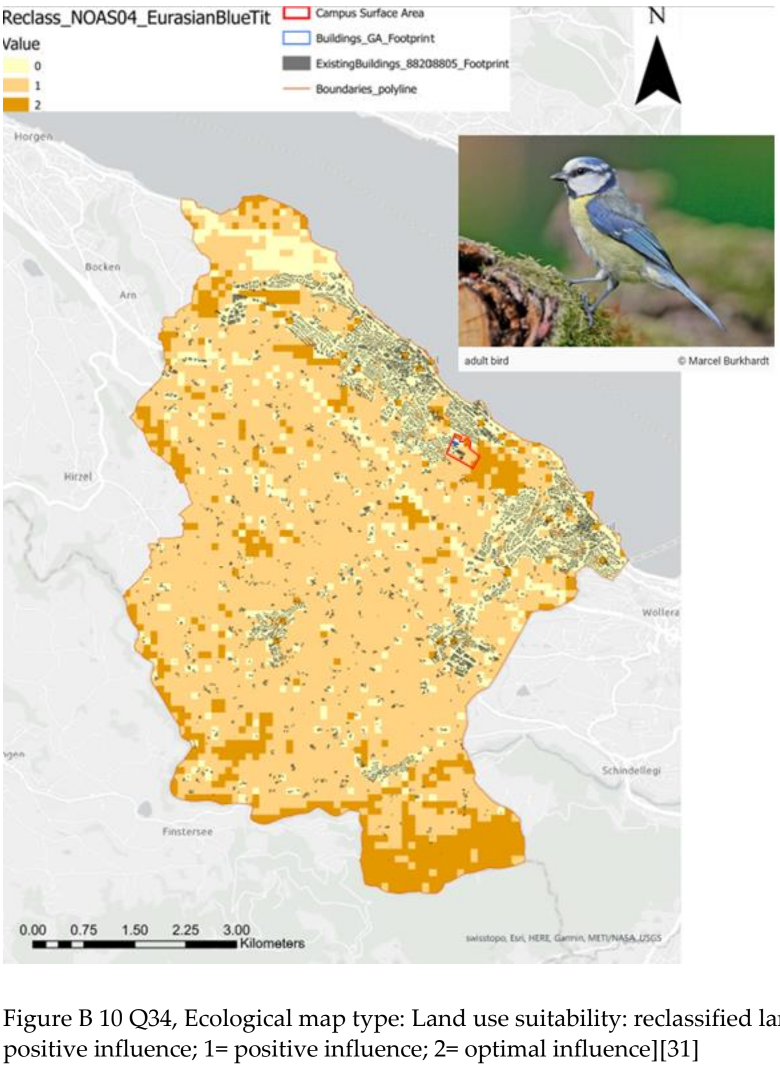

Figure B 10 Q34, Ecological map type: Land use suitability: reclassified land use values according to the species preferences [0= no positive influence; 1= positive influence; 2= optimal influence][31]

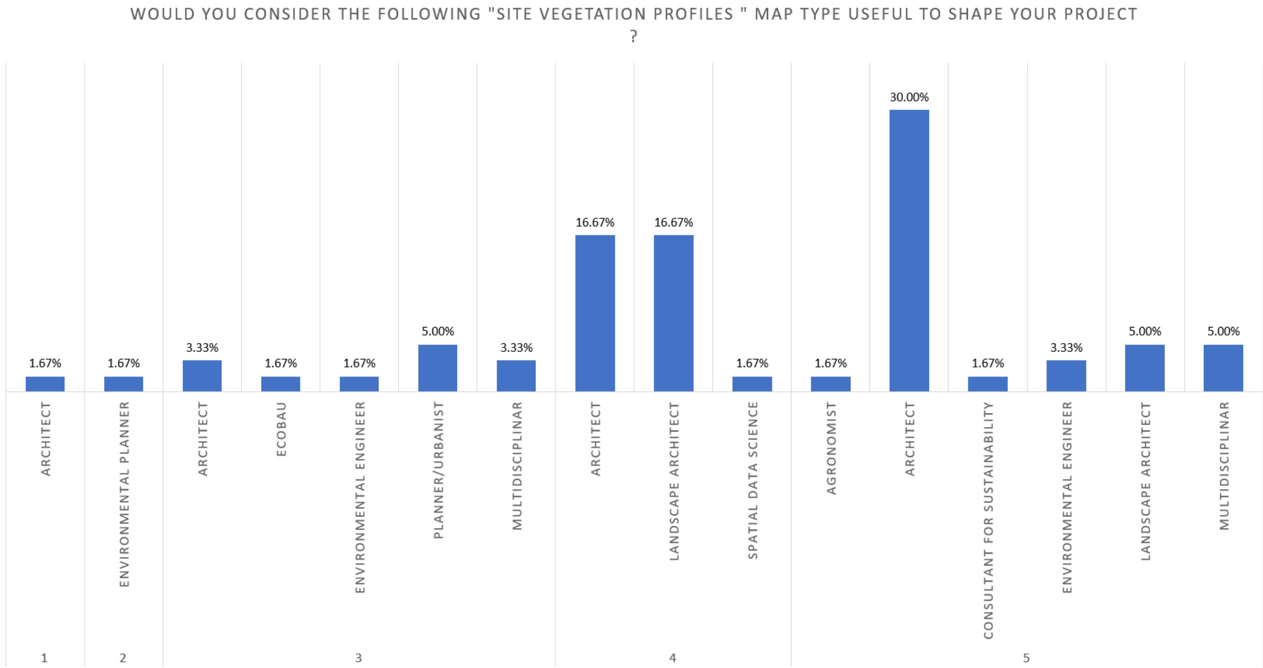

Figure B 11 Q35 Results divided per category; Site Vegetation Profiles

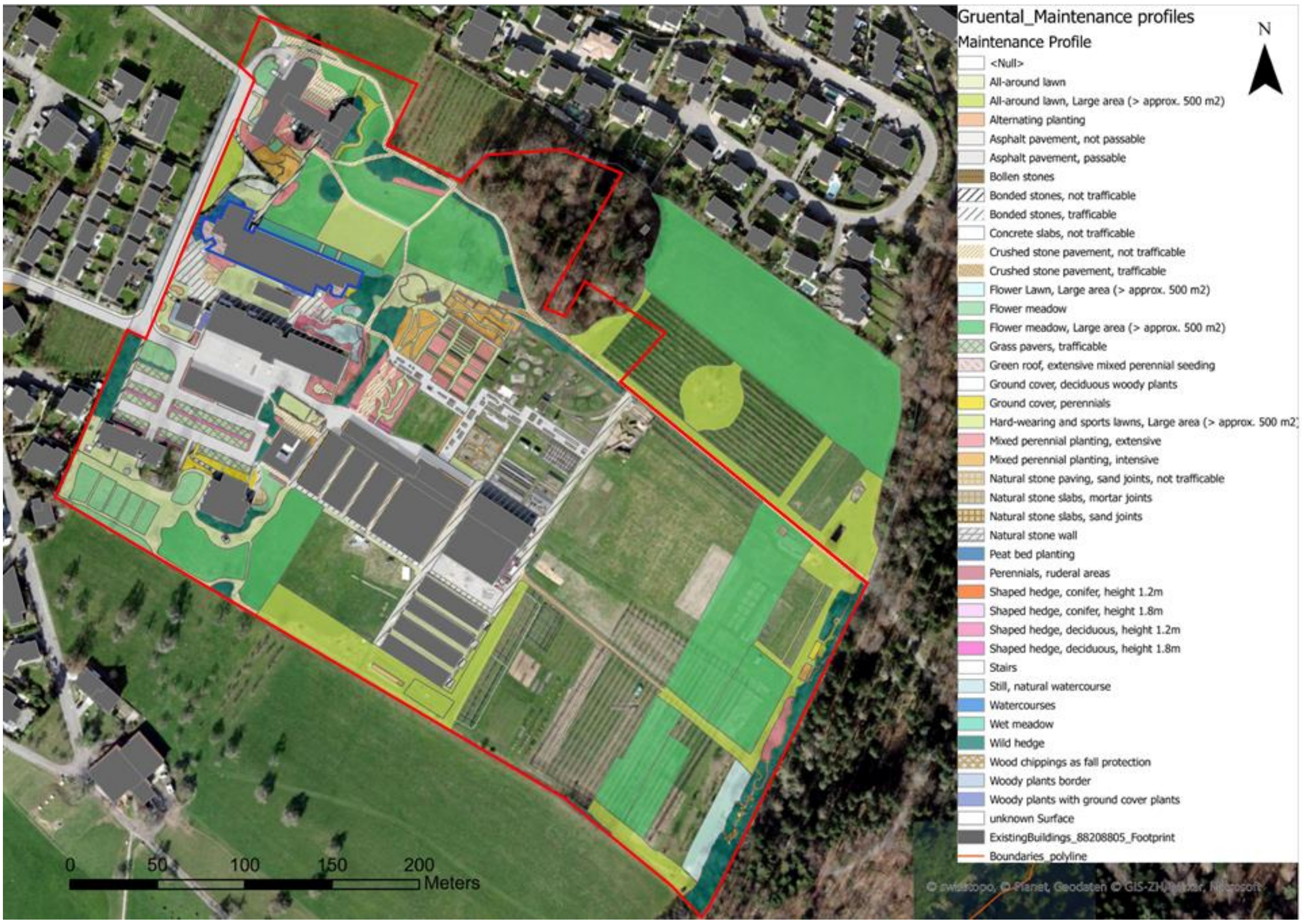

Figure B 12 Q35, Ecological map type: Site Vegetation Profiles: Site specific vegetation profiles present on the project site (Source: ZHAW, Research Group Freiraummanagement and Geoinformatik, 2016)

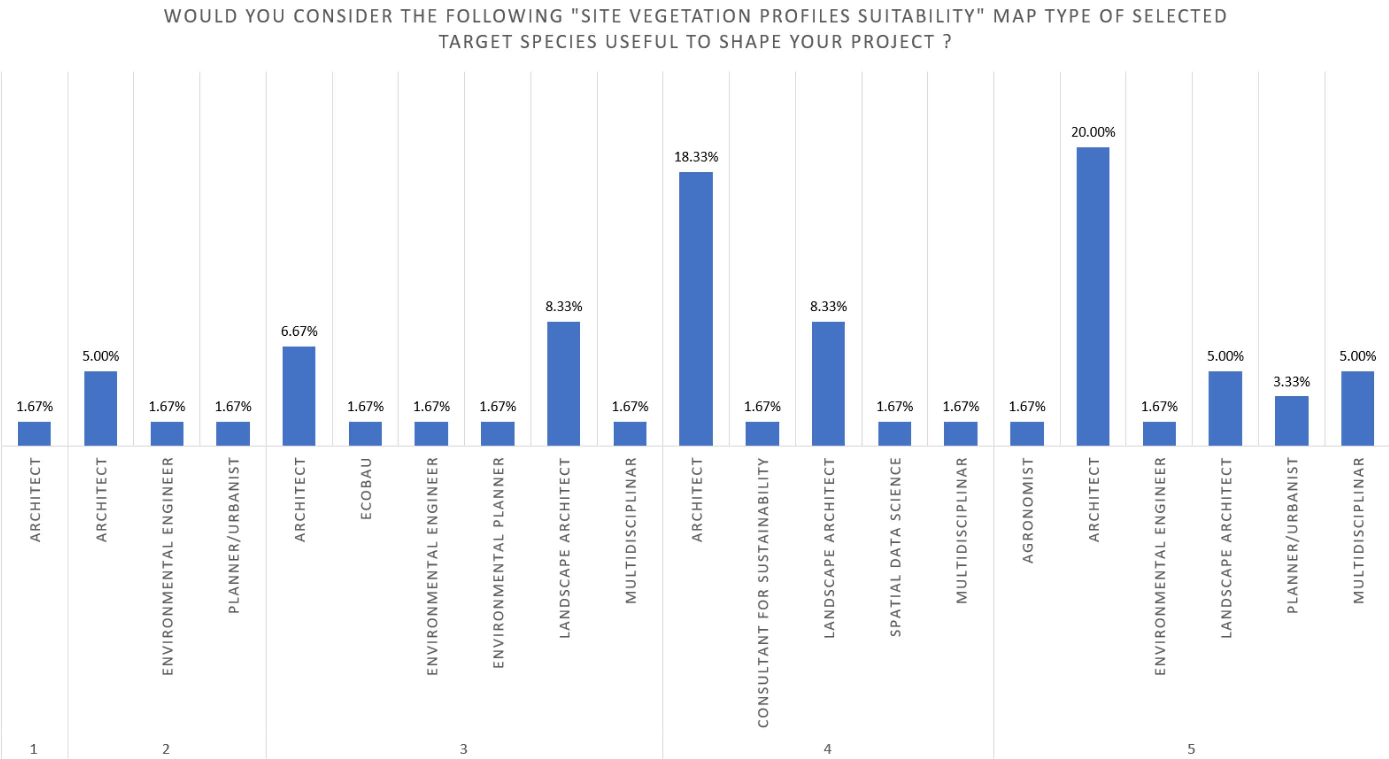

Figure B 13 Q36 Results divided per category; Site Vegetation Profiles Suitability

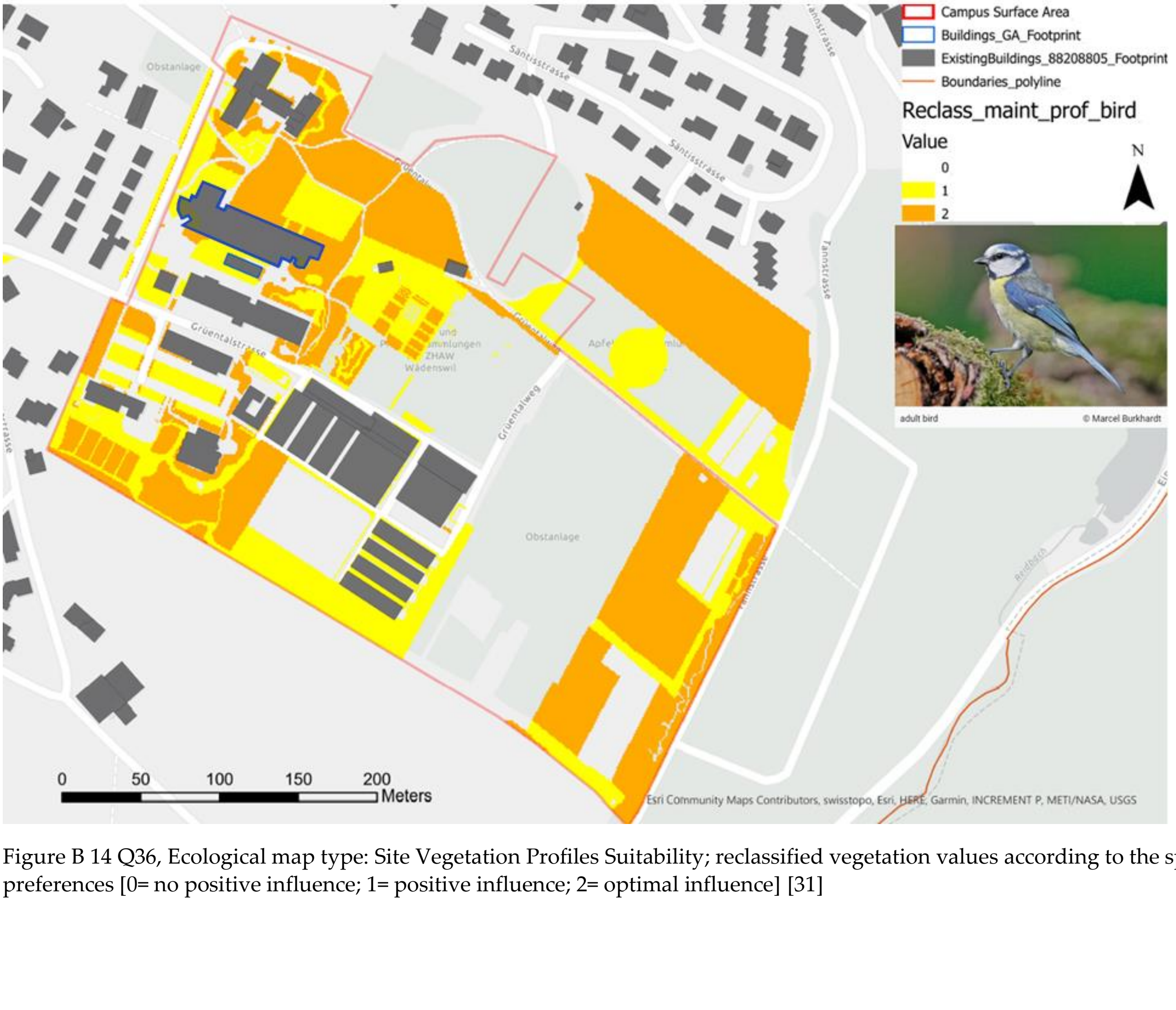

Figure B 14 Q36, Ecological map type: Site Vegetation Profiles Suitability; reclassified vegetation values according to the species preferences [0= no positive influence; 1= positive influence; 2= optimal influence] [31]

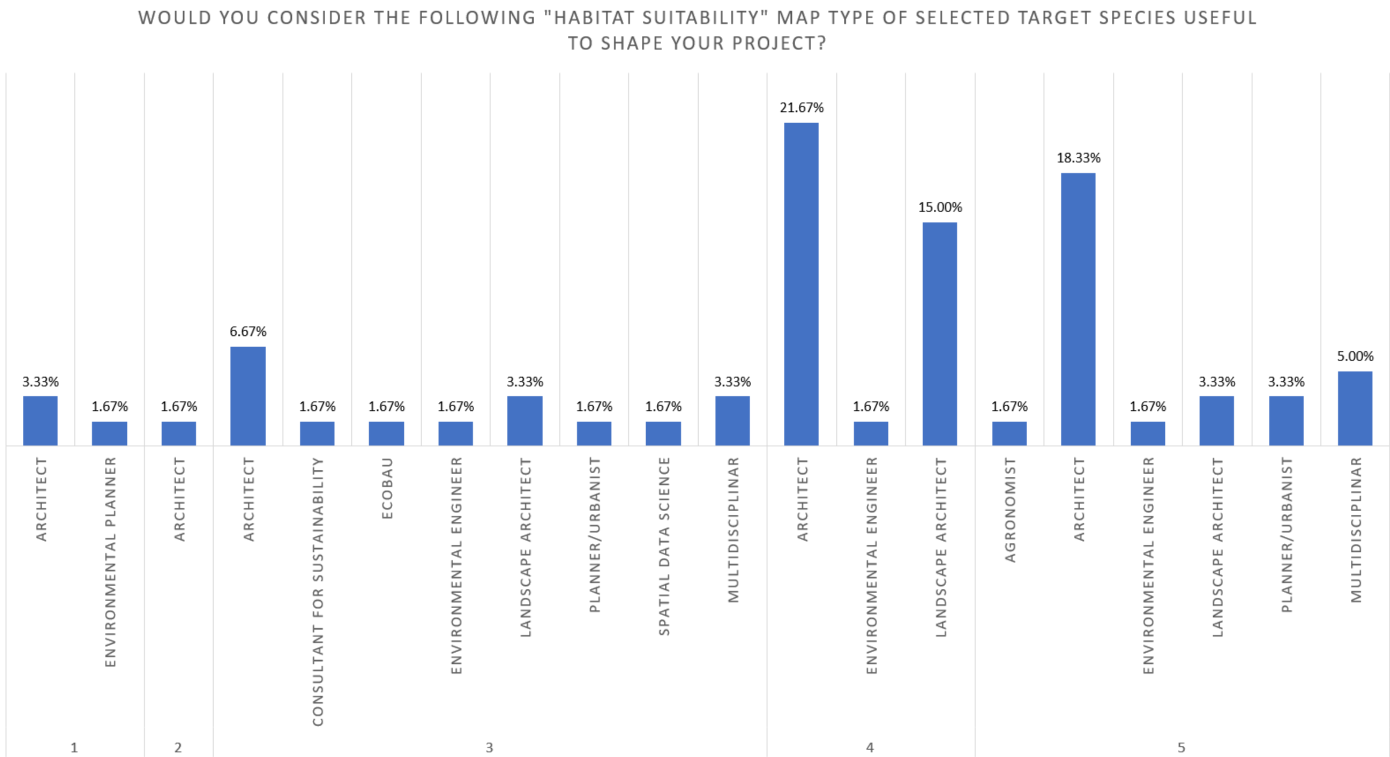

Figure B 15 Q37 Results divided per category; Habitat Suitability

Figure B 16 Q37, Ecological map type: Habitat Suitability; extrapolated by overlaying target species forage range, tree density, land use, and site vegetation profiles information. [0= Low suitability ; 8= high suitability][31]

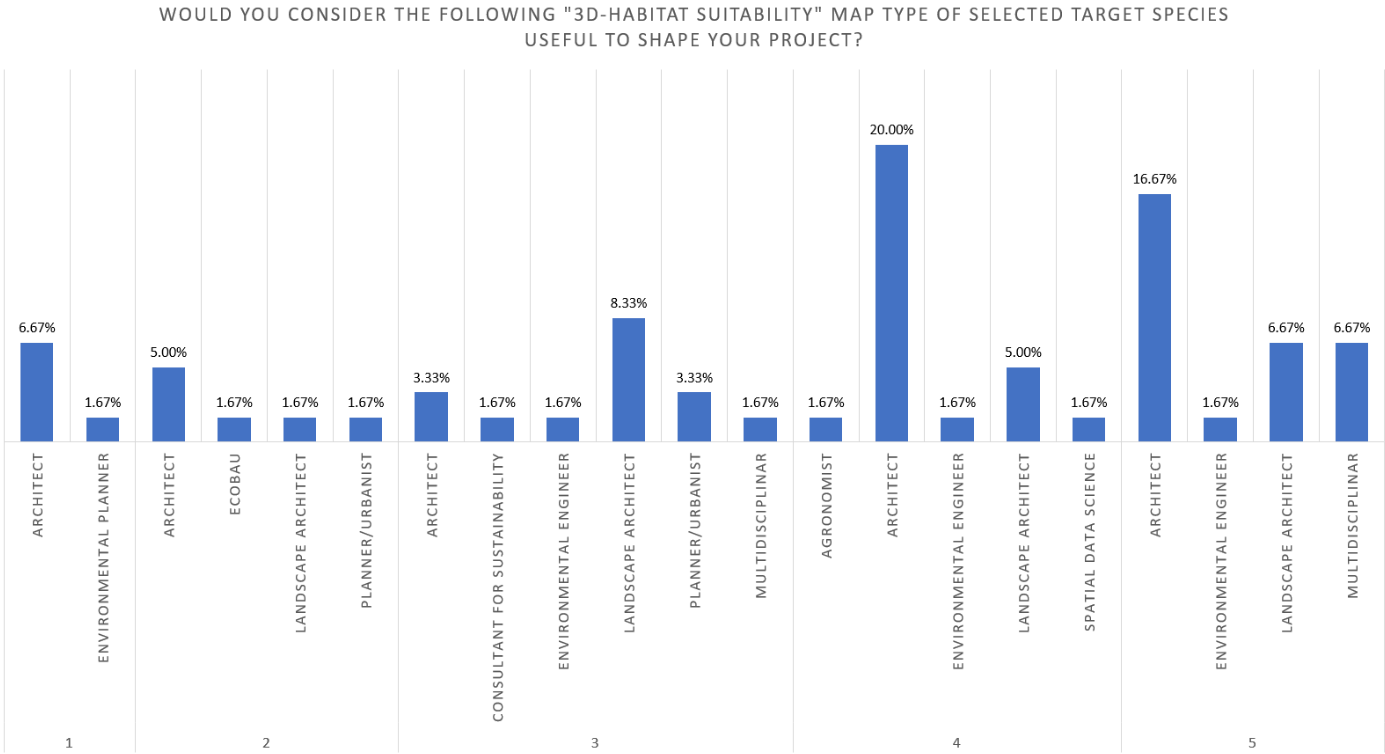

Figure B 17 Q38 Results divided per category; 3D-Habitat Suitability

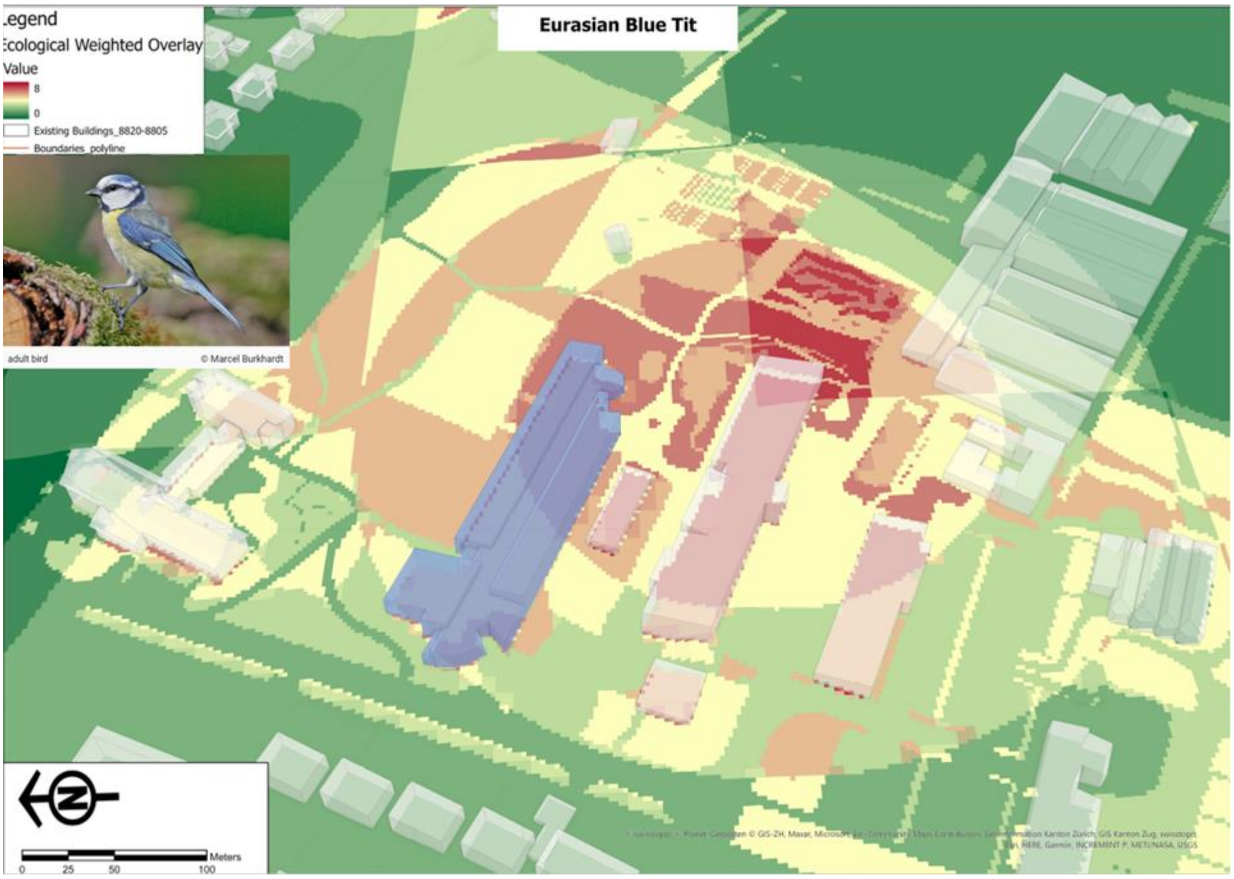

Figure B 18 Q38, Ecological map type: 3D-Habitat Suitability; overlay of suitability maps [0= Low suitability ; 8= high suitability][31]

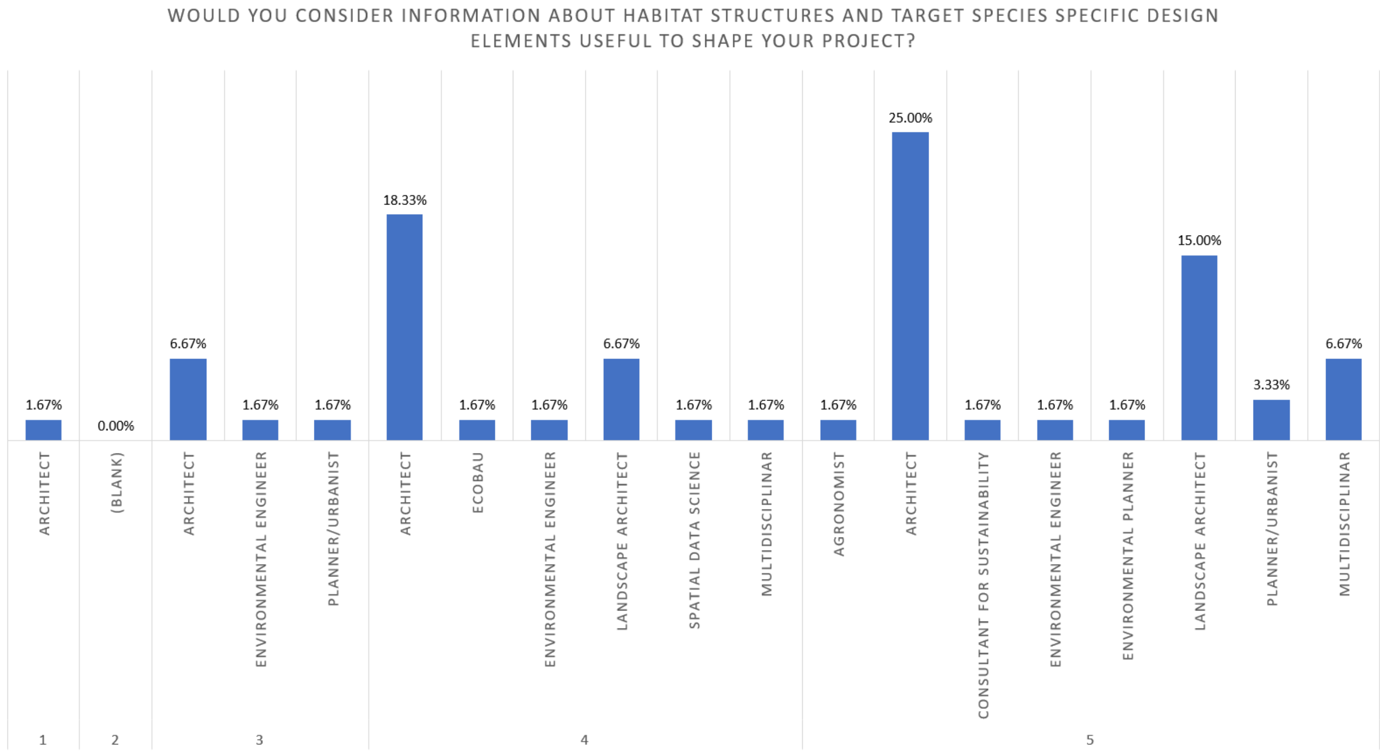

Figure B 19 Q39 Results divided per category; Habitat structures and target species specific design elements

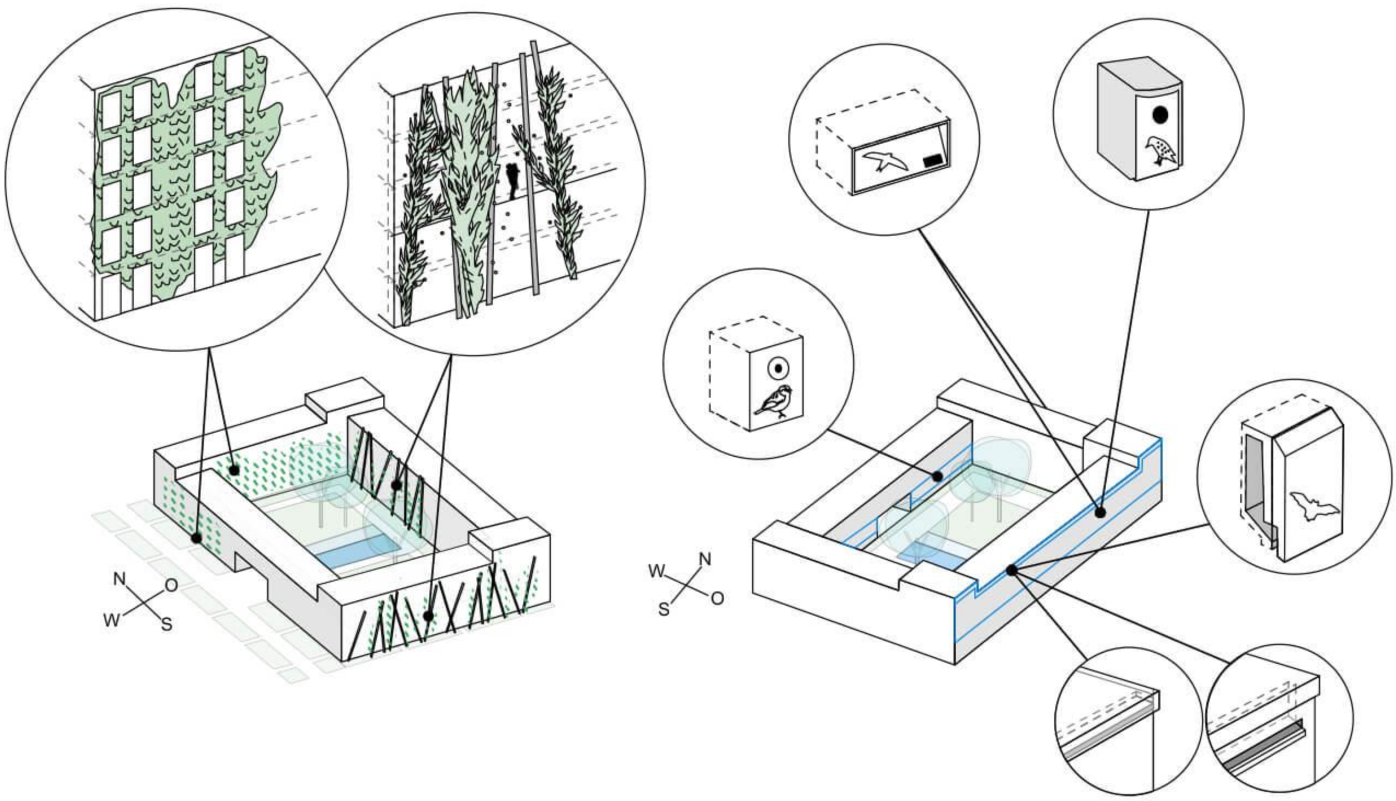

Figure B 20 Q39, Habitat structures and target species specific design elements: Array of elements and modules for biodiversity conservation and building integration (Source: Studio Animal-Aided Design)