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Simulating Ecological Connectivity and River Behaviour for Dynamic Territorial Mapping

An Analytical Methodology to Support Data-driven Workflows for the Design of Living Cities

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Centres for human life, cities represent the main threat to fine ecological balances, which are in turn responsible at multiple levels for the health of citizens. Metropolitan areas are therefore key in addressing such issues to maintain the well-being of all living things. Within today's digital culture, designers have the opportunity to face these unprecedented challenges by approaching landscape under a dynamic, collective, multidisciplinary and multiscalar perspective, enabled through digital tools and data driven processes. These enablers have the potential to empower designers to engage with nature as an active partner, gaining a new understanding with which to represent these landscapes. The article discusses an experimental methodology for the analysis of urbanised ecological territories that detect and amplify potential and beneficial ecological connections or embedded behaviours, providing an opportunity to use this as the basis to design cities consciously for, and within, climate change adaptation.

Urbanisation today represents the main threat to fine ecological balances. Home to the majority of citizens across the globe, cities are considered to cover 3% of the world's surface, yet 70% is transformed by human processes into a state of rapid alteration.[1] This creates ever growing risks for the ecology, and is also responsible at multiple levels for the health of the citizens inhabiting these spaces. In this sense, urbanised areas, and consequently their design and planning, are key in addressing such issues, in order to maintain the well-being of all living systems.

Despite the fact that the relevance of restoring green and blue infrastructures, for the mitigation of human impacts over natural systems, is certain and institutionalised – the Paris Agreement, SDG 14 and 15, the European Green Deal[2] – the pathways to reach such an objective are not always clear. To this end, rewilding and renaturing processes, as conservation strategies, have recently experienced a wave of attention from scholars and politicians thanks to their potential for restoring anthropocentric landscapes to a higher level of ecological prosperity. Yet, they have proven to be difficult to assess and often – due to deficiency in governing the implicit complexity – resulted in unexpected scenarios where the initial issue, if not unaltered, was simply transferred or further amplified.[3]

These approaches are often undertaken in order to counteract the impacts of anthropogenic pressures on the ecology, rather than empowering ecology to actively adapt within today's highly urbanised world, becoming an active partner within the definition of this transition. This is highlighted by the fact that the great majority of today's legal systems only protect the rights of humans, often considering nature as one of the resources to be exploited "for the exclusive benefit of our own species".[4] Although this legal condition has begun to shift with the emergence of several national and international conventions, ordinances and even the revision of some constitutions, the modus operandi applied until this shift has created a condition whereby land and ecology, through property laws, have been fragmented; a condition that is in profound "contradiction to ecological principles of wholeness and interconnection."[5] Within the realm of urban design and planning, this condition raises the essential question of how nature and ecology can have an operative voice there as well.

To this end, concepts such as renaturing and rewilding – both intended to not only restore nature, but allow it to thrive independently – offer an unprecedented challenge for designers: to approach landscape under a dynamic, collective, multidisciplinary and multiscalar perspective. Whether by the identification of keystone animal species, as major landscape constructors, or by the simulation of major territorial dynamics, happening in distinct time scales, these frameworks have the potential to empower designers with a new set of tools to understand and represent territorial urban ecologies. In doing so, they reconsider the polarisation

1 Alice Siragusa, Michele Melchiorri, Martino Pesaresi and Thomas Kemper, eds., JRC. *Atlas of the Human Planet 2016: Mapping Human Presence on Earth with the Global Human Settlement Layer* (Luxembourg: Publications Office of the European Union, 2016), available at https://data.europa.eu/doi/10.2788/889483; Alex de Sherbinin, A *CIESIN Thematic Guide to Land-Use and Land-Cover Change (LUCC)* (Palisades, NY: Center for International Earth Science Information Network (CIESIN), Columbia University, 2002). https://sedac.ciesin.columbia.edu/binaries/web/sedac/thematic-guides/ciesin_lucc_tg.pdf

2 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement; https://www.un.org/sustainabledevelopment/oceans/; https://www.un.org/sustainabledevelopment/biodiversity/; https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

3 International Union for Conservation of Nature and Natural Resources, and Species Survival Commission, *Guidelines for Reintroductions and Other Conservation Translocations* (Gland: IUCN Species Survival Commission, 2013). https://portals.iucn.org/library/efiles/documents/2013-009.pdf

4 John Thackara, *How to Thrive in the Next Economy: Designing Tomorrow's World Today* (London: Thames and Hudson, 2015), 151-156.

5 https://www.garn.org/universal-declaration/; https://www.smgov.net/departments/council/agendas/2013/20130409/s20130409_07A1.htm; https://pdba.georgetown.edu/Constitutions/Ecuador/ecuador.html

between environmental forces and anthropocentric ones and provide an opportunity to use this process as the basis for embedding nature as an active partner, and to consciously design cities for, and within, climate change adaptation. In order to facilitate the operability of this paradigm shift in terms of urban planning and design, there is a clear interest in embedding data-driven approaches – computational modelling, data analytics, simulation, and more – taking advantage of the large availability of datasets, often accessible as open data. In fact, with the emergence of the *Information Age* and its evolution into the *Experience Age*, these shifts bring new principles and technologies with which to rethink not only the functioning and structure of the spaces we inhabit, but also of the way in which we design them.

The body of work that follows introduces and discusses an experimental methodology for the analysis of urbanised ecological territories enabled through the contemporary digital culture, producing a shift within the realm of these disciplines in order to actively engage with ecology, as a partner, within their development. Specifically, this methodology detects and amplifies potential and beneficial ecological connections within urban and non-urban areas, in order to potentiate the ecological performance of the system as a whole, towards the development of strategies for life-centred and resilient cities. It does so by embracing the complexity of cities, their surrounding territories and their ecological systems at multiple scales of analysis, and by identifying site-specific major drivers of change to support this process. In this regard, the proposed data-driven methodology uses computational logics exploited in environmental studies to foresee ecological patterns for analysis and validation purposes, which can then feed design pipelines. To this end, the paper collects the work produced within the Institute for Advanced Architecture of Catalonia's (IAAC) research and educational environment, including two years of experimentation alongside students of IAAC's Master in City & Technology, showcasing the results, developed in the cities of Barcelona, London and Luxembourg. From the simulation of fauna movement, with circuit theory algorithms, to the territorial one of river flooding patterns, through cellular automata, the paper offers a multi contextual benchmark for the comparison of sustainability-related assessment methodologies and some design explorations developed within an educational environment.[6] This consequently provides an overview on viable analytical and territorial mapping approaches – enabled by ecological data and simulations – that inform designers from two main collaborative perspectives: developing territorial solutions in collaboration with river systems, and with fauna dynamics, both engaged as active partners to feed the design process with newly found ecological potential. This becomes the basis with which to effectively and dynamically design for the ecological transition of urban areas.

6 Viral Shah and Brad McRae, "Circuitscape: A Tool for Landscape Ecology," in Gael Varoquaux, Travis Vaught, Jarrod Millman, eds., *Proceedings of the 7th Python in Science conference* (SciPy 2008), 62-65, https://conference.scipy.org/proceedings/SciPy2008/SciPy2008_proceedings.pdf; Marco J. Van De Wiel, Tom J. Coulthard, Mark G. Macklin and John Lewin, "Embedding Reach-Scale Fluvial Dynamics within the CAESAR Cellular Automaton Landscape Evolution Model," *Geomorphology,* vol. 90, no. 3 (October 2007): 283–301.

7 R. T. Paine, "A Note on Trophic Complexity and Community Stability," *The American Naturalist 103,* no. 929 (1969): 91–93.

8 Sanne de Visser, Elisa Thébault and Peter C. De Ruiter, "Ecosystem Engineers, Keystone Species," in Rik Leemans, ed. *Ecological Systems: Selected Entries from the Encyclopedia of Sustainability Science and Technology* (New York: Springer, 2013), 59–68.

Ecological Connectivity to Support Ecosystem Engineers as Active Partners in Design

Actively engaging with the metropolitan area of a city challenges designers with a set of constraints and possibilities that increasingly step away from the realm of the designed or planned. In this manner, dealing with landscape as an active force for design implies a hierarchical identification of actors, which goes beyond the pure human-centric perspective of nature/artifice, rethinking design as a series of actions in continuous disturbance with the surrounding environment, and therefore, as a dynamic and open system. In this regard, since the 70s, ecologists have been referring to the concept of keystone species as those animal or plant species whose activities exert a disproportionate influence on the patterns that define an entire ecosystem.[7] More specifically, ecosystem engineers, defined as organisms that alter the availability of resources in a territory while physically shaping it, represent a unique opportunity for collaboration with designers to achieve long-lasting design intentions, which are not only resilient – as produced by living organisms – but can also autonomously thrive, and adapt – expand or shrink – if necessary.[8]

Simulating the likelihood for these natural engineers to thrive in heterogeneous landscapes, such as in the metropolitan areas of many cities around the world, as well as the territorial consequences of their living, is crucial for their inclusion in the design process. The following section introduces three case studies where the simulation of insect pollinators, beavers, and bats is used to drive a design process to restore degraded landscapes in the metropolitan regions of Barcelona, Luxembourg and London. The adopted methodology exploits ecological connectivity, as expression of the implicit and planned tensions between these fragmented landscapes, in order to study, filter, and later validate design decisions that directly impact the aforementioned ecosystem engineers.

The Case Studies of FlowerPowder, [Echo]nnect, and Rewilding Luxembourg

Metropolitan areas are by definition fragmented landscapes resulting from the uncoordinated initiatives of different stakeholders, at different scales. In these conflicting contexts, changes in land use often echo into uncontrolled consequences that deeply impact surrounding areas and, therefore, need to be tackled at a wider dimension compared to the one where the physical changes apparently take place.

Engaging with renaturing and rewilding concepts as strategies to drive such dynamics, the case studies of FlowerPowder, [Echo]nnect and Rewilding Luxembourg offer an operational and context-specific framework to dynamically understand, and later design, within fragmented landscapes, towards achieving restoration goals. While focusing on three different global issues (post-agrogenic lands, wetlands loss, and urban sprawl), and collaborating with three different keystone species

(insect pollinators, beavers, and bats), they all exploit ecological connectivity analysis – computed through the open source Circuitscape application – as means to overcome the aforementioned territorial fragmentation and identify ecologically relevant areas and corridors to support through design and citizen engagement.

Compared to traditional practices, the case studies show that basing design on the application of data-driven tools such as Circuitscape allows not only a detailed understanding of complex land-interactions between fragmented landscapes under current conditions to be obtained, but also design decisions to be computationally empowered, as the effect of planned land change can be visualised and assessed within the scope of each design intention.

More specifically, considering ecological connectivity in heterogeneous landscapes as performing similarly to electrical current in heterogeneous material, they predict the main flows of ecological exchange according to land-specific degrees of conductance for each of the keystone species selected, before and after their design implementation. By simply altering the conductance with pre- and post-intervention values (low conductance to higher conductance), they actively engage with the territorial dynamics to design, and in this manner, through design they successfully identify and support assets crucial for the accomplishment of the restoration goals within a general set of land-change opportunities. (Figure 1)

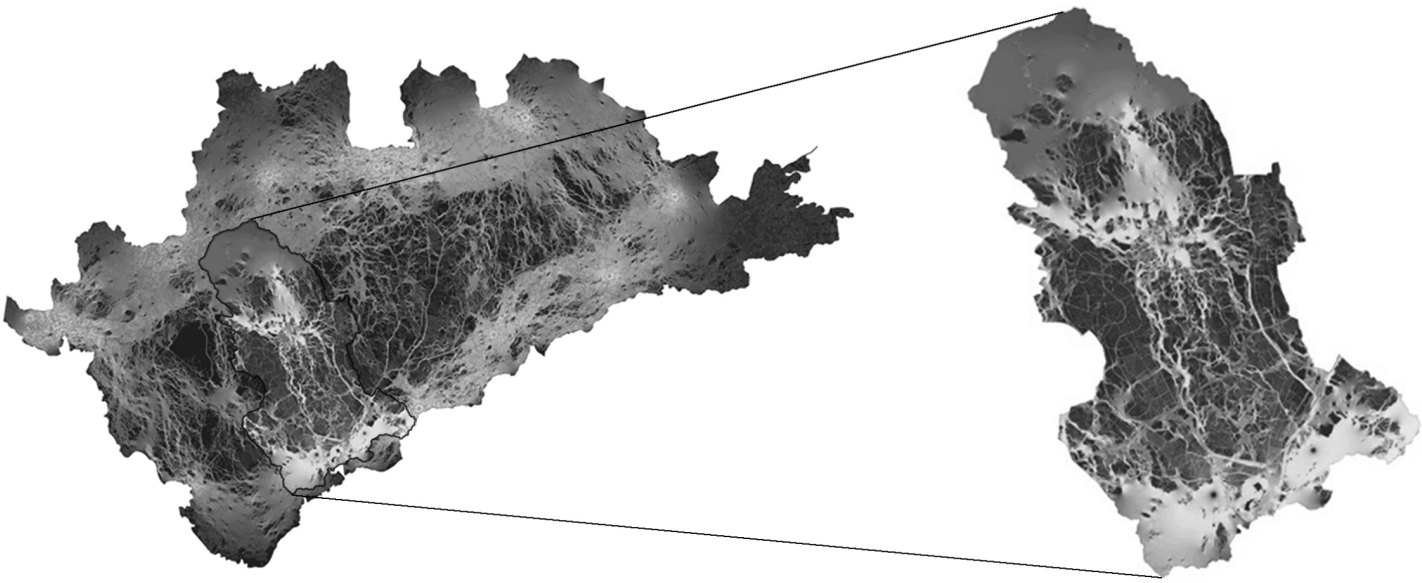
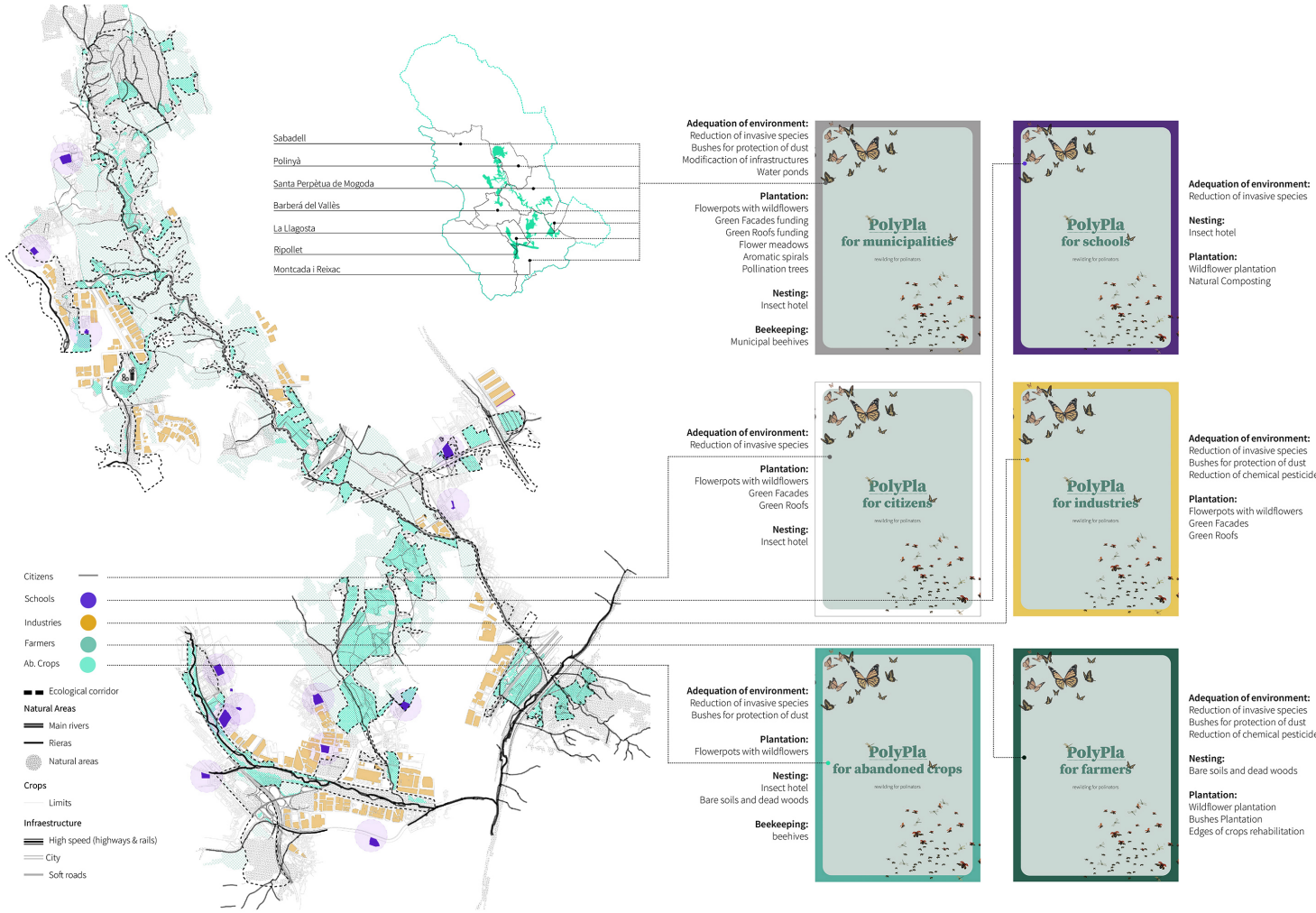


Fig. 1 The image illustrates the scaling down process within the El Vallès area to identify crucial areas for ecological connectivity at multiple scales. FlowerPowder. Developed by students Adriana Aguirre Such, Simone Grasso, Matteo Murat, Riccardo Palazzolo Henkes. Master in City & Technology, IAAC, Barcelona, 2021.

FlowerPowder: Revitalising the Abandoned Crops of el Vallès through Contextualised Participation

Inspired by rewilding approaches, the FlowerPowder case study engages with the issue of abandoned agricultural plots fostered for the design of ecological corridors that act as both spatial and analytical tools to coordinate human stakeholders and pollinators – as ecosystem service providers – in a process of revitalisation for these degraded landscapes. Focusing on the region of El Vallès, in the metropolitan area of Barcelona, it exploits ecological connectivity presented in maps to visualise dynamisms along the north-south axis while scaling down from the regional to the



municipal scale. This process allows, the most relevant areas at every scale to be highlighted – those with the highest ecological potential in relation to the corridor as a whole – to initiate the process of revitalisation. In this regard, using connectivity as a metric to select key locations permits effort and cost to be minimised while maximising results, since the echo of the localised interventions is guaranteed to resonate on the broader ecosystem, at the regional scale.

A largely altered territory, the area of El Vallès offers an interesting case study where the coexistence between natural and anthropogenic ecosystems, historically relevant for agriculture but in decline since the beginning of the 20th century, has resulted in a highly diverse and fragmented territory including urban settlements, large cultivations and industrial districts. These fuse together in a heterogeneous valley surrounded by a system of protected highlands – the Prelitoral and Litoral mountain ranges – respectively on the northern and southern limits. For this reason, in support of the connectivity analysis conducted between the protected patches at the limits of the valley, a categorisation of the abandoned crops identified as relevant for the activation process was carried out in order to give specificity to each plot based on its local and surrounding land-use conditions. This resulted in the definition of five categories: inside a natural ecosystem, between two or more natural ecosystems, between a natural and an anthropogenic ecosystem, between two or more anthropogenic ecosystems, inside an anthropogenic ecosystem. The categories add a qualitative perspective to the merely quantitative understanding of each plot's connectivity potential, therefore laying the ground to support the following participatory process with specific human stakeholders and spatial conditions, in support of pollinators.

These considerations are gathered and used to trigger the design of the Polypla participatory process, which comprises a set of guidelines and actions enabling each location, in consideration of its specificity, to reinforce the proposed pollinator corridor. This therefore condenses into meaningful activities based on the insights gained through the correlation of connectivity, land uses, and stakeholder maps at multiple scales of analysis (Figure 2).

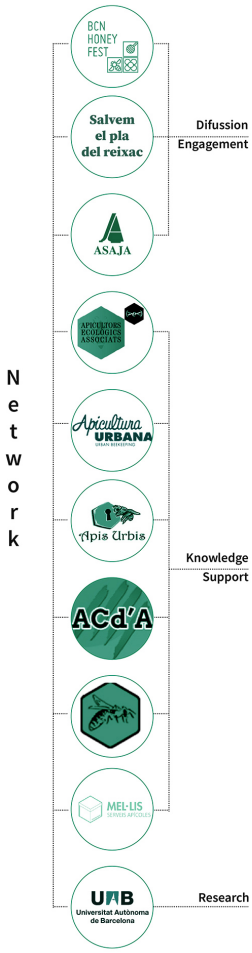


Fig. 2 The Polypla initiatives and the proposed stakeholders. FlowerPowder. Developed by students Adriana Aguirre Such, Simone Grasso, Matteo Murat, Riccardo Palazzolo Henkes. Master in City & Technology, IAAC, Barcelona, 2021.

[Echo]nnect: Establishing Mutually Beneficial Partnerships with Ecosystem Agents

From pollinators in general to bats in their role as ecosystem service providers and moving from Barcelona to focusing on the metropolitan area of London as a test bed, the [Echo]nnect case study introduces a strategy to plan the conversion of highways into ecological corridors. This case foresees a necessary reduction in private vehicular traffic over the coming years, and encourages a possible future where such infrastructure, due to its conformation, could become infrastructure for alternative transport and diversity of species. Challenged by the pioneering objective of the English

metropolis to be independent from cars by 2030, the project exploits ecological connectivity analysis to evaluate the potential of the roadways in mending and reconnecting the highly fragmented metropolitan area of London.

In this sense, Epping Forest was identified as a promising gateway between the system of outer patches and the internal parks, highlighting a section of the A406 trunk road as an area of interest, allowing the potential of ecological connectivity to multiply across different scales (Figure 3). A catalogue of interventions is consequently proposed to facilitate the repurposing of the aforementioned infrastructure into a catalyst for bats – considered a celebrity species – to thrive, according to the spatial, economic and societal conditions – connecting lower and higher income communities – of the specific surroundings. The interventions were proposed in three main spatial conditions: urban settlements, infrastructure, and natural areas, to be activated on different scales, and encouraging the bats to further proliferate in the area and become agents to enhance biodiversity and ecological connectivity.

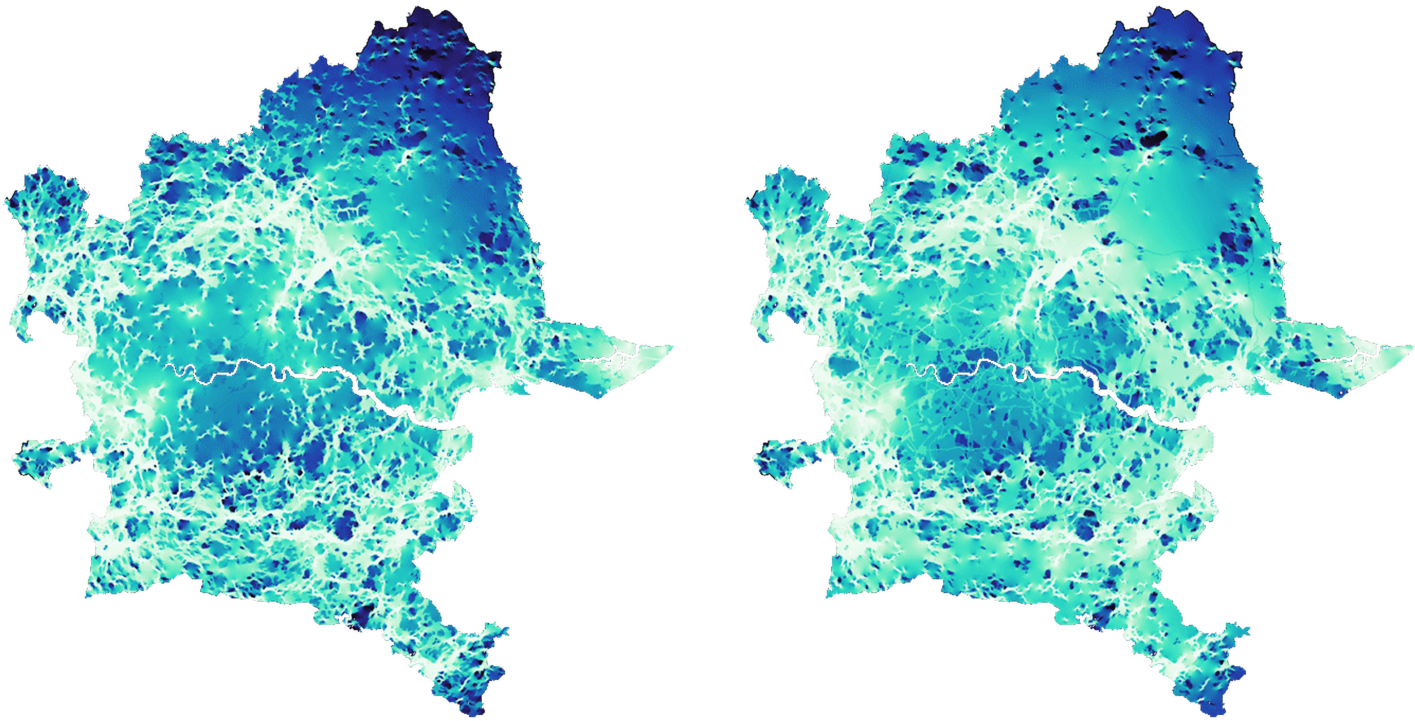


Fig. 3 Connectivity studies for the metropolitan area of London. On the right, the simulation considers the road infrastructure with high connectivity values. [Echo]nnect. Developed by students Dimitrios Lampriadis, Joseph Bou Saleh, Julia McGee, Kriti Nirmal. Master in City & Technology, IAAC, Barcelona, 2022.

Rewilding Luxembourg: Empowering Ecosystem Engineers through Citizens Science

Challenging the binary view of existing rewilding strategies in human and non-human realms, the Rewilding Luxembourg case study proposes an integrated framework between species and for both planning processes and co-management strategies – supported by ecological connectivity studies – to compensate for the nation's critical level of landscape fragmentation. In Luxembourg, ongoing urban sprawl and the consequent infrastructural requirements, alongside the relatively limited dimensions of the country, have generated one of the most fragmented territories of the European Union, constantly threatening its constituent habitats. As wetlands have been registered as having experienced the highest habitat loss, the case study calls upon beavers to play an active role as ecosystem engineers in the restoration of these threatened areas, working collaboratively alongside children, as cross-species collaborators and citizen scientists, in order to trigger a behavioural change which would guarantee the long-lasting achievement of its restoration goals (Figure 4).

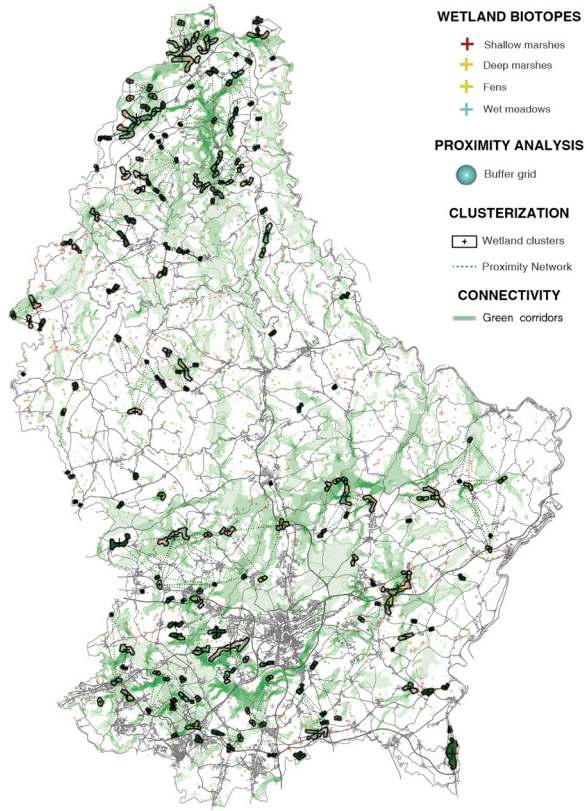


Fig. 4 Wetland connectivity map, with darker green areas showing higher attractivity for beavers' activities Rewilding Luxembourg. Developed by students Alvaro Cerezo Carrizo, Arina Novikova, Dongxuan Zhu and Stefania-Maria Kousoula. Master in City & Technology, IAAC, Barcelona, 2021.

For this reason, community engagement and co-management become key elements within the conversion process in parallel with the connectivity analysis, constituting a base understanding of the most favourable locations for beavers to thrive and therefore succeed in the ecological restoration process. To this end, an initial ecological connectivity analysis among the wetlands at the regional scale is further cross-read with the proximity to primary and secondary schools, providing a necessary spatial understanding for the implementation phase, which indicated the city of Bertrange, in the south-western area of Luxembourg, as an ideal test bed. Similarly to the case study of FlowerPowder, the change in scale is further strengthened by higher-resolution connectivity studies, which allowed trial fields along the river Petrusse to be identified as a system of core and buffer areas at the intersections between the human and the wetland infrastructures. This design framework has spatially allocated different degrees of responsibility and freedom of action to beavers, exclusive dwellers of the core restoration zones, and to children, monitoring partners of the buffer zones. This permits the resilient co-management of the restoration process while providing a fruitful case study of multi-species collaboration to assess rewilding strategies. The project also foresees the monitoring and continuous collection of data in order to measure the impact and success of the approach, through a citizen science approach.

Simulating Flooding Patterns to Engage with River Systems

Rivers, and waterbodies more in general, might not be as invisible to the eye of the designer as a community of keystones species that dwell in a specific habitat. Yet their highly dynamic nature, taking place at such drastically different rhythms and scales from ours, constitute a highly complex challenge from both the conceptual imagery and from a tangible perspective for design. Despite this, climate change, alongside the recent catastrophic floods, the decline in species diversity, and more generally river pollution, represent issues that can no longer remain unaddressed, both within urban and rural contexts. This therefore leaves designers with no option but to strategically interact with these territorial water forces.

In this fluid context, unforeseen changes, both in the water course as well as in its immediate surroundings, have the potential to alter areas kilometres away from the original site with undesired consequences for both the environment and society. Actively engaging with rivers within the design process means understanding, foreseeing, and finally driving the dynamics resulting from specific interventions in order to emphasise, rather than limit, the design through, and with, floods. To this end, two case studies are presented that computationally delve into river systems and their renaturalisation, in the metropolitan contexts of Barcelona, and Luxembourg, respectively for the Llobregat and Alzette rivers.

The Case Studies of Re(naturing) BCN and Alzette 2.0

Rivers are highly complex systems, and are in principle highly natural systems, yet due to the vast amount of human interventions within their morphology, notably river bed modifications, these rivers lose their capacity to function naturally, causing both flooding and loss of habitat. The case studies of Re(naturing) BCN and Alzette 2.0 – River Re-visioning both engage with river renaturing, meaning different strategies and techniques applied to enhance the natural state and functioning of rivers and catchments, in order to tackle these challenges. The case studies aim to assist this recovery and increase resilience by addressing hydrological, morphological and biological issues within the river catchment.

In order to understand and design with such dynamic complexity, hydrological simulations of both cases were performed using the CAESAR Lisflood morphodynamic model allowing study of the behaviour of the rivers. This also allows the introduction of new meanders and channels based on hydrogeological analysis, as well as rainfall data, in order to extract the preferred conditions for the river through dynamic simulations, in adaptation to flood risk and habitat loss (Figure 5). In order to implement these preferred and dynamic configurations for the river to renaturalise its habitat and functioning, both cases engage in the revaluation of land use

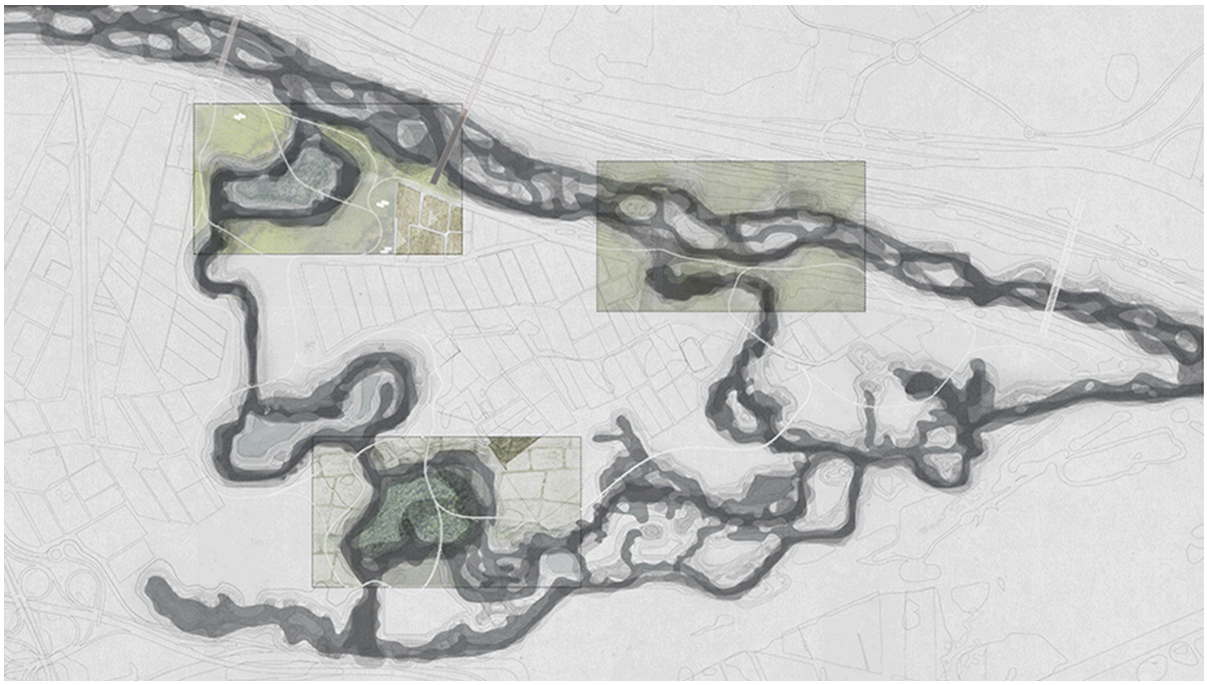


Fig. 5 The image shows the final stage of the river expansion simulated with CAESAR Lisflood and contextualised within a multi-phase design intervention. Re(naturing). Developed by students Aishath Nadh Ha Naseer, Hebah Qatanany, Laura Guimaraes, Mario Jose Gonzalez, Sinay Coskun. Master in City & Technology, IAAC, Barcelona, 2021.

within the river bed, enabling the integration of nature based solutions, to tackle pollution issues, as well as reduce soil erosion and improve biodiversity, allowing the ecosystem to thrive holistically.

Re(naturing) BCN: Integrating Hydrologic and Urban Expansions

With an extensive history of human interventions, the Llobregat river is the second longest stream of Catalonia, in Spain, and represents a crucial resource for the region. Springing from the mountains of Sierra del Cadì, the watercourse flows for 170 km before reaching the metropolitan area of Barcelona where it dives into the Mediterranean sea. Along its riverbanks, several industrial and other economic activities take place, ranging from textile industries and factory towns to agricultural fields, as well as hosting quarries that have been active since Roman times. Such a complex and resource intensive system resulted in the environmental degradation of the river, culminating in the delta area, where the challenges of increasing flooding and water pollution currently question the plans of urban expansion of the city of Barcelona.

Here is where the focus of the project is placed. Blending morphological dynamism with anthropogenic interests, the Llobregat Delta embodies a high level of complexity that requires an in-depth analysis from both a spatial and temporal perspective. For this reason, the methodology introduces river flooding simulations on which to base the future development of the area, which structures the proposed intervention into five phases, adaptively integrating the hydrologic forces into the planned urban tissue. Computing the river expansions through the CAESAR Lisflood toolkit allowed not only such territorial processes to be visualised, but also the results to be cross-read with additional datasets describing other conditions of the landscape, such as in the case of its land use (Figure 6). Relevant to the economic prosperity of the delta area, an impact assessment ranking the local farmlands from mildly influenced to severely affected was calculated as per the extension of overlap between the agricultural plots and the simulated riverbank. By identifying the trade-offs for this renaturing process to happen at the expense of the local businesses, the methodology aims at using data and simulations to provide a base understanding for further design accurate compensation plans for the most afflicted communities. There is also the possibility of triggering collaborative and participatory processes involving both the food industry and the farmers in order to accentuate these.

Alzette 2.0: Informing Participatory Process with Long-Term River Visions

Similarly to the case study of Re(naturing) BCN, the methodology proposed in Alzette 2.0 aims at mitigating the consequences of river renaturation processes, from hydrological, morphological, biological and societal perspectives. Home to the largest catchment area of the nation, the Alzette

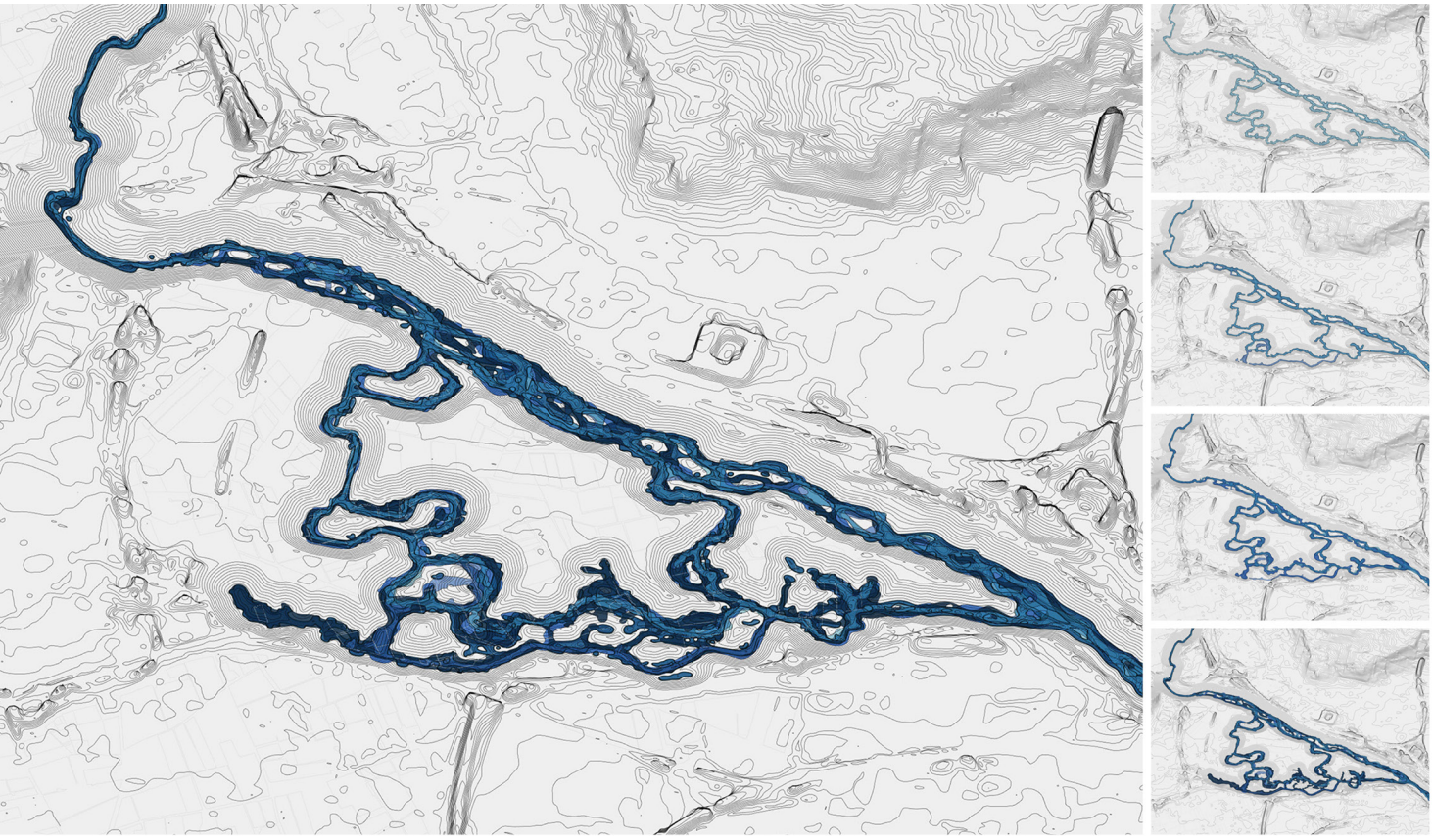
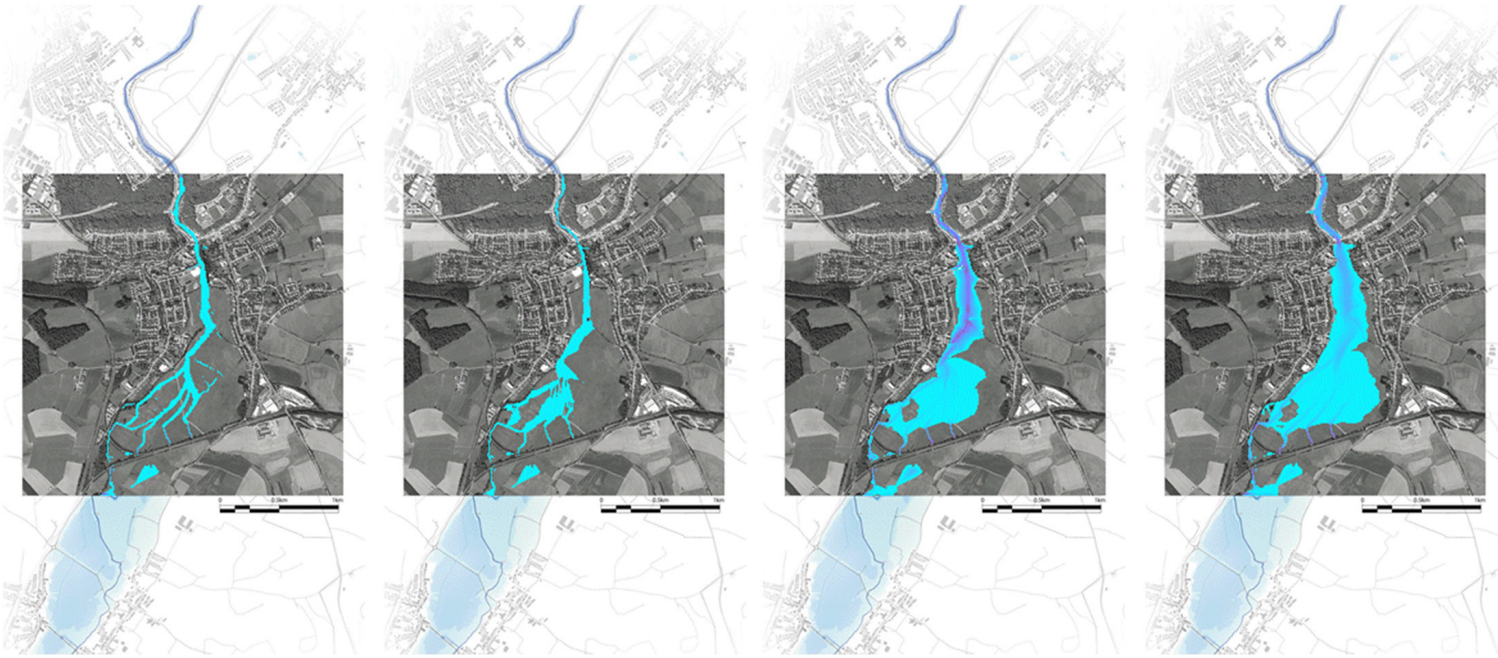


Fig. 6 Phases of the river flooding simulation in CAESAR Lisflood cross-read with the existing agricultural fields. Re(naturing). Developed by students Aishath Nadh Ha Naseer, Hebah Qatanany, Laura Guimaraes, Mario Jose Gonzalez, Sinay Coskun. Master in City & Technology, IAAC, Barcelona, 2021.

river receives a dangerous level of pollutants, specifically in the proximity of urban settlements, majorly visible in the surroundings of Luxembourg. Following an initial territorial risk assessment concerning population density, water pollution levels and ecological status, as well as the location of mines and disposal facilities to mention a few, two main areas are identified, respectively, in the upstream valleys of the Esch-sur Alzette canton and at the doors of the city of Luxembourg. Tackling water pollution from the very beginning of the stream and alleviating the risk of flooding before entering the urban fabric, these strategic locations were further analysed to study the river's behaviour according to several rainfall data and design configurations.

In this sense, the adopted methodology engaged with the design of the meandering intervention through a data-design feedback loop supported by river flooding simulations. This allowed the territorial testing of multiple design solutions in respect to the hydrological dynamics that they would create, therefore permitting a design towards the desired consequences. After the digital testing phase, a landforming intervention was proposed to guide the expansion of the river over the years into a shallow wide marshland, mitigating flood risk and placing the first stone to improve biodiversity in the selected locations. (Figure 7).

Fig. 7 Data-design feedback through river flooding simulations. Alzette 2.0 River Re-visioning. Developed by students Leyla Saadi, Marta Maria Galdys, Sridhar Subramani, Ivan Reyes Cano. Master in City & Technology, IAAC, Barcelona, 2021.



Finally, the riverbank proposal alongside its constituent flooding simulations is used as a base to inform a participatory process for the co-design and co-management of a bioremediation forest, crucial for the functional integration of the river within the surrounding ecosystem. Primarily planned to clean the soil and the water from the heavy metals it carries, the forest becomes an opportunity to positively engage with the local communities on site through a simple digital platform. Through this participatory process, the forest would eventually provide a new source of income for those affected the most, while diversifying the economy of the area; integrating anthropogenic interests and non-human forces within the long-lasting renaturation process.

Conclusions

Through the methodology presented we can begin to unpack the complexity related to understanding ecological and morphological connectivity, and its potential to further empower these environmental systems. Ecological connectivity, being a global priority for preserving biodiversity and ecosystem functions (IUCN, 2017), underlines the interest in empowering designers with a set of new tools and analytical processes to understand and represent these conditions in order to create new landscapes that embed nature, and its dynamics, as an active partner.[9] In doing so, we are enabled to reconsider the polarisation between environmental forces and anthropocentric ones, with the finality of providing an opportunity to use this as the basis to design cities consciously for, and within, climate change adaptation. In this sense, today's digital culture provides an interesting platform to facilitate the operability of this paradigm shift in terms of urban planning and design, by embedding data driven approaches – computational modelling, data analytics, simulation, and more – into the analytical and design pipeline, taking advantage of the large availability of datasets, often accessible as open data. On a broader scale, this opens opportunities to rethink the potentials and responsibility of design, enabling it to respond in an informed manner, and in line with the New European Bauhaus initiative, opening a new space of reflection in the fields of architecture and urbanism, with a focus on sustainability, aesthetics, and inclusion.[10]

Furthermore, the approach presented directly enables a response to one of the more impending environmental challenges of today:

> The degradation, fragmentation and disconnection of natural habitats on land and in the sea … has resulted in the alteration and isolation of habitat important for movement of organisms and for the maintenance of ecological processes present in previously connected landscapes and seascapes.[11]

9 International Union for Conservation of Nature (IUCN), 2017. https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/connectivity-conservation (accessed February 2022).

10 https://europa.eu/new-european-bauhaus/index_en

11 "Frontiers 2018/19: Emerging Issues of Environmental Concern," 2019, https://wedocs.unep.org/20.500.11822/27538

This disruption presents serious threats to vital ecosystem services in both the ecological and anthropogenic spheres. We need to act and we need to do it fast. To do so, we need to reconnect habitats and prevent any further fragmentation.

By exploiting data relative to context specific ecological actors to frame the effectiveness of their ecological networks, we can combine this with the physical properties of specific metropolitan environments to evaluate connectivity towards the identification of relevant pathways for ecology to connect and thrive. This consequently provides the methodological basis and a viable approach for designers to effectively, dynamically and systemically design for ecological transition towards connected living environments.

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FlowerPowder: a new ecological corridor for pollinators, 2020/21, by students: Adriana Aguirre Such, Simone Grasso, Matteo Murat, Riccardo Palazzolo Henkes;
[ECHO]NNECT: Mutualistic symbiosis driving back nature, 2021/2022, by students: Dimitrios Lampriadis, Joseph Bou Saleh, Julia McGee, Kriti Nirmal;
Rewilding Luxembourg: A co-existence experiment with beavers as engineers and children as citizen scientists, 2020/21, by students: Alvaro Cerezo Carrizo, Arina Novikova, Dongxuan Zhu, Stefania-Maria Kousoula;
Re(naturing) BCN: future Llobregat, 2020/21, by students: Aishath Nadh Ha Naseer, Hebah Qatanany, Laura Guimaraes, Mario Jose Gonzalez, Sinay Coskun;
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