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Perspective

Architectural Multispecies Building Design: Concepts, Challenges, and Design Process

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Abstract: This perspective paper explores the concept of multispecies design in architecture, focusing on the building scale. Historically, architects have prioritized human needs, neglecting nature's integration in urban settings, leading to environmental and social challenges. To address these issues, a new multispecies approach that promotes the integration of ecological knowledge into architectural design has evolved. This paper aims to map existing concepts, challenges, and gaps in this novel multispecies approach, focusing on the building scale design process and suggests a roadmap for its implementation. This paper analyzes the existing literature and current architectural practices. This analysis is complemented by the findings from an architectural design studio that have highlighted real-world challenges not readily apparent in the literature. By promoting a multispecies architectural paradigm, this research not only underscores a transformative approach to building design but also positions multispecies design as an essential strategy in combatting the challenges of declining biodiversity and escalating climate change.

Keywords: multispecies design; building envelope; architecture and ecology; sustainability; nature-based solutions; architectural design process; non-anthropocentric design; greenery systems

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1. Introduction

In recent decades, the global human population has experienced rapid expansion, rising from six billion individuals in 1999 to nearly eight billion in 2022. While some projections indicate a decline in growth rates, the urban population is projected to grow by 2.5 billion people by the middle of this century, resulting in rapid and substantial urban expansion [1]. Global analyses have shown that this rise has already occurred and is expected to cause further significant impacts on biodiversity, especially in vulnerable ecoregions of high endemism [2–4]. While cities have become thriving centers of economic growth, innovation, and knowledge production, they also generate a myriad of complex social challenges [5,6]. An urban lifestyle is associated with detachment from nature, rising allergies and respiratory system problems, chronic stress, and mental fatigue, leading to non-communicational diseases such as depression and obesity [7]. Sustainable urbanization is thus emerging as a major contemporary environmental global challenge.

To address the ecological and social implications of urbanization, environmental design solutions have been developed with the aim of restoring natural ecosystems, mitigating climate change, and promoting urban well-being [8] (final report of the Horizon 2020 expert group in 2011). While traditional solutions have largely focused on establishing natural ecosystems alongside the urban fabric through the creation of protected areas (e.g., nature parks and reserves) and ecological corridors, these approaches, while valuable, are insufficient. The rate of species extinction is increasing, while human interactions with nature are dwindling, leading to an "extinction of experience" [9]. The recognition that cities and buildings can be hotspots for biodiversity [10,11] highlights the need for innovative research that explores the potential of embedding nature-based design approaches in general [11,12], and especially at the building scale [13].

Shifts to the multispecies design of buildings is perceived as an integral and synergistic element in current conservation efforts, considering both ecological and sociological perspectives. Multispecies design in this context refers to an architectural design process that considers human and non-human needs (e.g., animals, plants, and microbiota) [14]. This transformation can notably enlarge the volume of urban green spaces and facilitate the interconnectivity between pre-existing conservation strategies. Sociologically, the concept of multispecies edifices offers a substantial contribution to reconnecting humanity with the natural world. This fusion has the propensity to promote individual well-being and counteract the growing alienation of humans from the natural environment, a disconnection that yields a multitude of consequences [14,15].

A shift towards multispecies design at the building scale represents a departure from the current anthropocentric approach to architectural design. This approach is grounded in the recognition that creating a new type of synergetic environment necessitates an ethical shift in which non-human species are assigned equal consideration as stakeholders in the building design process. Achieving this requires a deep understanding of the needs of non-human species and how these needs can be translated into architectural form [13]. However, architects have limited practical knowledge of ecology in general, and specifically, in understanding the needs of non-human species and their translation into architectural form. Therefore, integrating this new direction into architecture requires incorporating knowledge and methods from other research fields, such as ecology, animal geography [16], and multispecies ethnography [17].

A gap in the availability of design tools and databases that include information about non-human species is limiting the development of this field. Models that incorporate ecological community dynamics are currently unavailable in the architecture engineering and construction (AEC) sector and are mostly oriented toward the urban and regional scales in ecology. In addition, the concept of multispecies design is particularly relevant at this moment in time due to recent advances in architectural design and fabrication technologies. Natural animal habitats are often characterized by complex morphology that has previously been difficult to design and fabricate. Yet, the integration of computational design and fabrication tools into architectural practice has made it possible to design and create complex building elements that were once unattainable [18,19].

2. Aims, Methodology, and Paper Structure

The aim of this perspective paper is to map the challenges and gaps associated with the transition towards multispecies design at the architectural building scale. It draws upon a thorough review of the existing literature, established research, and current architectural practices.

The paper is part of a larger research project, "Ecolopes" (www.ecolopes.org, accessed on 16 October 2023), which develops a methodology and computational design framework and design tools for designing a building envelope as a dynamic space shared between humans, animals, plants, and microbiota. The previous publication from this project outlined the general ecological and architectural challenges of this suggested paradigmatic shift [14]. Based on the foundation of the general conceptual framework in earlier publications, this paper focuses on the multispecies design process on the building scale and proposes answers to the questions of how, when, and why a multispecies design process, such as the one developed in the "Ecolopes" project, will be employed by architects, and what its implications and contributions to the architectural design process and to a more sustainable urban environment would be.

In the context of sustainable research, the methodology of this prospective paper follows the general protocols for integrative review, as outlined in [20]. The papers were selected by an integration of search results from databases that include Engineering Village, Web of Science, Google Scholar, and CumInCAD. The search terms used included "multispecies design"; "multispecies architecture"; "architecture design" and "multispecies" "architecture design and animals/plants/microbiota"; architecture and "animals/fauna"; architecture and "plants/flora". The results of these searches were screened for relevance through title and abstract screening and used to locate other relevant publications.

The paper begins with a background section that reviews previous approaches to incorporate nature into architecture and points out why they are not sufficient for multispecies design. It also discusses the architectural precedents, i.e., what has been and is being built, and demonstrates why this is not multispecies construction.

This is followed by a section that discusses the challenges when moving from current anthropocentric to multispecies design, including a review on the current negative effects of architecture on nature, the lack of positive effects of current architecture on nature, the "perceived" negative effects of nature on architecture, and ethical challenges in the shift to multispecies design. We then outline how multispecies design could work and be integrated into the traditional design process, as encapsulated in the RIBA formal design process. Next, we discuss findings from an architectural multispecies design studio that highlights real-world challenges not readily apparent in the literature. Finally, we outline areas where more research is needed and lay out a roadmap for the implementation of multispecies design in architectural practice.

3. History and Precedents of Including Nature in Architecture

This section aims to provide a comprehensive review of the historical context and practical precedents that have shaped the inclusion of nature in architectural design. The section begins by exploring the conceptual approaches of connecting with nature. It then explores existing research on the integration of plants and non-human species in building design, including green walls, green roofs, and prototypes for multispecies envelope systems.

3.1. Previous Conceptual Approaches of Taking Nature into Account in Architectural Design

3.1.1. "Connecting" with Nature

The increasing impact of human settlements on natural resources in the 20th century has promoted a movement of thinkers, calling to reexamine the way humans design and build their cities. Ideas that promote reconnecting with nature, such as design with nature [21,22], argue that nature should not be exploited only as a resource but rather be respected and embedded as part of the design. Approaches such as Biophilia, hold that humans have developed a need and dependency to connect with the natural world and therefore we need to strive to include nature and reconnect to nature in the way we design and build our habitats [23,24].

Other research directions search for the application of functions derived from nature. One of the leading approaches in this realm is biomimicry, literally referring to imitating biological mechanisms in architectural design. The term derives from Janine Benyus seminal book on the subject. However, it is also related to earlier terms of the same approach, such as bionics ("biology" and "technics"), biomimetics, and bioinspiration [25–27].

3.1.2. Nature-Based Solutions

Traditional approaches towards the connection to nature in architectural design are defensive and focus on minimizing the effect of humans on nature and preserving nature in specific areas such as nature reserve corridors and parks [28]. Other "nature-based solution" approaches argue that designers need to employ nature and solutions inspired by nature to resolve environmental problems within urban environments [29]. These approaches focus on creating synergies between humans, plants, and the demands of other species in a multispecies approach to design [13,30]. Cities, in this view, can be designed and built to include (to a certain extent) natural wildlife, which will live and prosper parallel to humans and will contribute, together with the traditional solutions, to tackling the ecological and social challenges that increased urbanization generates.

Another idea in this direction is Biodiversity Inclusive Design (BID). As opposed to a nature-based solutions approach, BID calls for the deliberate inclusion of features supporting other species in the urban environment [31,32]. These lines of research concentrate mainly on the urban and regional scale in landscape architecture, ecology, and related fields.

3.1.3. Integrating Nature at the Building Scale

Research on integrating nature into architectural design at the building scale, which is the focus of this paper, has been receiving less attention. The early manifestations of research and practice in this field were morphologic in nature. One of the earliest manifestations of this connection emerged with 'zoomorphic architecture', where architectural elements or entire building forms were taken directly from animals or plants [33]. Movements such as Organic Architecture [34] and Art Nouveau [35] likewise focused on the morphological aspects of natural forms and their manifestation in building elements and argue for the beauty of the natural form and its positive perceptual effects. No specific research on the multispecies design process at the building scale was found.

3.1.4. Integrating Elements of Nature at the Building Scale: Plants

There are several research directions on the integration of non-human species in building design, especially concerning the integration of plants in buildings. Research related to plants at the building scale comprises mainly research on green walls and green roofs populated with plants. Although both green roofs and walls have received wide attention in research and practice in the last two decades, the main focus of the research is still human-centric and somewhat defensive in terms of the attitude towards plants, e.g., an investigation into the utilization of botanical systems in architectural contexts to mitigate the environmental impact of buildings, with a focus on enhancing thermal insulation, mitigating thermal loads and heat island effects, and contributing to flood prevention through rainwater retention.

Recent review papers that discuss cutting-edge research and implementation in these fields show little research that focuses on the integration of ecological knowledge in the design process of buildings [36–39]. Other research directions suggest systematic integrating living trees with building structures [40], which contributes to building greening.

3.1.5. Integrating Elements of Nature at the Building Scale: Animals

There are some examples of research that examine the integration of animals in buildings in general and specifically in building envelopes. In architecture, these lines of research are mainly led by practitioners and will be described in the next section. Research in this direction in other fields usually focuses on the potential benefits of the relationship between buildings and animals. A recent review paper by De Wilde et al. [41] examined the interactions between buildings and animals. One of its main conclusions is that viewpoints held by design stakeholders regarding animals are anthropocentric, utilitarian, subjective, contextual, and influenced by their comprehension of the significance of various species within the ecosystem. They also state that there is limited knowledge regarding the specific building features that should be encouraged to facilitate positive interactions with animals.

Other research mainly focused on specific animals. Examples of these research directions include Kettel et al.'s [42] research on raptors nesting in cities, which found differences in breeding timing and brood sizes in an urban environment compared to rural environments. They also found that urban environments may act as ecological traps for some raptor species. Another example is Meier et al.'s [43] research on insect habitats integrated into building envelopes that investigated the interactions between integrated insect habitat systems in façades and the building of physical aspects to create test objects. The research found some positive benefits on the integrated system from both ecological and building physical points of view. The research identified challenges at a socio-ecological and technical level. It calls for a special focus on the "skepticism and lack of knowledge of people, as well as on the comfort of the insects".

Another line of research is the development of building envelope systems to be multispecies friendly. An interesting recent example is Larikova et al.'s study [44], which investigates the potential of computational design and fabrication for the creation of building envelopes that can host cavity-dependent animal species. The research developed a prototype for a building envelopes and provided initial insight into how emerging digital technologies could enable the creation of site-specific multispecies solutions.

3.1.6. Excluding Animals from Buildings

Contrary to the lines of research that identify a positive connection between buildings and animals, there is a large body of research on preventing animals (pests) and plants from populating and using buildings. This includes research directions such as the prevention of birds nesting [45,46], prevention of habitats for rodents and other animals that are considered as a potential hazard to building or human health [47], damages to the building by tree roots [48], and damages to stone cladding by plants and lichens [49].

Cities like San Francisco have created guidelines for pest prevention in building designs, aiming to tackle the issue not just at the building level, but also city-wide [50]. These guidelines cover understanding local pests, designing buildings according to each situation's physical context, the pest tolerance level, and the use of pest-resistant materials. They also recommend easy-inspection designs, moisture minimization, sealing openings, eliminating harborage, engineering slabs and foundations to deter pest entry, and making structures unappealing to pests. Although these approaches follow the opposite direction to the paper at hand, we argue that using the inverse of these pest-prevention recommendations could be a start, as understanding what deters fauna and flora may reveal what would encourage them to inhabit buildings.

3.1.7. Summary and Gaps—Approaches of Taking Nature into Account in Architectural Design

Architectural design has seen movements from a foundational and formal connection with nature to the applied integration of flora and fauna within structures. Notably, many past initiatives were heavily human-centric, aiming to offset environmental impacts. Although some research exists on deterrent mechanisms for preventing flora and fauna from infiltrating buildings, limited rigorous studies in architecture address their deliberate and beneficial inclusion. A notable gap exists in multispecies architecture: the knowledge on how to actively and synergistically integrate diverse species into the building design remains sparse.

3.2. Practical Architectural Precedents of Integrating Plants and Animals Needs in Building Scale Designs

The following section examines the precedents of including animal and plant habitats in architectural design. This section focuses on residential and public buildings in which a decision was made to include other species habitats that do not bring a direct benefit to people. It is important to note that there are stand-alone artificial habitats for animals, such as bird's nests and insect's habitats, that are currently placed as stand-alone objects in urban environments [51]. These stand-alone habitats for other species will not be discussed in this paper.

The discussion in this section is divided into animals and plants. Animal integration with building envelopes has received less attention. While there seems to be no building designed with a declared multispecies design strategy, many examples were found for a partial allocation of space and resources in buildings for other species. Small-scale examples include integrated bird nests in building roofs, such as Klaas Kuiken birdhouse roof tile (https://klaaskuiken.nl/birdhouse-new-stock, accessed on 16 October 2023). Although there is some evidence provided by the designers and manufacturers showing that these solutions work and attract animals, we did not find scientific research on this, nor did we find research on the multispecies aspects of the design process of these elements.

3.2.1. Multispecies Tiles and Facades

On a larger scale, several prototypes have been developed for a multispecies envelope tile system. These examples are design interpretations of the conceptual idea of a multispecies building envelope. An example of such a system is a building envelope prototype by Buro Happold and Cookfox architects for birds, plants, and insects (see https://cookfox.com/news/cookfox-and-buro-happold-acaw, accessed on 16 October 2023). These examples tried to develop a façade system that is both multispecies but also contributes to the thermal insulation of the building and potentially also works for flood mitigation by retaining rainwater. However, no empirical evidence on that was found. Also, these prototypes were not extended beyond a single element prototype, probably due to the high cost of these elements for an entire building.

There are some precedents to multispecies design thinking also on a larger scale of an entire building, for example, the Mellor Primary School habitat wall by Sarah Wigglesworth architects (see Figure 1). Similarly, the office Animal-Aided Design, a design and research office in this field, developed a strategy that integrated elements for birds, hedgehogs, and other animals in elements that were embedded in residential projects in Germany. However, while the methodological approach of Animal-Aided Design has been implemented in planning, the design approach at the building scale has not yet been systematically explored [13,30]. Another example is the projects by the French Chartier-Dalix architectural firm, which developed building envelopes that integrate spaces for extensive plants [52] (Figure 1). The firm also developed several prototypes integrating vegetation in brick or concrete walls (Figure 1). Although the results seem to offer a successful integration of plants on the building envelope, no scientific research results on this were found.

Figure 1. Upper row left to bottom right: concrete building envelope with integrated planters Chartier-Dalix Architects (source: Chartier-Dalix Architects Photo credit: Takuji Shimmura). Lower row left to right: Animal-Aided Design building integrated bird nest in the Brantstraße in Munich (source: Animal Aided Design). Mellor Primary School habitat wall by Sarah Wigglesworth architects (source: Lower row left to right: Animal wall (bats)—art installation in Cardiff bay by Gitta Gschwendtner (Source: Gitta Gschwendtner. Photo credit: Kiran Ridley).

3.2.2. Greenery Systems on Buildings

Greenery systems in buildings include horizontal systems, e.g., green roofs, and vertical systems, e.g., green walls. Both systems can be divided into two main types according to the level of maintenance and the type of plants they include: extensive and intensive [53]. Extensive systems do not contain irrigation and are usually designed for minimal maintenance, which is achieved by employing local plant species. On the other hand, intensive systems include irrigation and need continuous maintenance, allowing more plant choice freedom.

Extensive green roofs are common. They are used for their ecological contribution and building performance contribution both at the building level (mainly reducing thermal loads and preservation of thermal insulation [54]) and the urban level (mainly increasing biodiversity and preserving habitats for plants and animals [55]). Extensive roofs can be based on initial planting or left alone for nature to evolve, according to natural and social demands and local biodiversity [56].

Well-known examples of an extensive roof are the California Academy of Sciences in San Francisco by Renzo piano workshop (2008) (see Figure 2).

Figure 2. California Academy of Sciences in San Francisco by Renzo piano workshop (2008) (source: Renzo piano workshop photo credits: **Left**: Fox, Tom_SWA Group, **Right**: Tim Griffith Photographer).

Extensive green façades or walls are divided into direct façade greenery, where the plants grow on the façade from the ground; indirect greenery, where the plants grow on the façade from a planter on or close to the ground; and living walls, where plants grow on planters distributed over the façade [54]. The implementation of extensive vertical green systems poses a distinct set of challenges. There are precedents of evergreen or summer green-climbing flora embellishing building exteriors in many climate zones. Typically, these climbing plants initiate growth from the ground and ascend the building structure. The prevailing expectation for vertical green systems leans towards maintaining an evergreen appearance, a condition that is often unattainable given the varied climatic scenarios worldwide. Consequently, the potential negative perception of desiccated plants within these green infrastructures could contribute to an overall diminished appeal, thus limiting their wider acceptance.

Further impediments to the successful implementation of such green systems are inherently climate-related, such as variations in solar radiation, the absence of reliable irrigation systems, and exposure to frost. These factors underscore the intricate balance required to navigate the challenges of implementing extensive green façades or walls effectively.

Intensive green systems are highly controlled environments. Their design is derived from a functionalist approach that considers the human aesthetic and performance preference as the main drivers for design. Function, in this context, refers to ideas such as increasing thermal insulation, growing vegetables (on raised bed roof gardens), and creating areas for human leisure. Aesthetically led approaches, which can also be read as a specific type of function, elevate the visual expression of the building envelope to increase human pleasure and admiration of the façade. Plants, in this case, are usually used to create an aesthetically pleasing composition that transmits design and social ideas such as livelihood and sustainability. This approach to green systems can increase the danger of invasive species of plants and animals [57]. Known examples of intensive roofs and façades are the Quai Branly Museum green wall (2006), which includes plants from all over the world, "Bosco verticale", Vertical Forest (Figure 3) (2014), and the Porter School of Environment Studies, which use the green roof for research on succulent plants (Figure 3) (2014).

Figure 3. "Bosco verticale", Vertical Forest by Stefano Boeari Architects (2014) (Photo credit: Dimitar Harizanov). Green roof at the Porter School of Environment Studies By Axelrod Grobman, Geotectura and Chen Architects, and Braudo Maoz landscape (2014) (Photo credit: Shay Epstein).

3.2.3. Summary, Gaps, and Limitations of Practical Multispecies Design Approaches

Although significant research has been conducted on the contribution of greenery systems on buildings to biodiversity, the design process for these elements remains largely inadequate in addressing multispecies considerations. The existing body of knowledge in this area reveals several limitations that hinder the effective integration of diverse species into design practices.

While there have been many instances of spaces and resources in buildings being allocated for other species, **no building was found to have been designed with a declared multispecies design strategy**. While there is evidence of multispecies thinking at the scale of individual building envelope tiles or elements, **there is a notable gap in the systematic exploration of such designs at the building scale**. Moreover, although there are some individual building elements or envelope tile system prototypes, like the one by Buro Happold and Cookfox architects, these **were not extended beyond a single element**, potentially due to the lack of research on design methodology for an entire façade and the high costs of fabrication of such façades.

One of the primary limitations pertains to the insufficient understanding of the specific needs of various species and the challenge of translating this knowledge into design briefs. While research has shed light on the importance of accommodating different species within the built environment, there is still a **lack of comprehensive knowledge regarding their individual spatial requirements and the way these change over their life cycle**. This knowledge gap impedes the formulation of design briefs that effectively address the diverse needs of multiple species. Moreover, another significant limitation arises from the **lack of ecological expertise among designers** involved in multispecies design projects. Often, designers lack the necessary ecological knowledge and expertise to incorporate multispecies considerations into their designs. The absence of ecological understanding limits their ability to create environments that adequately support and sustain diverse species.

Integrating these various elements within a building's design requires a holistic understanding of ecological principles and the interactions between different species and their built environment. However, the existing research and guidelines often **lack the necessary ecological knowledge at the building scale** to support the introduction and implementation of such integrative solutions.

4. Buildings and Multispecies Interactions

Building envelopes consist of vast vertical and horizontal areas that have the potential to become habitats for animals, plants, and microbiota [13]. Large areas from building envelopes are unreachable by humans and currently mainly act as a border between the inside and outside, while other areas, such as windows and balconies, are used by humans daily. In this section, we outline and summarize the literature on the mutual impacts of building and multispecies interactions at the building scale.

4.1. The Perceived Negative and Unknown Positive Impacts of Animals on Buildings

Animals are known to impact buildings, both directly and indirectly. There is evidence that animals such as cats and owls that can indirectly benefit buildings by controlling pests that cause damage to building utilities [58]. Animals can cause direct damage to building structures and utilities by feeding on building materials, breaking windows through collisions, and even causing electrical breakdowns by electrification [59–61]. In addition to direct damage, animals can also cause indirect damage to building structures and utilities, such as clogging plumbing systems with dirt and debris. Animals can also create temporary negative effects on buildings by leaving dirt on windows, walls, and roofs, which can affect the aesthetic and functional qualities of the building [45,62].

On the other hand, while animals can have indirect positive impacts on buildings, there is limited evidence to suggest that they have a direct positive impact on buildings that are not related to human use and enjoyment.

The foregoing discussion highlights the complexity of the relationship between buildings and animals and underscores the negative impacts that can result from this relationship. While there are some positive effects of building elements on animal populations, these benefits are often indirect and related to the human use and enjoyment of buildings, i.e., the human benefit. Because it is the goal of architecture to benefit humans, any negative effect on the building (through wear and tear) needs to be put in perspective with the positive effects on human inhabitants. In this respect, animals are no different than high temperature or UV; we enjoy living in a sunny place even though this puts the building material under pressure. The challenge for architects is thus to use materials that can cope with the negative effect of sunlight or animals on buildings to facilitate the positive effect on humans.

4.2. The Positive and Negative Impacts of Buildings on Animals

The positive impact of buildings on animals has been the subject of scientific inquiry in recent years. Building elements such as overhangs, crevices, and leftover and unused spaces have been found to provide shelter and sleeping/nesting opportunities for various animal species [44,63–65]. Additionally, buildings can provide better conditions for some animals to feed and hunt by offering more light and extended hunting hours, prey on windows/under light, and heated warm areas [42]. The incorporation of green roofs and green façades in building design has also been found to provide new habitats for animals [66–68]. Furthermore, buildings can provide food and water sources for animals, including leftover food/garbage, water leaks, and open water tanks [68,69]. Finally, buildings can provide refuge from predators, which can be particularly important in urban areas where natural habitats may be limited [70]. These findings suggest that buildings can have a range of positive impacts on animal populations and highlight the importance of considering the potential effects of building design and construction on local ecosystems.

The negative impact of buildings on animal populations is an area of concern in contemporary scientific inquiry. Collisions with building elements such as large glass windows have been identified as a significant source of harm to animal (mainly bird) populations, resulting in injury, damage, and mortality [71]. Buildings can also have harmful effects on animals through light pollution, heat sources, and electricity, which have been shown to cause injury, disorientation, and death [68,72–74]. The construction of buildings can also lead to the isolation of animal habitats, blocking movement and creating ecological traps [75]. Furthermore, animals can be captured and locked in spaces within buildings, which can lead to dehydration, starvation, injury, and death. The impact of buildings on animal populations can also extend to reductions in food sources, which can have negative effects on the health and survival of animal populations [76]. These findings underscore the need for careful consideration of the potential impacts of building design and construction on local ecosystems, also when, at first hand, the effect may be positive and suggest the importance of implementing strategies to mitigate negative effects on animal populations.

4.3. Summary of Challenges and Gaps in Buildings and Multispecies

Buildings and their envelopes present significant opportunities and challenges for multispecies interactions, serving both as habitats for various animals, plants, and microbiota, and impacting their survival and behavior. While animals can indirectly benefit buildings by controlling pests, they can also inflict direct and indirect damage to the structure, affecting aesthetics and functionality. Conversely, buildings can offer shelter, food, and better living conditions for animals but can also pose threats, notably from window collisions, light pollution, and habitat disruption (see Figure 4). This complex relationship emphasizes the architectural need to balance materials and designs that cater to human interests and well-being while minimizing negative impacts on other species. The current literature shows many benefits and threats for animals while showing that humans will only marginally benefit from this integration (see Figure 4). This demonstrates the need to examine other types of benefits of animal integration in building.

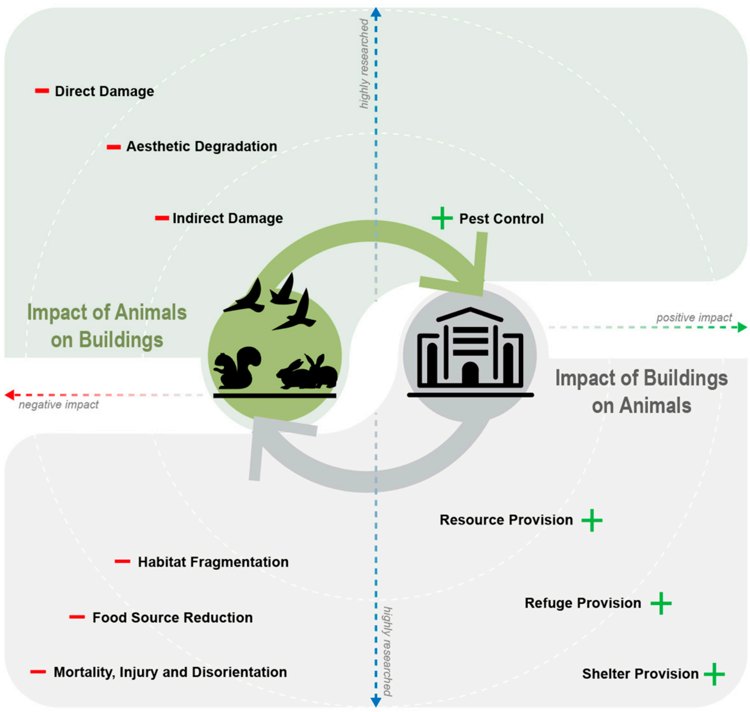

Figure 4. Challenges for including animals in the architectural design process.

4.4. Multispecies Cohabitation: Evaluating the Psychological, Sensory, and Health Impacts on Humans

The influence of cohabitation with other species (animals, plants, and microbiota) on humans can be analyzed according to attitudes, health, and well-being. Human attitudes towards animals that share human habitats, whether invited or not, are complex and multifaceted. These attitudes can range from biophilia and the acceptance of animals as part of the natural environment to feelings of inconvenience, disgust, fear, and even phobia. A range of animal phobias have been identified by researchers, including zoophobia (fear of animals), ophidiophobia (fear of snakes), ornithophobia (fear of birds), and entomophobia (fear of insects).

The integration of animals and plants as equal stakeholders in building design, or the creation of habitats for them on building envelopes, can elicit strong emotional and sensory reactions from humans. A growing body of research has shown the positive effects of exposure to nature on human health, well-being, and cognitive function [77]. However, there is also a significant amount of research on the negative influence of animals on human well-being and health, with a focus on companion animals and urban pests (e.g., mice and cockroaches). It is important to note that human attitudes towards animals can vary greatly across cultures and time periods and may be influenced by a range of cultural factors such as festivals, movies, and TV series [78–80]. For instance, some animals, like butterflies and hedgehogs, may be viewed as cute and beautiful in one culture, while others may elicit feelings of fear and disgust. Similarly, some animals, such as crickets, may be kept as pets in one culture but considered pests in others [81–83].

However, negative reactions of humans towards animals and plants can also have significant impacts. These negative reactions can include feelings of fear, disgust, and discomfort/tension, as well as negative sensual reactions to animal noise, smell, and visual discomfort [84–86]. Exposure to animals and plants can also generate negative health hazards such as allergies and zoonotic diseases [87,88].

Positive reactions of humans towards animals and plants can contribute significantly to improving well-being and overall quality of life. Several studies have shown that exposure to nature and animals can generate positive emotions, increase satisfaction with one's home and job, and contribute to faster recovery from illness [89,90]. Additionally, exposure to nature has been found to have a restorative effect on mental fatigue, improve prosocial tendencies, relieve stress, and enhance mood [91–93]. Other studies have reported that exposure to nature, such as to the sound of birds singing and to the smell of nature, can generate positive sensual reactions as well as positive aesthetic and visual pleasure [94,95]. Direct and active engagement with nature (involving senses such as touch and vision) also has positive effects on well-being [96].

Despite humans' inherent biophilic inclination to establish connections with nature [22], human attitudes and perceptions towards nature are multifaceted and comprise both positive and negative reactions. Human behavior towards nature is dynamic and has undergone transformation, largely due to the "extinction of experience" [9] and the escalating urbanization of human habitats [14]. Such disconnection from nature has resulted in worrisome phenomena, such as plant blindness [97]. Therefore, for the introduction of the multispecies building envelopes to be successful, it must be a gradual process. In selecting the animals and plants to be incorporated into the building envelopes, ecological and environmental factors must be carefully considered along with the human attitudes towards, and perception of, the chosen organisms.

The literature shows that an increase in natural microbiota levels in urban environments has a positive impact on human health by mitigating allergies and sensitivities in humans [98]. The integration of multispecies design in building envelopes has the potential to enhance exposure levels to humans of various microbiota types from the earth, plants, insects, and animals compared to conventional buildings. This may have a beneficial impact on human health in the short and long run. However, an uncontrolled introduction of species may also give rise to undesired species, such as venomous insects and hazardous microbiota that can endanger human health. Hence, in designing and implementing multispecies building envelopes, a careful risk assessment must be conducted to identify the potential risks and develop appropriate monitoring and maintenance strategies to manage such risks effectively.

4.5. Ethical Challenges of Multispecies Design

Beyond the practical and design challenges, multispecies environments are expected to introduce a variety of ethical challenges or dilemmas as well, which will have to be acknowledged and deliberated on during the design and implementation processes. These ultimately relate to the overall goal of the design, i.e., how the different stakeholders, humans, animals, but also non-animals (plants and microbes) should be weighted, and what the exact aim should be with respect to the non-human stakeholders.

In the environmental ethics discourse, there are various approaches with regard to the moral status of the various species [99]. The anthropocentric approach holds that humans ought to be the focus of moral concern, whereas the status of animals and plants is instrumental to the flourishing of humans. The anthropocentric approach generally characterizes current architectural design and practice. Multispecies design implies that non-human entities ought to become stakeholders in the design, adding these hitherto ignored stakeholders into the moral calculation. This creates several possibilities, depending on one's moral standpoint:

- The biocentric approach holds that every organism, species population, and community of life has a good of its own, and as such possesses inherent worth [100].
- The pathocentric approach holds that species that have the ability to feel pain ought to have moral status [101], and that the pleasure and pain of individual entities counts towards the total sum of the pleasure and pain of all entities [102].
- The hierarchical biocentric approach holds that while all beings have moral standing, the extent of their moral considerability varies [103].
- The ecocentric approach holds that entire ecosystems have moral status and that animals, plants, and microbiota are not merely instrumental to humans, but are intrinsically valuable [104].

The challenge that these approaches pose for multispecies design is the following: in each approach (except the ecocentric approach), species types have a different moral status in relation to the other species types. This, in turn, dictates that in each design end-product, there will be a different balance or combination of species. Designers adopting the anthropocentric approach will prioritize the humans by ensuring that animals and plants do not create what would be perceived by humans to be nuisances or threats to safety or human well-being (e.g., attracting dangerous animals or microbiota etc.). Designers adopting the ecocentric approach will focus on the health of the ecosystem as a whole, whereby human needs, interests, and preferences will inform the design on par with the perceived needs and interests of the other species (animals, plants, and microbiome). In other words, as a matter of principle, human needs, interests, or preferences will be considered equal to those of other species. Regarding the hierarchical biocentric approach, designers will afford animals and humans higher moral status, compared to plants or microbes. For the pathocentric approach, it will be necessary to determine which species are capable of feeling pain, and for the hierarchical biocentric approach, it will be necessary to determine which beings have greater moral standing than others.

There are further ethical challenges associated with multispecies design. One such challenge is that the design will inevitably reflect certain values, which therefore ought to be ethically justified. The values that can potentially be built into the design include well-being (of humans and/or non-human animals/plants), autonomy (of humans and/or non-human animals), safety, convenience, fairness, and sustainability. These values will manifest differently between the aforementioned ethical approaches but will also manifest differently within each approach.

5. Multispecies Design and the Architectural Design Process

The previous chapter presented the state of the art in the literature and practice on multispecies research at the building scale. The following chapter brings an expert's analysis of the challenges related to the introduction of multispecies design into the architectural design process at the building scale.

The anthropocentric architectural design process, which has been employed for countless centuries and is deeply ingrained in the design tradition, faces inherent challenges when attempting to accommodate unfamiliar species. While architects possess firsthand knowledge of human customers and their needs, designing spaces for other species presents a formidable task [105]. Architects not only lack direct experience regarding the requirements of their animal and plant "customers," but they are also unable to engage in direct communication with them to acquire pertinent information. Furthermore, to effectively translate animal needs into architectural forms, designers must adeptly incorporate the sensory modalities of diverse species and gain a comprehensive understanding of animal perception and their unique perspectives of the world. Animals perceive the world through distinct visual systems, encompassing variations in vision type, field of view, and viewpoint. Their auditory and olfactory senses also differ from humans, and they navigate and explore their surroundings through flight, crawling, and alternate vantage points. Additionally, animals and plants exhibit diverse environmental needs in terms of their habitats, food resources, and their desire for security, including the need to hide and be protected from various predators, including humans. Moreover, the aesthetic dimensions of design for animals (and potentially plants) might diverge fundamentally from the aesthetics that humans favor or have gotten used to. Given the pivotal role of understanding the customer in architectural design, designing for non-human species poses a considerable challenge.

The challenges encountered in the process of multispecies architectural design can be classified into the following primary categories, aligning with the traditional architectural design process described by the Royal Institute of British Architects (RIBA) [106]:

1. Developing the brief—how to define the multispecies aspects of the architectural brief? What plants and animals to include in the design brief? What are the ecological objectives of the brief?
2. Concept design and spatial coordination—how to design architectural geometry for the chosen species and how to distribute the species on the architectural form? How to receive information on the selected animal and plants' spatial, material, and other needs? How to understand other species and plants' needs? How to mitigate conflicts between the needs of animals, plants, and humans? How to represent other species as stakeholders in the design process?
3. Technical development, manufacturing, and construction—who represents other species in this process? How to receive information on the selected animals' and plants' spatial, material, and other needs for the detailed and technical design stage?
4. Handover—need for a definition of the concept of handover from an animal and plant point of view.
5. Post-occupancy evaluation—how to evaluate the performance of the building from an animal and plant point of view (not a formal part of the design process of RIBA).

The subsequent section aims to delve deeper into the aforementioned challenges and establish an initial roadmap for the integration of multispecies design principles in architecture.

5.1. A Multi Species Architectural Brief

The development of a traditional architectural brief typically follows a linear and systematic process. Initially, the brief must cater to the needs articulated by a diverse array of stakeholders and conform to relevant laws, such as building codes, urban plans, and the specific requirements of the building owner, as well as other stakeholders, including neighboring parties. In the case of privately owned properties, the project's concrete definition is primarily shaped by the owner's vision and objectives. Conversely, for public buildings, the brief development process is typically led by an individual entrusted with a mandate from the public. In either scenario, the brief is subjected to presentation, evaluation, and critique from the various stakeholders involved in the project, ensuring a comprehensive and inclusive approach.

The foremost challenge encountered in the realm of multispecies design lies in the initial decision to embrace a multispecies approach and incorporate animals and plants as stakeholders in the design process. Undeniably, this paradigm shift towards multispecies design entails an initial increase in costs, primarily attributable to necessary modifications in the design process and the introduction of novel elements within buildings. It is reasonable to infer that only a limited number of private property owners would willingly opt for a multispecies design approach for their projects. In the case of public buildings, the transition towards a multispecies design framework and its associated implications necessitates official approval by the public through legislative channels. Moreover, the development of new building regulations, urban concepts, and guidelines tailored specifically to multispecies design becomes imperative. Thus, surmounting the primary challenges of multispecies design mandates the proactive involvement of local and state authorities, who are responsible for promoting legislation favoring the integration of multispecies elements in building design and allocating resources to facilitate the requisite changes.

Once this initial challenge has been addressed and legislation supporting the integration of multispecies design into building practices has been enacted, the subsequent significant challenge within the architectural brief pertains to determining the ecological strategy and objectives. The ecological strategy may involve various aspects, such as enhancing biodiversity or focusing on the preservation of specific endangered species. This strategy should subsequently be translated into a comprehensive list of species that need to be seamlessly integrated across different scales, encompassing the city, urban areas, neighborhoods, and individual buildings. The selection of the ecological strategy and objectives should be guided by expert knowledge encompassing the environmental, climatic, and ecological characteristics specific to the project's location.

The development of the aforementioned ecological strategy necessitates a depth of knowledge of plant and animal behavior that is not typically present within traditional design teams. Consequently, it becomes crucial to bridge this knowledge gap by involving experts such as ecologists and animal specialists, as well as by enhancing the designers' own understanding of other species. In this context, knowledge encompasses both theoretical and practical design-related insights into multispecies dynamics. However, it also extends to somatic knowledge and design ethnography acquired through firsthand experiences of spending time with these species in their natural habitats and attempting to perceive the world from their unique perspectives [107].

In contemporary architecture, there is a notable absence of relevant knowledge concerning other species. A preliminary examination of curricula from selected architectural schools, including TUDelft, U.C.L., Technion, and Yale, reveals that, currently, there are no mandatory courses dedicated to the study of plant and animal behavior within the professional education of architects. Knowledge pertaining to plants is often associated with landscape architecture, where it is indeed included as a mandatory subject in numerous educational institutions. However, mandatory courses on animal knowledge are noticeably absent from the curricula of landscape architecture programs within the aforementioned universities.

Another challenge concerns the ethical approach that will ground the brief. The brief will inevitably be either anthropocentric, biocentric, or ecocentric, and the ethical principles underlying the design must be acknowledged and articulated in the brief.

5.2. Concept Design and Spatial Coordination

The concept design stage involves translating the design strategy and the brief (mainly textual or diagrammatic instructions) into an initial architectural design proposal. Two main challenges are evident in this stage: the generation of the design proposal alternatives, and the evaluation and optimization of these alternatives.

The generation of architectural design alternatives is based on explicit and tacit knowledge. Explicit knowledge refers to concrete instructions such as dimensions, materials, and connectivity instructions from sources such as the brief, building, and city laws. Tacit knowledge comes mainly from the designer's experience. As mentioned earlier, there is little explicit knowledge of multispecies design and almost no tacit knowledge. Architects need to develop the tacit knowledge of multispecies design through formal education on multispecies and firsthand observation from a human and non-human perspective. A temporal solution for this gap (until such tacit knowledge is developed) would be to substantially increase the explicit knowledge of animal and plant behavior in relation to environmental, spatial, and material needs. A new type of Neufert Architectural Data [108], a reference book for spatial requirements in building design which include explicit design instructions, could be prepared for every functional group of animals (a set of species, or collection of organisms, that share similar characteristics) or for every species.

Another challenge in this stage is the representation of non-human stakeholders in the design process. As self-representation is impossible, a possible solution is adding a new member to the design team, one responsible for representing other species. The new member will support the design team in complementing missing explicit and tacit knowledge and will help to negotiate design conflicts between the various stakeholders in a quest for a synergetic relationship.

Regarding the evaluation and optimization of the initial form, two main challenges must be confronted. The first is the extraction of architectural and ecological objectives and key performance indicators (KPI) from the design brief strategy that represent the stakeholders' needs in the design process (human and non-human). The second is developing a multi-criteria decision-making process (M.C.D.M.) to evaluate the design according to the selected objectives and KPIs. The nature of a traditional design processes comprises decision-making complexity. This complexity is increased with the inclusion of an multispecies approach. These complexities can be negotiated via M.C.D.M. processes that require the integration of multidisciplinary, quantitative, and qualitative criteria. In Selvan et al. [109], an example of such an approach is shown.

5.3. Technical Development, Manufacturing, and Construction

At this juncture of the design process, the focus shifts towards the development of construction drawings, models, and specifications. Subsequently, following a tender process and the selection of a contractor, the project transitions into the construction stage. From a multispecies design perspective, this stage presents several noteworthy challenges. Primarily, the issue of representing non-human stakeholders reemerges. To address this, the inclusion of a dedicated team member responsible for advocating for the needs of other species and mediating conflicts becomes essential. Additionally, attention must be directed towards the presence of pre-existing non-human stakeholders at the construction site. Conventional construction practices often overlook the utilization of the site by other species, resulting in the flattening or disruption of their habitats without consideration or provision for alternative solutions. A multispecies approach to construction could involve evaluating the site prior to construction and implementing measures to accommodate and protect existing species during the construction phase.

Another crucial aspect pertains to the construction technologies and materials employed during this stage. As the detailed architectural design is finalized and building materials are selected, careful consideration must be given to ensure compatibility with the needs of other species. In line with the aforementioned requirement for specialized knowledge and attention to non-human species' needs in the early stages of design, the choice of materials and textures becomes significant. Optimal selections may include textures featuring cavities and bumps that can serve as habitats for insects and birds, as well as materials that do not emit repellent odors harmful to animals.

The construction stage is known to generate substantial noise pollution and other potential forms of pollution that can impact the surrounding environment. Analogous to construction restrictions implemented to protect human well-being, a comprehensive set of general and site-specific restrictions should be developed, specifically tailored to accommodate the needs of other species. This may include imposing noise restrictions during construction to mitigate disturbances experienced by non-human stakeholders.

5.4. Handover and Maintenance

The formal handover of a building encompasses a comprehensive inspection and approval process, verifying compliance with building laws and urban plan instructions. Parallel to this, an evaluation and approval by the customers or future users also takes place. Once official approval is obtained, after addressing any rejections or necessary modifications, the building is officially handed over to the future users. In the context of multispecies design, the inspection and evaluation process for non-human stakeholders necessitates the involvement of a representative who can assess the building on behalf of these stakeholders and negotiate any rejections or required changes.

Another distinction between traditional design and multispecies design in this context relates to the habitation and maintenance process following the handover. In traditional project design processes, users can occupy the building once it is approved and adopt it to their needs to a certain extent. However, in multispecies design, the non-human species may be physically introduced to the project or provided with the opportunity (and time) to naturally discover and inhabit the space. Nevertheless, natural habitation is a gradual and dynamic process influenced by various factors, including weather, seasons, availability of prey, and the presence of predators. Consequently, the intended species will only occasionally inhabit the building, and the variability in the non-human habitat within the building will remain dynamic.

Furthermore, embracing multispecies design necessitates an understanding that sharing a building with other species will transition it into a less controlled environment, susceptible to seasonal changes in form, noise, and other factors associated with the life cycles of animals and plants. The traditional perception of the building envelope as uniform, clean, and inert, requiring regular maintenance to maintain its condition, needs to evolve.

Maintenance is another critical aspect to consider. While multispecies buildings would probably be designed with minimal maintenance requirements resulting from the inclusion of other species, they will still require more maintenance than traditional buildings, adding to the responsibilities of humans. Moreover, building envelopes will not remain as pristine and intact as they are today. Consequently, the perception of the building envelope as a clean, homogeneous surface will need to evolve among humans to accommodate the presence of other species.

5.5. Summary and Gaps

This section delves into the challenges and complexities of integrating multispecies considerations into the architectural design process, especially on a building scale. Historically, architecture has been human-centric. The lack of direct experience and understanding of the requirements of other species poses significant hurdles as animals and plants perceive their surroundings differently from humans, in terms of vision, auditory senses, spatial needs, and aesthetic preferences. Key challenges and gaps include (see also Figure 5) the following:

Developing the brief: defining ecological objectives, determining which species to accommodate, and establishing how these considerations align with traditional design goals.

Concept design and spatial coordination: addressing the lack of explicit and tacit knowledge about other species and understanding how to represent them as stakeholders in the design process.

Technical development, manufacturing, and construction: advocating for the needs of other species, ensuring the choice of construction technologies and materials are compatible, and addressing the potential disruptions to existing habitats.

Handover and maintenance: ensuring a comprehensive inspection process for non-human stakeholders, understanding the dynamic nature of habitation by various species, and redefining perceptions of building maintenance in a multispecies context.

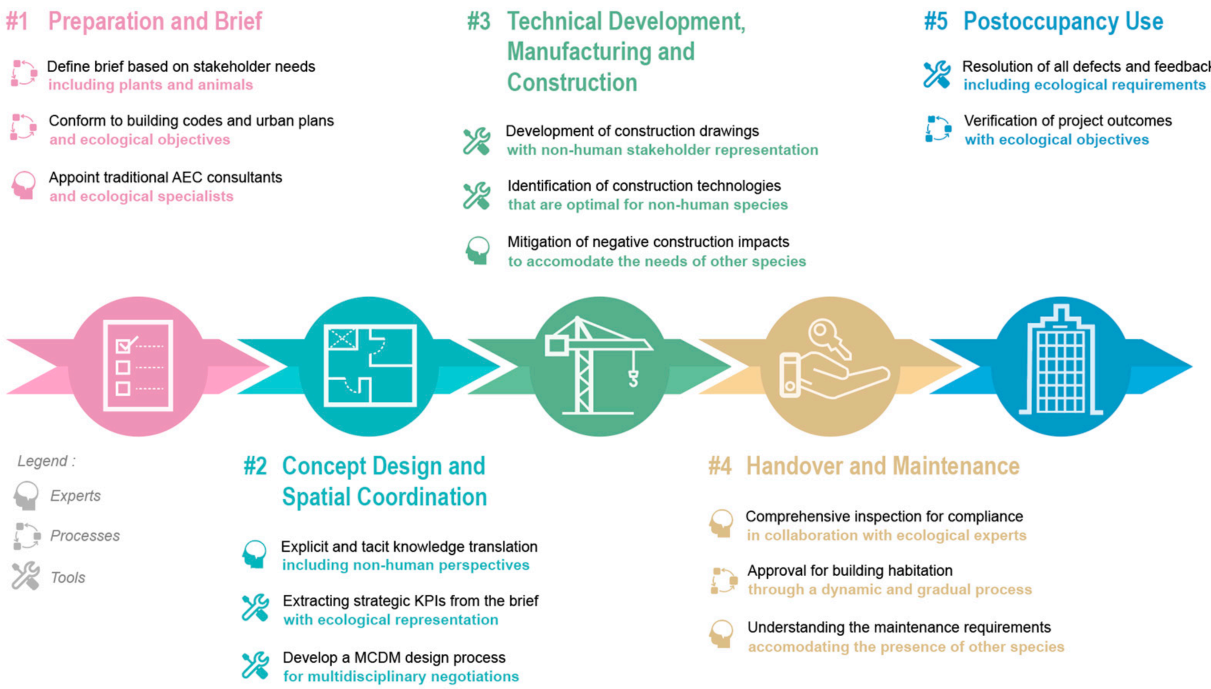

Figure 5. Challenges encountered in the multispecies architectural design process.

6. Multispecies Design in Practice—A Studio Case Study

The subsequent section presents the findings of a design case study conducted to explore the implementation of a multispecies design process. Given the scarcity of previous evidence concerning the application of a multispecies design approach at a building scale, and the lack of literature of this type of design process, this academic design case study provides initial insights into the challenges that this novel design approach may introduce to the architectural design process. This case study was carried out within the framework of a design studio involving ten third-year architectural students, two architect supervisors, an ecologist, and an expert on residential buildings as advisors. The focus of the study was a multispecies building design exercise for an urban residential building.

The selected site for the study was a plot situated in a suburb of Tel Aviv, Israel. Notably, the site is located adjacent to Yarkon Park, the largest metropolitan park in Israel, renowned for hosting unique natural habitats [110] (see Figure 6). The design brief stipulated the creation of a new type of residential building that incorporates multispecies elements while adhering to existing state and city urban planning regulations and laws.

Figure 6. Building's site (Image source: Shahak Shavit).

The design process encompassed the following key elements:

- Development of a design brief integrating multispecies considerations.
- Development of a multispecies concept for the building, seamlessly integrating it with the concept of a residential building.
- Creation of a multispecies building envelope tile system (including the roof) and the formulation of a strategy for populating the system with plant and animal species.

It is important to note that the design process employed in this educational studio project addressed only the initial two stages of the RIBA professional design process discussed in the preceding section: development of the brief, and development of the conceptual design and spatial coordination (without, however, an explicit account of the ethical approach that grounds the design). The insights garnered from this studio case study will be further examined and discussed with respect to only these two design stages.

6.1. Case Study Brief Development

The provided design brief encompassed two distinct components: a residential section and an ecological multispecies section. As the focus of this paper lies outside the scope of the residential aspects, it will not be discussed in detail here. Instead, attention will be directed towards the ecological multispecies brief, which called for the development of an ecological strategy to integrate the multispecies approach. Students were given the opportunity to explore general strategies, such as enhancing biodiversity, while also having the freedom to develop alternative strategies, including a specific focus on the conservation of particular species. The students were expected to formulate a multispecies strategy by selecting animal and plant species that could potentially populate the building. Subsequently, they were tasked with conceptualizing the spatial distribution of the chosen species on the building envelope.

An example figure, diagrammatically depicting the selected animals and plants, and developed as part of one project's species selection process, is presented in Figure 7. The figure illustrates the chosen species and their interconnectedness, emphasizing direct connections between specific species in terms of food sources or predation relationships.

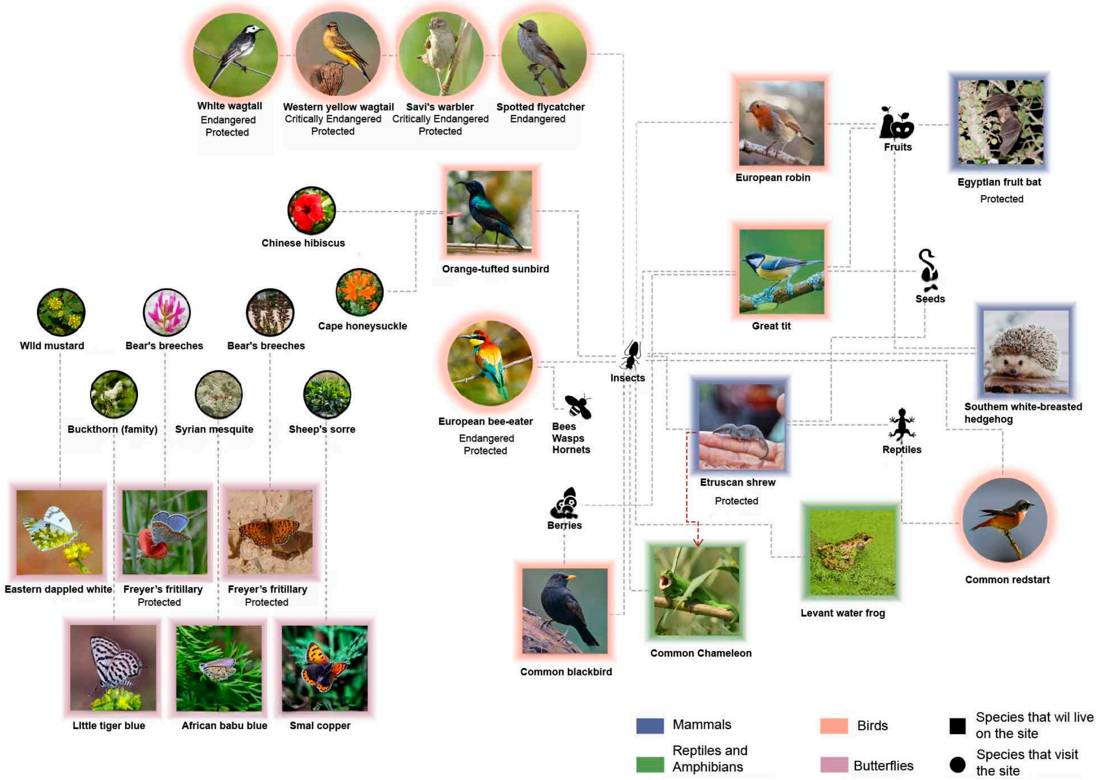

Figure 7. Species diagram (Image source: Adapted from Tetyana Marchenko).

The lack of ecological knowledge and experience in ecological thinking posed challenges when it came to selecting animals and plants for the project. Consequently, choices often exhibited a conservation bias, rooted in personal preferences for certain animals and plants (e.g., admiration for specific bird species found in the area or an affinity for butterflies), or strategies focused on conserving species commonly observed in the local environment. It is important to acknowledge that conservation bias, a term coined to critique the allocation of resources towards preserving charismatic or likable species at the expense of less favored ones, is not unique to multispecies design and can be observed in other research domains such as research on mammals [111].

An additional demonstration of the students' constrained ecological understanding was manifested in their omission to account for functional groups of fauna and flora, opting instead for a concentration on singular species. This approach stimulated solutions of excessive specificity, which appeared deficient in the required adaptability and redundancy necessary to navigate the anticipated intricate and fluctuating circumstances within the architectural building envelope. Additionally, the dynamics of species inhabitation due to seasonal changes were not adequately comprehended or considered.

6.2. Conceptual Design and Spatial Coordination

During the conceptual design phase, various initial building form alternatives were generated. The objective outlined in the studio brief was to incorporate elements derived from multispecies design concepts into the initial building form, encompassing both the internal organization and the building envelope. The students devised two primary types of interventions pertaining to multispecies integration. The first type concentrated on incorporating multispecies elements within the building's public spaces and vertical circulation, while the second type centered on the integration of multispecies features within the building envelope.

As depicted in Figure 8, a vertical circulation space serves as an illustrative instance wherein humans and animals coexist. This particular design aims to establish an ecological pathway connecting two expansive green areas: the ground-level garden and the green roof.

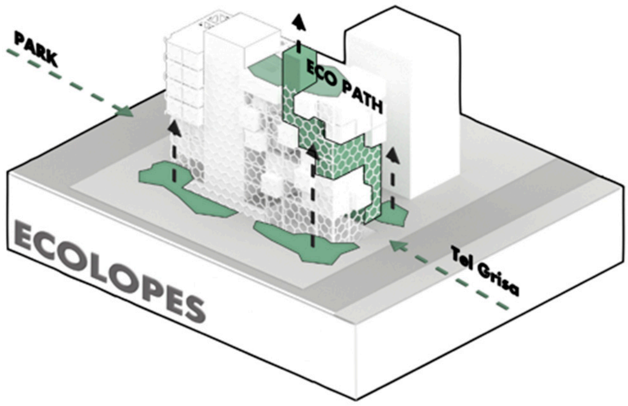

Figure 8. Multispecies vertical circulation (Image source: Yair Rahabi).

Within the context of the second intervention, which centered on the building envelope, the students were tasked with formulating a tile system intended for multispecies habitation. This concept entailed a departure from the prevailing notion of the building envelope solely serving as a homogeneous barrier demarcating interior and exterior spaces. Instead, the objective was to design a building envelope system that could accommodate the habitation needs of various organisms, particularly plants, insects, birds, and small mammals and reptiles. In this case study, ten distinct parametric building envelope systems were developed. Of these, six were predicated upon a rectangular grid incorporating infills, such as those presented in Figure 9. Additionally, one system was grounded in a Voronoi diagram framework and another employed a hexagonal grid schema, and the final system utilized a triagonal grid configuration.

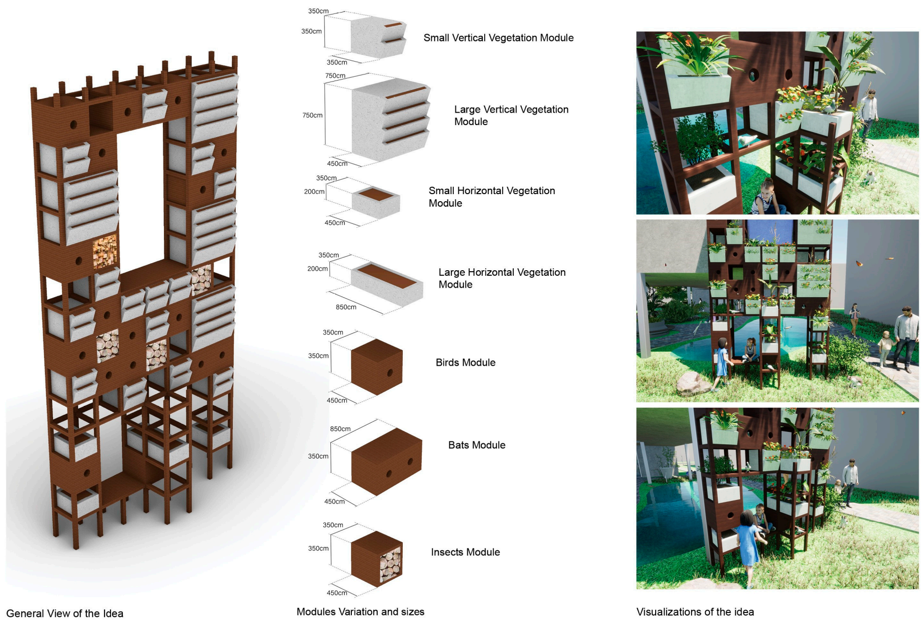

Figure 9. Multispecies design envelopes tile system (source: Tetyana Marchenko).

The implementation of a multispecies envelope tile system necessitates the inclusion of a well-defined distribution strategy for the various tiles on the building envelope. This distribution strategy must account for multiple parameters, including environmental conditions such as solar radiation (direct sunlight exposure on the southern façade versus shaded areas on the northern façade), height variations (as different animal species exhibit distinct preferences regarding tile location and elevation on the building envelope), and proximity to human-occupied spaces (e.g., windows and balconies). To accomplish this, a parametric approach was employed to integrate distribution "heat maps" representing environmental factors, species preferences, and other relevant parameters onto a two-dimensional representation of the building envelope facades. Figure 10 provides an illustrative example showcasing the outcomes of this particular stage.

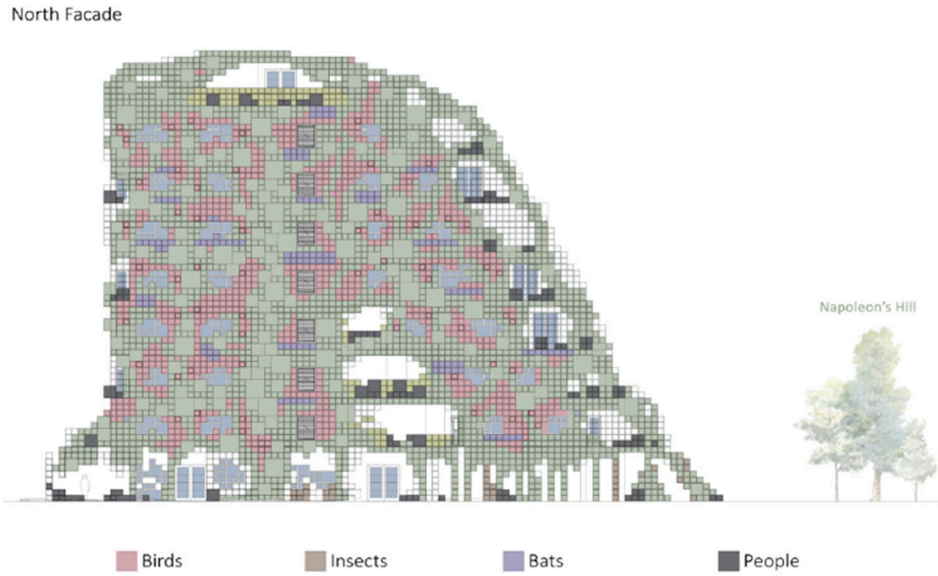

Figure 10. An example of multispecies distribution strategies on the building envelope (source: Tetyana Marchenko).

The conceptual design and spatial coordination stage presented several challenges that required careful consideration. One prominent challenge was the limited knowledge and information available regarding the design requirements of non-human stakeholders, including the specific forms, dimensions, and materiality of habitats suitable for the targeted species. Additionally, the lack of comprehensive understanding of animal and plant behaviors and needs posed difficulties in developing a nuanced strategy for habitat distribution on the building envelope, particularly in terms of establishing interconnectedness and interrelationships between different species. Consequently, the interconnections established within the projects remained relatively straightforward, primarily focusing on direct relationships between animals and their food sources. For instance, a connection might be established between a specific type of butterfly or insect, the preferred plants serving as their food or habitat, and the birds that prey upon these insects or nest within the chosen plants.

Another significant challenge involved determining the optimal interaction between humans and the multispecies environment. It was evident that most animals would prefer to maintain a safe distance from humans, and it was likewise evident that the students felt that humans would prefer to keep a distance from certain animals. However, defining what constitutes an appropriate distance between humans and animals, as well as determining the proximity at which different species could coexist, proved to be unclear and complex.

6.3. Case Study Main Conclusions

Ten different multispecies residential projects were developed in the case study design course (see example of final results in Figure 11). The case study aim was to provide initial insights into the implementation of a multispecies design in the architectural design process due to the lack of literature on this type of design process. For a start, it demonstrated the feasibility of incorporating a multispecies building envelope design process within a contemporary residential building while adhering to prevailing building regulations. As anticipated, the design process of the case study underscored a knowledge gap pertaining to the behaviors and requirements of non-human stakeholders, encompassing factors such as food sources, environmental conditions, and the architectural specifications of their habitats in terms of dimensions, proportions, and materials. In terms of cohabitation, the case study emphasized the delicacy of the exposure to other species and showed the possibility of managing cohabitation by accessibility.

Additionally, the case study brought to light a potential conservation bias favoring more aesthetically appealing or likable species, potentially neglecting the needs of less "likable" species.

Figure 11. Computer renders of multispecies residential building projects (source: Upper left: Shahak Shavit, Upper right: Yair Rahabi, Lower left: Yoav Dabas, Lower right: Tetyana Marchenko).

7. Future Work and Roadmap

Multispecies architectural design represents a shift from anthropocentrism towards biocentrism, where all living organisms have a good of their own and intrinsic value. The notion of biocentrism or multispecies design has been gaining support in academia and practice at the regional and urban scales, but is a relatively new field of research at the building scale.

This research aimed to elucidate the main concepts of multispecies architectural design, to define the challenges and the knowledge gaps in this field, and to develop a road map towards a successful paradigm shift toward the establishment of biocentrism of multispecies design as the leading practical approach to architectural design.

7.1. Open Questions and Future Research

7.1.1. Integrating Ecological and Architectural Knowledge

One of the primary obstacles encountered in this field pertains to the insufficiency of research and knowledge. While there are existing studies addressing isolated aspects of multispecies design, the overall body of research and practical experience in this domain remains limited. Specifically, there is a scarcity of research and knowledge concerning the design of animal habitats and the reciprocal effects of human–animal cohabitation. As a result, there exists a disconnect between ecological knowledge typically developed at the urban or regional scales and the architectural design requirements at the neighborhood and building scales. Currently, no design methodologies and tools are available to assist designers in the creation and evaluation of multispecies design, although ongoing research initiatives like Ecolopes strive to develop such tools and methodologies. However, current projects such as Ecolopes also shed light on fundamental gaps within this field, manifesting on two complementary scales: the macro scale and the micro scale.

On the macro scale, the fruitful outcomes of research endeavors such as Ecolopes are poised to empower designers with the capacity to infuse ecological considerations into the design process. This entails delineating the presence and distribution of various species across building envelopes. Nevertheless, the impact derived from the realization of individual multispecies building envelopes remains inherently limited. To induce substantial change, a network of multispecies buildings, underpinned by a strategic connectivity scheme, is imperative. Such a network, which is currently missing, will facilitate the judicious allocation of resources by municipal authorities and decision-makers, enabling the formulation of comprehensive multispecies renovation strategies.

Furthermore, the microscale level presents an even more pronounced and pressing lacuna. Upon the development of methodologies and tools for designing multispecies building envelopes, an essential and pressing need arises for the design and fabrication of individual components within these envelopes. Regrettably, the current body of architectural and ecological knowledge fails to adequately address the intricate microscale relationships between the requirements of animals and plants and the geometric attributes and materials of building elements. The micro scale component design will necessitate complex geometries that will call for design towards digital fabrication.

In addition to the scarcity of practical and scientific knowledge on multispecies design, there is also a lack of foundational knowledge among designers regarding the needs of animals and plants. Typically, mandatory courses on these subjects are not included in the curricula of architectural schools. This knowledge gap often leads to design projects incorporating animals or plants without due consideration of ecological principles and can result in conservation biases towards more aesthetically appealing or "trendy" species.

7.1.2. Understanding Buildings as Dynamic Entities

Another significant challenge associated with integrating multispecies design into architecture is the prevailing perception of the building envelope as an inert and static entity. Populating the building envelope with non-human species is a dynamic process that varies with seasons, years, and local conditions, all of which heavily influence biodiversity. Consequently, a multispecies building envelope will not remain pristine as traditional building envelopes are often perceived; it will generate various types of "waste" and may introduce noise and odor disturbances to humans. Recognizing and addressing these shifts in perception and maintenance requirements will likely incur additional costs to building design and construction.

Maintenance and monitoring represent further aspects of multispecies design, wherein dangers may arise for humans. As the multispecies envelope comprises a dynamic environment, it can potentially introduce harmful animals, plants, and microbial species that were not originally intended to be part of the envelope. This emphasizes the need for maintenance and monitoring beyond traditional buildings and thus contributes to a potential increase in costs. The potential hazard also raises ethical challenges. A multispecies design is a shift towards biocentrism, where humans would no longer be prioritized above other species. However, since buildings are constructed by humans, transitioning from being solely for human benefit to accommodating all stakeholders equally is a challenging task that necessitates further research. It is important to note here that multispecies building envelope design will also increase some traditional environmental performance (for humans) such as holding rainwater, and thus will contribute to design towards flood mitigation, and will increase the thermal insulation and decrease radiation via the multifunctional use of the volume and geometry of material for plants and animal habitats.

Regarding the architectural design process, apart from the lack of practical and scientific knowledge pertaining to other species, the main challenges lie in the need for novel methods and tools that can integrate scientific knowledge for practical implementation. Additionally, the inclusion of representatives for other species throughout the various stages of the design process poses a significant challenge.

7.1.3. Activating Policies for Multispecies Design

Ultimately, one of the most significant hurdles in transitioning to multispecies design at the building scale is the requirement for policy and legislative changes that endorse and provide the regulatory foundation for this paradigm shift. While the benefits of multispecies design are clear in terms of human health and biodiversity conservation, such a transition entails additional costs related to special elements, the design process itself, and ongoing maintenance. Without supportive policies, legislation, and regulations, it would be challenging to promote the adoption of a new multispecies building approach.

7.2. Initial Roadmap for a Shift towards Multispecies Design at the Building Scale

A strategic roadmap to facilitate the transition towards multispecies design necessitates an initial focus on transforming the education of architects and fostering the generation of scientific knowledge and practical expertise in this field. This approach would foster a deeper comprehension of the potential of multispecies design among practitioners and the general public, thereby laying the groundwork for subsequent policy and legislative changes that promote and support the adoption of multispecies design principles.

Nevertheless, a comprehensive shift towards a fully integrated multispecies envelope may appear excessively radical within the conservative building industry. Thus, an alternative strategy could involve the gradual introduction of multispecies buildings to carefully selected customers and structures, such as educational and public buildings. This phased implementation could commence with the allocation of specific sections within buildings as designated multispecies areas, wherein the integration of plants and animals takes place. Additionally, an initial stage might involve incorporating multispecies elements into urban infrastructure and landscape features, thus exposing a wider audience to this approach.

The incremental approach can also extend to the selection of plants and animals for integration. During the early stages of a project, the design team could prioritize target species based on criteria that encompass ecological considerations as well as their likelihood of survival and positive interaction with humans. By adopting this approach, the likelihood of success in initial projects would be heightened, while concurrently fostering positive responses and receptivity to the concept.

8. Conclusions and Future Research

This paper reviewed the key concepts and challenges associated with the adoption of multispecies design at the building scale, with a particular emphasis on the building envelope. The research has identified gaps and challenges in the existing literature and architectural projects concerning the potential shift towards multispecies design, and has provided a roadmap that suggests incremental stages in integrating multispecies design into the architectural design process. Moreover, the findings highlight a notable ecological knowledge gap at the architectural scale regarding the needs of animals and its conversion into architectural geometry. Future research is needed both in ecology and architecture to create a dynamic database of animal and plant needs, and the corresponding geometry and material it relates to. Other knowledge gaps were found among architects and architectural education providers regarding ecological considerations in multispecies design at the building scale. This gap calls for a revision in architectural curricula to include a mandatory course on animals and plants, and their contribution to the environment and human well-being.

This study revealed that while buildings have both positive and negative direct and indirect impacts on animals, the relationship between animals and buildings is predominantly characterized by negative effects. Therefore, the research hypothesizes that a decision to transition to multispecies design would be more related to larger challenges such as biodiversity and climate change rather than be connected to a correlation with the mutual influence of animals and buildings. However, future research on the legal and ethical aspects of multispecies design is necessary to better understand how to integrate moral consideration into the practice of multispecies design.

Furthermore, academic case study design project demonstrated the viability of incorporating a multispecies building envelope in the contemporary design process of a generic residential building, and addressed some challenges in the design process that related to ideas such as conservation bias.

This study primarily focused on a single building and the envelope. Further research is necessary to explore the effect of a network of multi-species buildings on biodiversity by developing connectivity computational modeling and simulations.

By addressing these research gaps, architects and designers can contribute to the development of sustainable and harmonious environments for both humans and non-human species.

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