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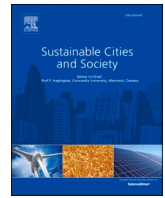
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Reconnecting neighbourhoods with ecosystem functioning: Analysis of solutions from six international case studies

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ABSTRACT

Urban design organises and transforms the space, reflecting human context on cities' shape. Since modernism, designers draw urban projects with the goal to improve cities performances based on a mechanistic worldview, in which living systems are almost not considered. This paradigm led to urbanisation that is prominent in ecological process simplification and biodiversity loss. Different emerging urban design frameworks engage with the challenge of integrating ecological information on the design of sustainable urban projects, using this knowledge to guide intervention choices. With a growing application in practice, as through regenerative design and biomimicry, there is still a lack of knowledge on how ecological urban projects operationalise their engagements. We explored this question with a case study approach, generating hypotheses on the topic. We identified that projects focus on reducing human pressures over the ecosystems instead of regenerating the ecosystem's structure. Furthermore, projects mainly deal with energy and material flows. We identified a taxonomy of 36 urban strategies that could inform new design tools. Finally, we argue that the ecosystem biophysical structure needs to be better addressed on urban projects, and that projects would benefit from better articulation between solutions to reduce human pressures with those regenerating the ecosystem state.

1. Introduction

1.1. Ecosystems logic on urban design

Urban design organises and transforms the space by reflecting human context on our cities' shape (Arab, 2018). The urban design practice is interested in the materiality of space to direct it towards a considered preferable situation from the design team's perspective. For this purpose, urban project stakeholders choose interventions, electing and combining relevant strategies and solutions to transform the space and its socio-economical dynamics (Arab, 2018).

Since modernism (from early to the middle of the 20th century), urban designers draw urban projects based on a mechanistic worldview, aiming to improve our cities performances (Du Plessis & Brandon, 2015; Ellin, 2020), but almost not taking living systems into account (Ellin, 1999; Steiner, Young, Zube & Ndubisi, 2014). This paradigm led our society to an urbanisation logic that reduces ecosystems and human health (Alberti, 2005; IPBES, 2019).

Shifting to an urban design practice that profoundly integrates the natural ecosystems logics in the urban space is a significant challenge for

our generation (Alberti, 2005; Du Plessis & Brandon, 2015; Pedersen Zari, 2018; Steiner, 2014).

In the political sphere, the Sustainable Development Goal 11 – Sustainable Cities and Communities invites designers to tackle this question, proposing to strengthen efforts to protect and safeguard natural heritage (Target 11.4) and to reduce environmental impacts of cities (target 11.6) (United Nations, 2018). In the same line, the New Urban Agenda also present engagements towards this paradigm shift, highlighting the need for new tools to assist this process (United Nations, 2017). Nevertheless, on the operational level, sustainable urban projects and sustainable urban design frameworks, as LEED-ND, BREEAM communities and GreenStar Communities, struggle to address this paradigm shift. These frameworks present limitations such as partial coverage of sustainability and a lack of integration of key elements of site context on the design (Grazieschi, Asdrubali & Guattari, 2020; Sharifi, Dawodu & Cheshmehzangi, 2021).

1.2. A new generation of urban design frameworks

However, some emerging urban design frameworks engage with the

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challenge of putting the ecological perspective at the centre of the urban design process (Bayulken & Huisingsh, 2015; Benne & Mang, 2015; Ellin, 2020). Regenerative design, ecosystem-level biomimicry and the French EcoQuartier are three examples that operationalise these engagements at different maturity levels (Bayulken & Huisingsh, 2015; Blanco, Pedersen Zari, Raskin & Clergeau, 2021; Chasten et al., 2016; Pedersen Zari, 2018). In this research, we have a particular interest in these three frameworks, aiming to understand how they impact urban projects and their lacks.

Regenerative Design aims to create urban projects that promote positive impacts on the socio-ecosystems, allowing social and ecological systems to co-evolve and thrive (Attia, 2016; Brown et al., 2018; Cole, Oliver & Robinson, 2013; Zhang, Skitmore, De Jong, Huisingsh & Gray, 2015). Although the concept got popularised in the 21st century (Benne & Mang, 2015; Brown et al., 2018), there is still a lack of tools to facilitate its operationalisation (Brown et al., 2018; Hes & Du Plessis, 2014). The Living Building Challenge, a North American design framework and rating system, can be cited as the most consolidated tool available nowadays.

Ecosystem-level biomimicry also relates to regenerative design objectives (Attia, 2016). Biomimicry draws upon emulation of, and knowledge transfer from, living organisms and whole ecosystems to find solutions to human problems (ISO, 2015). Emulating local ecosystems functioning on urban projects, through the notion of ecosystem services, has been highlighted to operationalise regenerative impacts (Pedersen Zari, 2018). In this process, designers try to emulate natural ecosystem functioning in the urban space, aiming for a measurable positive impact in terms of ecosystems services production (Hayes, Desha & Gibbs, 2019; Pedersen Zari, 2018).

Finally, the French EcoQuartier is a design framework and labelling program supported by the French government. Like other national frameworks, as the EcoDistricts in the United States and the CityLab in Sweden, it aims to foster sustainable urban neighbourhoods development at the national scale. The framework has a bottom-up approach with 20 holistic engagements, taking into account social, economic and ecological context as inputs for the design process (Chasten et al., 2016).

1.3. A lack of understanding of the ecological urban design practice

Even with the growing application of these emerging urban design frameworks (Bayulken & Huisingsh, 2015; Blanco et al., 2021; Brown et al., 2018; Buck, 2017; Chasten et al., 2016), a lack of knowledge from an urban design practice perspective persists. All of them aims to inform the urban design team on the design process. However, there is no common understanding of how urban projects translate and operationalise into urbanisation strategies and solutions their engagements to integrate the natural ecosystems logics in the urban system and to produce mutual positive impacts (Pedersen Zari & Hecht, 2020; Steiner, 2014).

Nature-Based Solutions (NBS) have gained a central place on the topic of solutions to face contemporary urban challenges (Almenar et al., 2021; IUCN, 2020). NBS has been widely adopted on policy and projects to foster human well-being while generating biodiversity benefits. The growing deployment and use of the term and allegedly Nature-Based solutions led IUCN to produce a Global Standard presenting eight criteria to frame and foster the application of NBS on urban policy and projects (IUCN, 2020). Nevertheless, NBS are not adapted to tackle all contemporary urban challenges (Almenar et al., 2021), and combining different solutions (as NBS, technological and educational) seems fundamental to reaching wide positive and mutual impacts.

In this context, we are here interested in three operational questions that remain to be explored: 1) Which urbanisation strategies and solutions are being used in the field to fulfil these engagements? 2) Are these solutions mainly aiming to reduce human pressures over ecosystems or to regenerate ecosystems state? 3) Are these emerging frameworks

holistically addressing ecosystem functioning, or do they only partially integrate the notion?

Our objective is to generate hypotheses related to these questions through a multiple case study approach, supported by content and typological analysis on projects design phase documentation. We analyse six urban projects designed using the three previously referred design approaches. Our case study sample was chosen using pragmatic and theoretical criteria. Thus, this study does not wish to exhaustively evaluate urban design solutions and strategies to design ecological urban projects. Instead, we propose exploring how these outstanding projects deal with the challenge of reconnecting their functioning to local ecosystem logic.

2. Materials and methods

We used a mixed-method approach, relying on case studies, content analysis and quantitative typological analysis. As an empirical investigation method, case studies help understand contemporary phenomena within their real-life context (Groat & Wang, 2013; Yin, 2018), and it is helpful to generate hypotheses on real-world phenomena (Small, 2009). We used a multiple case studies approach and followed Yin (2018) framework to design the study, supported by content analysis to generate data and a typological approach to analyse the data. Fig. 1 presents the main steps of our method, described in the following sections.

2.1. Case studies selection and cases description

Our case studies selection relied on pragmatic considerations and theoretical prominence of the projects, such as their scale and phasing, used design framework and documentation availability. Pragmatic approaches of case selection are legitimate in case studies, mainly in exploratory studies when used to generate and explore hypotheses (Seawnght & Gerring, 2008; Small, 2009). Our four pragmatic and theoretical criteria were:

- 1 Scale and use: Projects should be at the neighbourhood scale. They should have more than one building, public space, be mixed-use and have diverse stakeholders.
- 2 Design framework: Projects should have robust ecological engagements and use ecosystem-level biomimicry, regenerative design or EcoQuartier design approaches.
- 3 Project phase: Projects should have reached the implementation phase, even if partially (conceptual projects are excluded);
- 4 Documentation: Projects should have relevant documented information, in English or French, accessible online or through authors personal and professional network, allowing a deep comprehension of the case;

Following a brainstorming session, the research team identified 32 potential cases (Appendix A), we selected six urban projects that fit the presented criteria (Table 1). Projects are here briefly described.

2.1.1. Lloyd crossing sustainable urban plan

The Lloyd Crossing Sustainable Urban Plan is an urban requalification project for the Lloyd District, a mixed-use district located in Portland, Oregon, USA. Designed in 2004 by Mithun, under the Portland Development Commission's request, the project used a design approach that finds inspiration in the local ecosystem patterns to catalyse ecological, social, and economic regeneration. Using an ecosystem-level biomimetic approach, the design team assessed thirteen ecological metrics from the original ecosystem (a mixed conifer forest) as the first design step. This diagnostic allowed designers to build site-specific ecological comprehension that guided the sustainable urban strategies selection. The final project presents long term engagements and strategies to foster the district development and creates a neighbourhood that

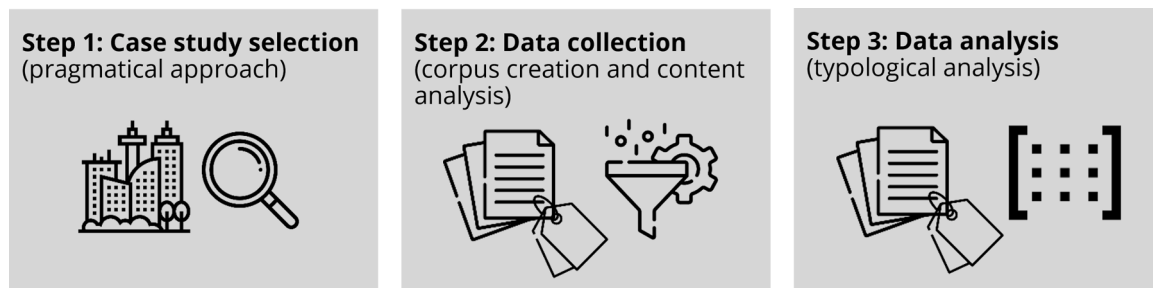


Fig. 1. Methodological framework.

Table 1
Case studies context information.

#	Project acronym	Project full name	Total area (ha)	% of green area	Location	Actual project status	Design approach
1	Lloyd	Lloyd Crossing Sustainable Urban Plan	21,8	30%	Portland, USA	Under implementation	Ecosystem-level biomimicry
2	Lavasa	Lavasa Hill	> 2 000	*	Mumbai-Pune region, India	Partially implemented; Abandoned	Ecosystem-level biomimicry
3	Blatchford	Blatchford Redevelopment Plan	217	27,8%	Edmonton, Canada	Under implementation	Regenerative design
4	Paddock	The Paddock	1,4	65%	Castlemaine, Australia	Under implementation	Regenerative design
5	Clause	Ecoquartier Clause-Bois Badeau	42	26%	Bretigny-sur-Orge, France	Under implementation	EcoQuartier
6	CIGV	Ecoquartier de la Cité Internationale de la Gastronomie et du Vin de Dijon	6,5	35,4%	Dijon, France	Implementation- authorisations requested	EcoQuartier

* No available information.

relies only on water and energy available locally, that regenerates habitats, and that reconnects the district functioning to the local ecosystem patterns (Hayter, 2005; Mithun, 2004; Pedersen Zari, 2018).

2.1.2. Lavasa hill

The Lavasa Hill project is a planned city in Maharashtra state in India's Mumbai-Pune region, covering over 2000 ha, designed in 2001. Part of it has been designed using the Ecological Performance Standards framework from Biomimicry 3.8, an ecosystem-level biomimicry design framework that relies on the notion of ecosystem services (Baumeister, Pedersen Zari & Hayes, 2020; Lazarus & Crawford, 2011). The design teams find inspiration from local monsoon ecosystems and organisms to solve sustainable urban design challenges, mostly related to rainwater management and erosion control. Through an ecological diagnostic process, engaging urban designers and ecologists, the HOK Architects and Biomimicry 3.8 design team identified six essential ecosystem services for the site's ecological functioning, rendered by the local forest. The designed project tried to replicate these ecosystem services through innovative bioinspired urban strategies, aiming to render ecosystem services, improve the project's feasibility, and reduce its environmental impacts (Baumeister et al., 2020; Datta, 2012; Lazarus & Crawford, 2011).

2.1.3. Blatchford redevelopment plan

The Blatchford Redevelopment project is an urban renewal project designed in 2013 and situated in Edmonton, Canada. The project aims to requalify 217 ha from the old city airport to a sustainable community that relies only on renewable energy, is carbon neutral, significantly reduces its ecological footprint, and empowers residents to pursue sustainable lifestyle choices. Perkins+Will designed the project using a regenerative design mindset and whole systems thinking. The design team creates a deep understanding of site logic and needs in their whole systems and regenerative design approaches. The project aims to restore the local ecosystem's health using several urban strategies to recreate habitat, reintroduce biodiversity and relink the urban site to the local ecosystem flows, aiming for renewable energy and carbon neutrality

strategies (Busby, 2015).

2.1.4. The Paddock

The Paddock is a small sustainable neighbourhood situated in Castlemaine, Australia, counting 26 homes and designed in 2008 Jeff Crosby designed the project to make the local ecosystem healthier with the urban project, presenting robust engagements towards biodiversity and local food production. The design relies on the Living Building Challenge (LBC) certification, a primary regenerative design framework and certification program. Following the LBC requirements, the project presents several strategies to restore habitat and biodiversity, be autonomous, rely only on locally available resources, and create a positive socio-ecological impact on the site. The project relied on a 3-day participatory site ecological diagnostic to draw the project baseline, identifying site's patterns related to water, soil, vegetation, birds, insects, amphibians, reptiles, and mammals (Pedersen Zari, 2018).

2.1.5. Clause-Bois Badeau

Clause-Bois Badeau is a sustainable neighbourhood in Bretigny-Sur-Orge, France, over 42 ha designed in 2005. GermeJAM designed the project aiming for the French EcoQuartier certification, now awarded as a delivered EcoQuartier. The project aims to requalify industrial and agricultural brownfields to reconnect the urban space with the local ecosystem and ecological networks. Clause-Bois Badeau presents meaningful engagements towards biodiversity reintegration, energy sobriety and the creation of a regional green network. A green park with a broad diversity of habitat types is in the centre of the projects and articulates the urbanisation. The project has been designed after several ecological and environmental impacts studies. The ecological studies were key to designing green areas that are functional and complex ecosystems (CEREMA, 2015).

2.1.6. Cité Internationale de la Gastronomie et du Vin de Dijon

The Cité Internationale de la Gastronomie et du Vin de Dijon is an urban requalification project in the heart of Dijon, France, over 6,5 ha and designed in 2016. The project integrates a touristic and event

infrastructure related to French gastronomy with a sustainable neighbourhood designed by Bechu & Associés and Eiffage. The project relies on the French EcoQuartier framework recommendations but does not aim for the certification. The project has a significant focus on protecting the existing ecological structure, improving the soil permeability, and reducing greenhouse gas emissions. The project also presents engagements related to local food production. The project used environmental impact assessments as a source of information to design relevant site-specific solutions (Eiffage Aménagement, Agence d'architecture A. Bechu, LAND'ACT & OTCI, 2016).

2.2. Data collection

To identify the projects' urban solutions and strategies to reconnect with the ecosystem functioning, produce positive impacts and potential urban ecosystem services, we created a documental collection (corpus) for each project. Relevant documentation related to the design phase was collected through scientific databases (Web of Science), projects websites, web research databases (Google), and directly with project stakeholders by e-mail. For online databases, we used the project names as keywords.

Only documents describing and presenting the project urban solutions in the design phase were retained for analyses, creating a relevant corpus concerning our research questions. As urban solutions, we understand any design solution aiming to reduce the impacts of urban projects over the ecosystems or create a regenerative (positive) impact on them, reconnecting the project to the local ecosystem and potentially producing urban ecosystem services.

The following type of documents composes the corpus:

- Scientific peer-reviewed articles
- Scientific reports
- Projects information available on the official projects websites
- Commercial project booklets and communications
- Urban design plans and related documents
- Public policy documents related to the projects
- Construction authorisations and related documents
- Books excerpts discussing the projects
- Architecture review articles describing the project (non-scientific documents)

Table 2 presents the number of documents analysed for each case study. Appendix B presents the name of each analysed document.

We imported the corpus to MaxQDA Analytics Pro 2020 software, where it was read and coded using thematic coding (Saldana, 2009). Data was coded only by one researcher and validated by the others at the end of the coding process. We coded the data using only one criterion, the urban solution type (described on 2.3). We used a two-round coding process. The first round was based on a grounded-theory approach, in which the corpus was read without any preliminary coding structure. Once an urban solution was identified, it was freely coded, creating a coding class to define its type or using a previously created class. At the second round, all the corpus was verified a second time, and coding classes were merged, leading to a final structure of six different codes

Table 2

Number of analysed documents and urban solutions identified in each case study.

#	Project	Number of analysed documents	Number of identified solutions
1	Lloyd	5	29
2	Lavasa	11	9
3	Blatchford	14	18
4	Paddock	6	19
5	Clause	20	21
6	CIGV	16	14

describing the solution types (described in Section 2.3).

This step allowed us to identify and register excerpts presenting the different urban solutions proposed by designers with a direct or indirect ecological objective and their types, that would be later typologically classified and analysed.

2.3. Data analysis

Every urban solution identified was classified using three typological criteria, defined to answer our research questions. They are:

- **Goal:** Each solution was classified regarding its main goal toward the ecosystems. To identify the goal, we based our observation on designers' context in the documents. Three goals were possible:
 - Reduce pressure over the ecosystem: solutions that focus on reducing, minimising and mitigating project impacts and their pressures over the ecosystems;
 - Regenerate the ecosystem structure: solutions that focus on regenerating or protecting the ecosystem structure on-site;
 - Both: solutions that have both previous goals;
- **Type:** Each solution was classified between six possible types:
 - Compensation: Solutions to compensate/mitigate the negative impact of the urban project;
 - Education: Solutions based on education and awareness-raising of final project users;
 - Nature-Based Solutions (NBS): Solutions relying on living systems. We adopted here the Nature4Cities classification for NBS identification (NATURE4CITIES, 2019);
 - Technological: solutions relying on urban technologies;
 - Urban rules and policy: solutions relying on the proposition of public policies, urban prescriptions and urban legislations;
 - Urban form and infrastructure: solutions that directly change the urban form and urban infrastructure.
- **Main ecosystem component:** for each solution, we identified one main ecosystem component that the solutions relate to and aims to deal with the local ecosystem. To this classification, we used Odum (1969) definition of ecosystems, with four main components:
 - Biological structure: Solutions that protect or restore the biotic ecosystem components (fauna, flora and microorganisms), improving its overall health, diversity and resilience.
 - Physical structure: Solutions that protect or restore the abiotic ecosystem components that characterise the ecosystem and their condition., like the soil and rocks composition and quality, the wind dynamics, the air quality, the water resources and the topography;
 - Energy flows: Solutions that deals with the energy flows (renewable energy, electricity, heat transfers...) in the built space and connects human-made flows to ecological ones.
 - Material flows: Solutions that optimise the material flows (water, carbon, food, nutrients, biomass, building resources...) in the built space and connects human-made flows to ecological ones.

Solutions classified as NBS were further analysed and classified to detail the NBS types observed in the sample. For this classification, we relied on the Nature4Cities NBS classification and the factsheets presenting the different classes (NATURE4CITIES, 2019). Each excerpt describing a NBS solution was then reclassified, matching the solution description with a NBS class description from the Nature4Cities NBS factsheets.

Appendix C presents the identified urban solutions and their classification.

2.4. Strategies hierarchical classification

Once all the solutions were classified using the previous criteria, we cross-examined them to identify co-occurrences and convergences. This

analysis allowed us to propose a homogenised and hierarchical classification from the solutions observed into larger groups, called strategies. Each strategy is related to a topic and ecosystem component, creating a hierarchical structure. This hierarchical classification aims to summarise in a taxonomy how the analysed projects are operationalising an ecological design.

2.5. Limitations and methodological choices

The identified solutions and strategies discussed here are placed at the end of the projects design phase. The design phase is justified by our interest in the design process, the step in which project teams select the main solutions and strategies. Nevertheless, we are aware that the solutions and strategies may evolve until their implementation. These evolutions and the mechanism behind them are not our objective but are worthy of exploration.

We analyse the number of strategies on each project and their types, not their specific characteristics (like extent, benefits, perceived impacts). The number of solutions and strategies helps understand trends in practice and are not proxies to these projects' ecological performance.

We are aware of the differences between the cases we studied, notably their size and their ecological, social and economic contexts. As we do not assess the project performances but how they deal with urban challenges through concrete solutions to build hypotheses, these questions do not interfere in interpreting our results.

3. Results

In the six case studies, we identified 110 urban solutions (Table 2). The main results are presented in the following topics.

3.1. Solutions goal: a focus on reducing urban pressures over the ecosystems

amongst the 110 identified solutions, 59,1% primarily focus on reducing the urban project impacts and pressures over the ecosystems. Examples are technological and awareness-raising solutions to reduce energy and water consumption in the neighbourhood, transport-orientated design and active mobility strategies to reduce air pollution and CO₂ emissions, and the use of low impact and locally resourced building materials.

In opposition, 31,8% of the identified solutions aimed mainly to regenerate the ecological structure. Nature-Based solutions, like green parks design, green roofs, and native species' reinsertion, are recurrent strategies in this topic.

Finally, 9,1% of the solutions had mixed goals, aiming to regenerate the ecosystem and reduce human pressures over the ecosystems. Examples are bioswales, designed to manage rainwater and recover habitats availability, local urban agriculture zones for food provisioning, and artificial lakes' design to improve the ecosystem complexity and treat grey and rainwater. Fig. 2 presents the distribution of the goals of the solutions on each project.

3.2. Solution types: nature-based and technological solutions as the most frequent types to tackle urban ecosystem challenges

"Nature-Based solution" is the most recurrent solution type in our case studies. They represent 39,1% of the identified solutions, followed by "Technological solutions", representing 29,1%. These two types represent 67,3% of the identified solutions, and both were observed in all cases.

Bioswales, pocket gardens, public urban green spaces, street trees, green roofs and green network connectivity represents 48,8% of all NBS strategies (Fig. 3) and 19,1% of all identified solutions in the sample. amongst the technological solutions, we observe various on-site renewable energy production propositions (through photovoltaic, geothermal, wind and biomass energy production). Other recurrent technological solutions are rainwater management through water collection and reuse, on-site wastewater treatment, waste management and recycling, efficiency upgrade on buildings to reduce energy and water consumptions, and low impact building materials.

"Urban rules and policy" type represents 17,3% of the sample. Examples are urban zoning and urban prescriptions to define high energy and water performances for new buildings in the project area. Codes and prescriptions seem necessary to ensure that the ecological engagements are kept over the project lifecycle and stakeholders changes.

The "Urban Form and infrastructure" type counts for 10,9% of identified solutions. Here we observe solutions to promote active mobility and transit infrastructure, soil management and topography protection. Finally, the "Education" and "Compensation" types represent only 1,8% each (addressed only by two projects). Examples for these two last classes are, respectively, the final user education to reduce energy and water consumption and project carbon emission offset through carbon credits. Fig. 4 illustrates the distribution of the strategy types for each case study.

3.3. Ecosystems components: urban solutions addressing material and energy flows instead of ecosystem biophysical structure

The ecosystem component criteria allow us to understand how the

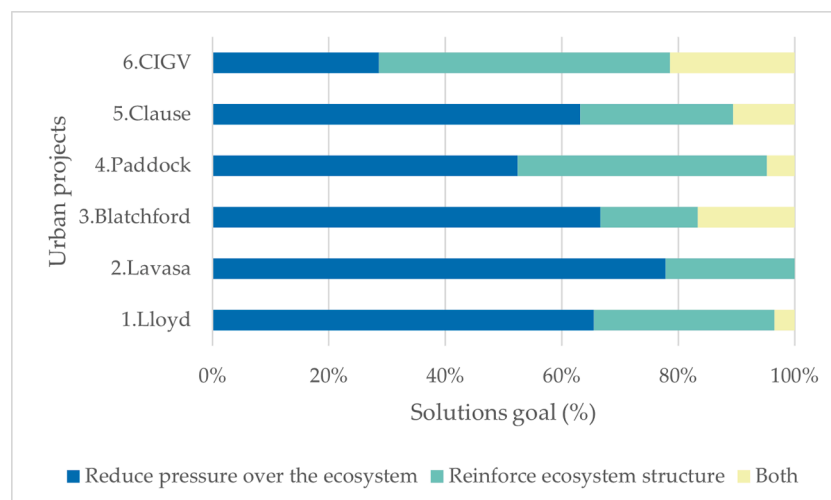


Fig. 2. Distribution of solutions goal for each project.

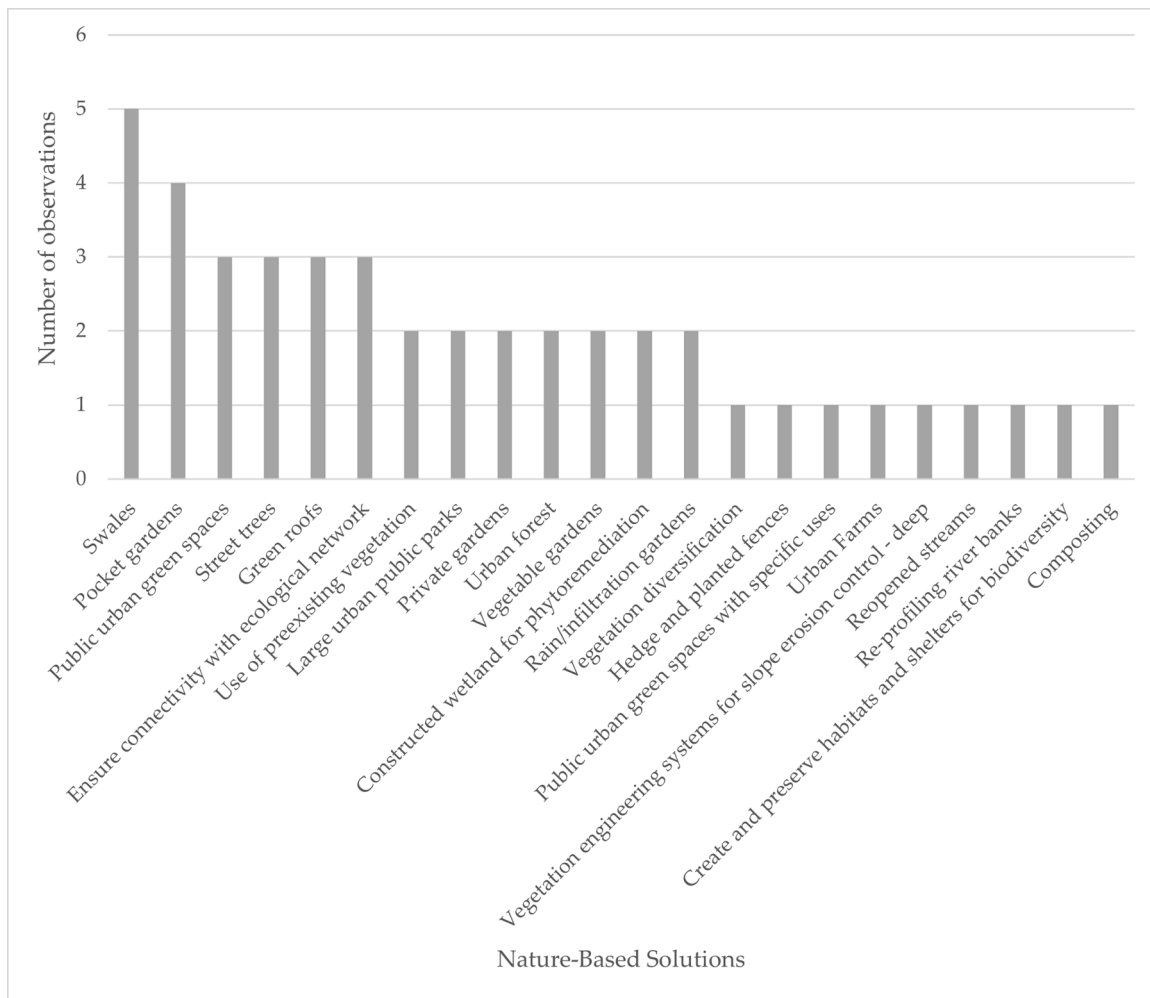


Fig. 3. Different Nature-Based Solutions occurrence (using Nature4Cities (2019) classification).

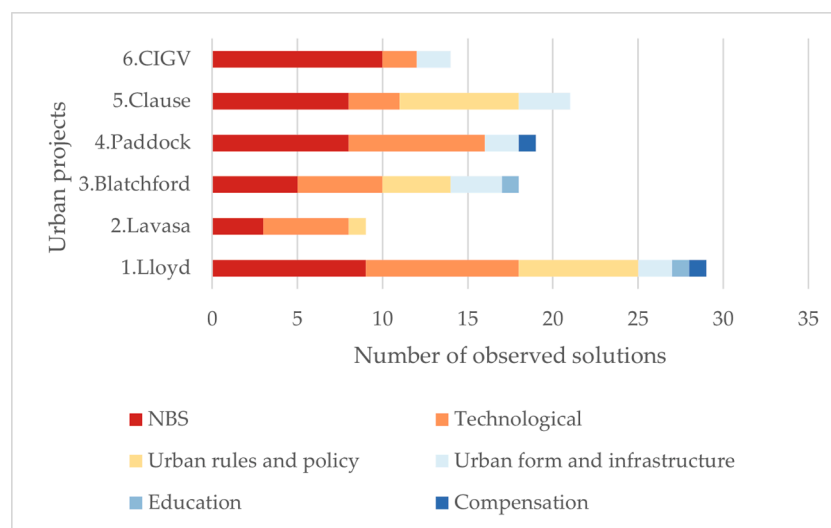


Fig. 4. Types of solutions per case study.

solutions contribute to different elements and processes that compose an ecosystem. We observe that 66,5% of the overall identified solutions deal with flows (energy and materials), while 33,6% will address ecosystems biophysical structure (biotic and abiotic).

The ecosystem component primarily addressed is the materials flows, counting for 45,5% of the identified urban solutions. Material flows strategies deals with diverse flows between urban space and natural ecosystems, like water, food, building resources, waste and carbon.

Examples of identified solutions in this topic are on-site rainfall water management, the reduction and compensation of embodied CO₂ emissions, local food production, the local sourcing of building materials and local organic waste management.

Solutions dealing with energy flows represents 20,9% of the sample. Examples are the local production of renewable energy, reducing energy consumption through fixtures, and optimising solar input and heat transfers between buildings.

Strategies primarily addressing the biological structure represents 27,3% of the observations. Examples are notably the NBS strategies previously discussed, such as green urban areas, bioswales and green roofs. Finally, only 6,4% of the identified strategies address the physical and abiotic structure of the ecosystems. Examples are water bodies design, water quality recovery, soil unsealing and erosion control solutions.

The distribution of strategies amongst the four components of ecosystems is different for each project (Fig. 5). It is possible to observe that none of the projects deals with the four ecosystems components equilibrated and holistically. Material flows is one of the most relevant category in every project.

3.4. NBSs regenerating ecosystems structures, technological solutions reducing the impacts of human-made flows

We can note that the NBS type is used mainly to regenerate the ecosystems' biological and physical structure. Technological ones are those that mainly relates to energy and material flows. Urban code and policy and urban form and infrastructure also present a stronger link with flows (Fig. 6).

Furthermore, NBS strategies represent 91,4% of all strategies with a primary goal to regenerate the ecosystem structure. Technological strategies represent 49,2% of all the strategies aims to reduce the pressure over the ecosystem

3.5. Strategies hierarchical classification: defining an urban strategies taxonomy

We were able to identify convergences amongst the different solutions in the six case studies. These convergences lead us to propose a hierarchical classification of the identified solutions on 36 urban strategies families used to reconnect urban projects with local ecosystems (Table 3). amongst the most recurrent identified strategies, we can list:

- on-site renewable energy production;
- the reduction of energy consumption;
- on-site stormwater management;
- design for active and low carbon mobility, and
- the design of minor public green areas.

Appendix D presents the identified strategies on each case study.

4. Discussion

This research provided innovative insights into how urban projects address and operationalise the challenge of reconnecting their functioning to natural ecosystems and finding inspiration on ecosystem models. We were able to identify trends in the urban solutions and strategies choices, related to our research questions, synthesised in the following hypotheses:

- Urban projects focus on reducing human pressures over the ecosystems instead of a proactive approach to regenerate ecosystem structures;
- Nature-based solutions have an essential role in ecological and sustainable urban projects, allowing to promote mutual benefits for society and nature;
- Technological solutions are important on the management of human pressures over ecosystems, mainly those related to materials and energy flows;
- Projects primarily address energy and materials flows and tend to give lesser importance to ecosystem biophysical structure;

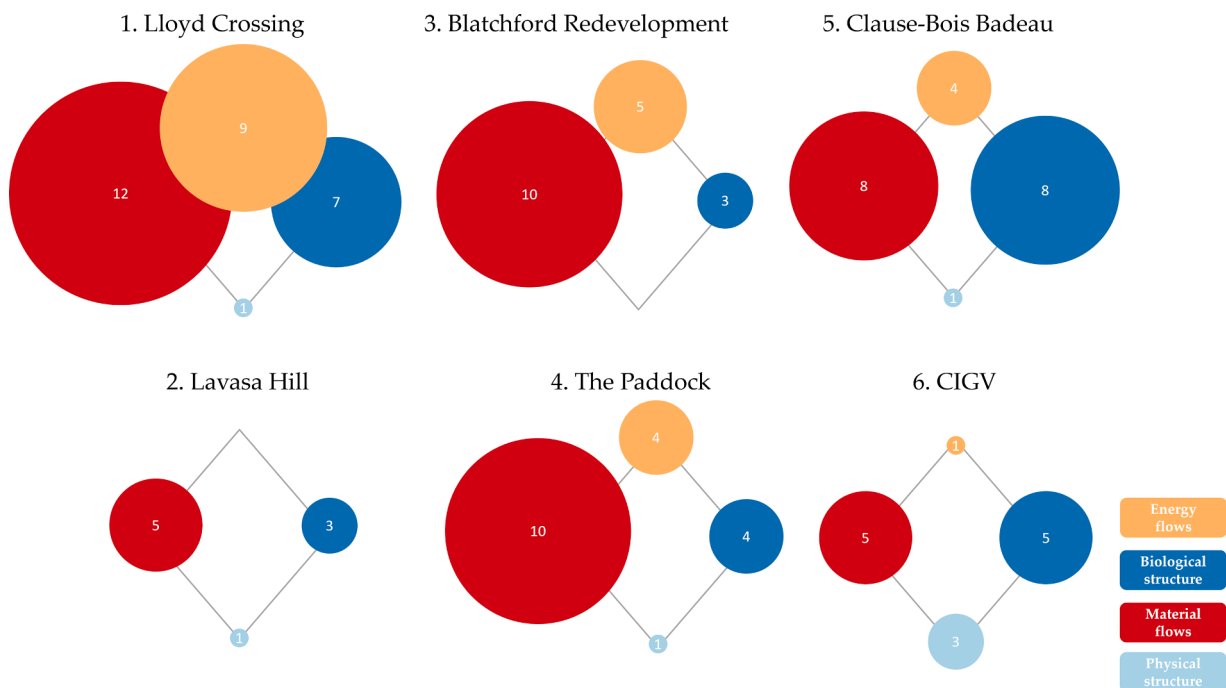


Fig. 5. Distribution of solutions for each ecosystem component per case study (The circles' size is equivalent to the number of strategies on each axis, the number of identified strategies is inside each circle).

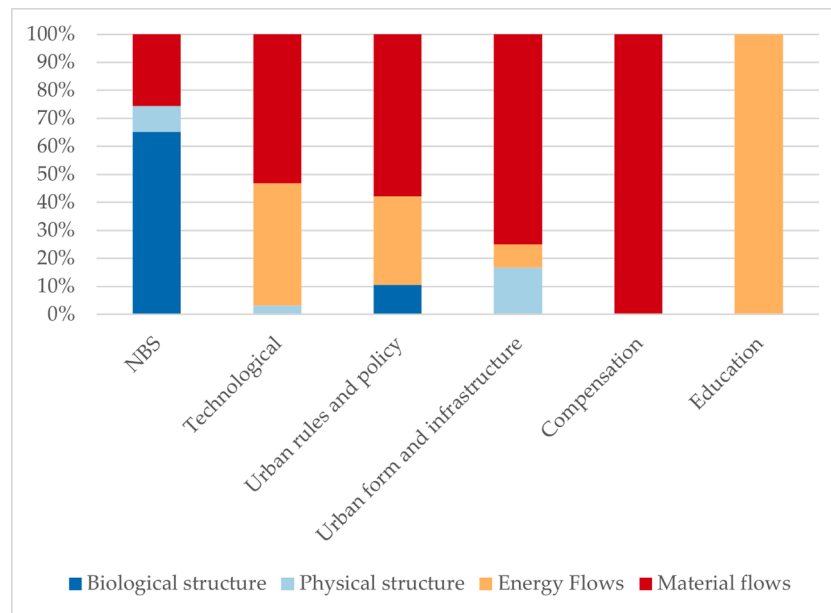


Fig. 6. Relation between solutions types and the ecosystem's elements they are addressing.

4.1. Enhancing the production of ecosystem services: the need for more solutions to regenerate the ecosystem biophysical structure

While solutions had distinct objectives, we observed a trend of focusing on reducing human pressures over ecosystems. Furthermore, 65% of the solutions primarily relate to material or energy flows, and ecosystems' biological and abiotic structures were treated with lower priorities.

Focusing on reducing material and energetic flows and their impacts in an urban metabolism manner, lead us toward misleading and simplistic approaches to the ecology of cities for urban design (Golubiewski, 2012). Conventional urban metabolism approaches take organism metabolism as models, in which flows are fundamental, but cities are complex socio-ecosystems and should be addressed as so (Golubiewski, 2012). This metabolic metaphor leads designers to focus only on inputs and outputs from the study area within the exterior, in a discrete body and linear manner. Thus, we tend to ignore the role of the components (the ecosystem biophysical structure) and the pathways of these flows in the urban ecosystem functioning (Golubiewski, 2012).

From the perspective of ecosystem services production, addressing the urban ecosystem components and the flows and their pathways seems fundamental. The ecosystem services cascade and the DPSIR frameworks highlight the importance of two elements on the provision of ecosystem services: (1) the ecosystem's biophysical structure state and (2) the incident human pressure over the existing biophysical structure (Kandziora, Burkhard & Müller, 2013; Kremer et al., 2016; Potschin et al., 2018), pressures that can be linked to the unbalanced flows from social to natural systems.

Better articulating solutions that enhance the ecological structure and reduce human pressures over the ecosystems seems a comprehensive way to improve potential ecosystem services in urban spaces. As we observed a trend in managing energy and material flows in this sample, giving more place for solutions that recover and regenerate the ecosystems biophysical structure could foster designs beyond mechanistic and anthropocentric emulation of nature, creating urban spaces that are supportive and integrated to natural ecosystems (Ellin, 2020; Puppim de Oliveira et al., 2011).

Nevertheless, integrating biodiversity and ecosystems' physical structure into the equation of urban design is more complex than dealing with flows. Much of it is due to the historical humanistic modes of working in urban planning, not acknowledging cities as multispecies

spaces (Houston, Hillier, MacCallum, Steele & Byrne, 2018), as well as to the lack of human knowledge on the biophysical structure elements and their complex interrelations (Clergeau, D'Arienzo & Younes, 2018; Golubiewski, 2012; Parris et al., 2018; Puppim de Oliveira et al., 2011).

This complexity is illustrated in our projects by the gaps observed in the 36 identified strategies. In our sample, biodiversity is mainly addressed through green spaces design, but few solutions concerns fauna management. Regarding the abiotic structure, the soil structure and quality have barely been explored.

Nevertheless, to move from only increasing green spaces coverage towards concretely addressing biodiversity, several solutions are available and could be further explored in urban projects. Examples are: 1) the use of native plant species and understory vegetation, that positively impacts birds' richness (Threlfall, Williams, Hahs & Livesley, 2016); 2) the design of green networks, promoting connection between habitat patches inside and outside the project area, positively impacting diversity (Shwartz, Turbé, Julliard, Simon & Prévot, 2014); and 3) exploring soil management strategies to enhance soil quality and biodiversity (Tresch et al., 2018).

4.2. Nature-based solutions: a central place promoting mutual benefits for society and nature

NBS has a central place in our sample and amongst the identified solutions directly addressing biodiversity and the physical structure of ecosystems. Nature-Based Solutions is well recognised for its role in urban resilience and human well-being (Zwierchowska, Fagiewicz, Poniży, Lupa & Mizgajski, 2019). It produces benefits for the whole natural system, not only humans (Raymond et al., 2017) and addresses complex urban challenges, addressing social, economic and environmental issues simultaneously (Dorst, van der Jagt, Raven & Runhaar, 2019).

Nature-based solutions are multifunctional and can tackle several urban challenges simultaneously (Almenar et al., 2021; Dorst et al., 2019), for example, with a single solution dealing with heat islands and rainwater management. However, they are not the answer to all contemporary ecological urban problems, also having trade-offs and blind spots (Almenar et al., 2021; Kotsila et al., 2021). This fact joins our observations in the case studies. NBS has been used to deal with diverse urban challenges and has been associated with other solutions, such as technological and regulatory ones, to solve complex problems.

Table 3
Identified urban strategies and the total number of observations on the sample.

Ecosystem component	Topic	Strategy	Observations
Energy Flows	Electricity	1. On site renewable energy production	9
		2. Reduction of energy consumption	8
Material Flows	Heat and light	3. Optimisation of solar input on buildings	4
		4. Optimisation of on-site heat and energy transfers	2
	Water	5. Reduction of on-site water consumption	3
		6. On-site stormwater management (reuse/drinking)	6
		7. Onsite stormwater management (infiltration/evaporation)	11
		8. On-site wastewater management	3
	Building materials	9. Reuse demolition materials	1
		10. Reuse existing buildings and infrastructure (renovation)	1
		11. Use building materials with low impact on human and ecosystem health	3
	Carbon	12. Source building materials locally	2
13. Offset CO2 embodied emissions - building phase		1	
14. Offset CO2 emissions - using phase		1	
15. Promotion of urban densification		3	
16. Design for Transit-orientated development (TOD.)		1	
17. Design for active and low carbon urban mobility		7	
18. On-site food production in small scale (for education and awareness-raising)		3	
Food	19. On-site food production in large scale (for local food provisioning)	1	
	20. Phytosanitary products restrictions	1	
Chemical products	Waste	21. On-site organic waste management	1
		22. Recycling and waste management	2
Physical structure	Water bodies	23. Water body restoration	1
		24. Water body design	2
	Soil	25. Erosion control	2
		26. Avoid soil sealing	1
	Built space	27. Avoid topography changes	1
28. Design artificial abiotic habitat structures		1	
Biological structure	Flora	29. Design of major green area using native species	3
		30. Protect existing vegetation area	2
		31. Green streets design	3
		32. Design of in-building vegetation	3
		33. Promote connection with the local green network	3
		34. Design of minor public green areas	9
		35. Design of minor private green areas	2
		36. Use of complex vegetation schemes	3

NBS can help tackle the challenge of regenerating ecosystem biophysical structure while reducing urban pressure over ecosystems, promoting mutual benefits for society and nature (Zwierzchowska et al., 2019). Nevertheless, NBS still has a minor place on sustainable design frameworks and neighbourhood sustainability assessment, as those aborbed here and others as LEED-ND and BREEAM Communities (Xing, Jones & Donnison, 2017). An effort to generalise and expand the use of nature-based solutions on urban design and policy is necessary. Project teams should refer to contemporary scientific productions on the topic as the IUCN Standard for Nature-Based Solutions (IUCN, 2020) and the Nature4Cities toolkits to plan and implement NBS (Jeuken, Breukers, Elie & Rugani, 2020).

4.3. Strategies classification: towards a design tool

The taxonomy of strategies from our case studies could be the first step towards a design tool to foster urban ecological design. Even if not exhaustive, this classification could inform and give insights to such tools. Pedersen Zari and Hecht (2020) proposed a first mapping of strategies to produce ecosystem services on urban projects based mostly on literature review that could benefit from this taxonomy from a case study perspective.

The more frequently observed strategies help us to visualise the main topics being addressed in these projects. These strategies reflect contemporary concerns of our society towards urban spaces and ecosystems. They also represent strategies that have reached a more considerable maturity and operationalisation levels, as energy sobriety, renewable energy production, rainwater management and urban greening.

Nevertheless, the proposed taxonomy presents gaps, as topics such as fauna, soil and air, and ecosystem processes, like species dispersion and trophic chains. Thus, it would benefit from an exhaustive analysis and expansion. Besides, it would also be helpful to identify performance indicators that could help designers assess their project performance and allow improvements and comparisons between projects and scenarios.

4.4. Insights from the urban design process

Even if not the focus of this research, we observed a common point in our six case studies related to the urban design process. A socio-ecological diagnostic supported all the projects design, using distinct methods and detail levels (briefly presented in the project's description). For example, we observed participatory and qualitative diagnostic in The Paddock as well as quantitatively ecological assessment using secondary data on the Lloyd Crossing project.

The realisation and use of diagnostics in the design process seems a pivotal element in these projects. Still, previous research highlighted a significant absence of diagnostics informing urban projects in the urban design practice (Leach, Mulhall, Rogers & Bryson, 2019). Thus, we argue that diagnostics could be a key element in integrating ecological knowledge into the urban design practice (Clergeau et al., 2018, 2019).

Another relevant point observed in our cases was the lack of education and awareness-raising strategies for urban dwellers and the lack of social participation in the project design process. Nevertheless, the projects probably have indirect influences on users' compartment and lifestyle through their solutions. For example, the Blatchford Redevelopment project shows this as a primary goal. But, few active education strategies have been identified as well as only marginal stakeholders involvement in the design process.

Users' role in sustainable and regenerative projects is more than necessary for their final ecological performance (Chicca, 2020). More than designed to be sustainable, urban projects have the challenge to help people adopt sustainable lifestyles, accelerating societal change.

Socio-ecological diagnostics and participatory design processes have already been highlighted as pillars of regenerative urban projects (Blanco et al., 2021) and have an important place in other sustainable

urbanism theories. Nevertheless, in practice, both seem to struggle to find their place in the project design process.

5. Conclusions

Based on six cases studies, this research delineated hypotheses regarding the ecological urban design practice. These hypotheses still deserve further exploration and validation, but they highlight challenges integrating ecological information and aspects in the urban design practice.

Even when analysing a sample of projects based on frameworks that try to deeply engage with ecosystem logic, we observed an anthropocentric focus, despite the urgent need to systemically tackle urban challenges in the context of climate change and biodiversity loss. Projects aim primarily to manage materials and energy flows and reduce human pressure over ecosystems, neglecting the ecosystems biophysical state and ecosystems processes. The predominance of an urban metabolism approach and the absence of focus on the ecosystem state is reductive and insufficient in terms of sustainability for urban ecosystems. We assume that this trend is still more substantial in conventional sustainable urban projects, like those designed under LEED-ND and other well-established neighbourhood sustainability frameworks.

To reach mutually beneficial projects urban design practice needs to move forward: Addressing the ecosystem biophysical structure and its state needs to gain a central place in the choice of sustainable urban solutions. Integrating this notion into existing urban design frameworks and proposing new tools that can inform the design practice is essential in this challenge. Our taxonomy of strategies is a first step towards more complete and holistic tools and could be further developed to fulfil these gaps. These tools need to highlight the need to go beyond only increasing the project green surface, addressing species richness, habitat availability and quality as well as connectivity.

Another necessary change in the urban design practice regards socio-ecological diagnostics. The analysed cases seem to integrate diverse forms of diagnostics to inform the selection of solutions and strategies,

contradicting the predominant urban design practice, in which diagnostics are understated. We argue that the realisation of diagnostics before any project design must become a wider practice. Diagnostics could even be used to define projects priorities, narrowing down the scope of possible sustainable interventions on pre-project phases.

Finally, articulating different types of solutions and strategies seems essential to achieve urban projects that reconnect with natural ecosystems functioning. From the perspective of the ecosystem service cascade and the DPSIR framework, both the strategies aiming to reduce human pressure and regenerate ecosystems' state are fundamentals to enhance the ecosystem services production and mutual benefits. Nature-Based solutions had an important role in our sample, and we believe their popularisation and integration on urban projects and urban policy play an essential part in this challenge.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix A. List of pre-selected projects and their suitability to selection criteria

#	Project name	Scale and use	Design Framework	Project phase	Documentation
1	Lloyd's Crossing	Mixed-use neighbourhood	Ecosystem-level biomimicry	Partially built	Available online and through project team
2	Lavasa Hill	Mixed-use neighbourhood	Ecosystem-level biomimicry	Partially built	Available online.
3	Terres de Versailles	Mixed-use neighbourhood	EcoQuartier	Under construction	Not available online and project team did not answer our information request.
4	CIRS	Educational building	Regenerative Design	Built	Available online.
5	Vale Living with Lakes	Educational building	Regenerative Design	Built	Available online.
6	Pôle du Biomimétisme Marin de Biarritz	Office building	Ecosystem-level biomimicry	Not built	Available through project team
7	Langfang	Mixed-use neighbourhood	Ecosystem-level biomimicry	Not built	Not available online.
8	RegenVillages	Mixed-use neighbourhood	EcoQuartier	Not built	Not available online.
9	Tour Hyperion	Residential building	EcoQuartier	Under Construction	Not available online.
10	Groupe Scolaire de la Science et de la Biodiversité	Educational building	Ecosystem-level biomimicry	Built	Available online and through project team
11	La vallée - Chatenay Malabri - Eiffage	Mixed-use neighbourhood	EcoQuartier	Under Construction	Not available online.
12	Ecoquartier de l'Eau Vive	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
13	Docks de Ris	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
14	Claude Bernard	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
15	Clichy-Batgnolles		EcoQuartier	Built	

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#	Project name	Scale and use	Design Framework	Project phase	Documentation
16	Seguin - Rives Seine	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
17	Bel Air - Grands Pêcheurs	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
18	Camille Claude	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
19	Fréquel-Fontarabie	Mixed-use neighbourhood	EcoQuartier	Built	Not available online and project team did not answer our information request.
20	Clause-Bois Badeau	Mixed-use neighbourhood	EcoQuartier	Built	Available online and through project team
21	Dong Tan	Mixed-use neighbourhood	Ecosystem-level biomimicry	Not built	Not available online.
22	Wanwhuang	Mixed-use neighbourhood	Ecosystem-level biomimicry	Not built	Not available online.
23	20/20 Park	Business Park	Ecosystem-level biomimicry	Built	Not available online.
24	Blatchford Redevelopment	Mixed-use neighbourhood	Regenerative Design	Partially built/Under construction	Available online and through project team
25	Darwin Ecosystème	Mixed-use neighbourhood	Regenerative Design	Partially built	Not available online and project team did not answer our information request.
26	Dockside Green	Mixed-use neighbourhood	Regenerative Design	Under Construction	Not available online and project team did not answer our information request.
27	Point Weels	Mixed-use neighbourhood	Regenerative Design	Not built	Not available online.
28	Chaudière Island (Zibi)	Mixed-use neighbourhood	Regenerative Design	Not built	Available online.
29	Cap Roger Curtis	Mixed-use neighbourhood	Regenerative Design	Not built	Not available online.
30	Smartseille	Mixed-use neighbourhood	EcoQuartier	Partially built	Not available online and project team did not answer our information request.
31	Cité de la Gastronomie et du Vin à Dijon	Mixed-use neighbourhood	EcoQuartier	Partially built/Under construction	Available through project team
32	The Paddock	Mixed-use neighbourhood	Regenerative Design	Partially built/Under construction	Available online

Appendix B. Analysed documents for each case study

#	Project	Documents titles
1	Lloyd	Request for Proposals #03-16 - Lloyd Crossing Sustainable Design and Development Project
		LLOYD CROSSING - Sustainable Urban Design Plan & Catalyst Project AIA TopTen - Lloyd Crossing Sustainable Design Plan Case Study Lloyd Crossing Sustainable Urban Design Plan and Catalyst Project - Portland, Oregon [2005 EDRA/Places Award – Planning] Lloyd District Development Strategy
2	Lavasa	Lavasa MasterPlan
		Lavasa to become the World's first city to set standards using biomimicry The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities Biomimicry: nature's design process versus the designer's process Lavasa: An Emerging Smart City Lavasa: Life in full Brochure Returning Genius to the Place New Urbanisms in India – Final Report The Private City: Planning, Property, and Protest in the Making of Lavasa New Town, India India's ecocity? Environment, urbanisation, and mobility in the making of Lavasa Lavasa: A mushrooming paradise
3	Blatchford	Busby: Architecture New Edges
		Request For Qualification Number 917843 - Edmonton City Centre Airport Lands - The Master Plan Negotiated Request for Proposals - Edmonton City Centre Airport Lands - The Master Plan City Centre Area Redevelopment Plan Consolidation Blatchford Concept Plan Implementation Analysis Blatchford Business Case Blatchford Plan and graphics Strategic Alignment with The Ways Blatchford Redevelopment Scenarios Financial Analysis of the Blatchford Development Scenarios Blatchford Development Governance Model Potential Advisors to the Blatchford Redevelopment Project Blatchford West Architectural and Urban Design Guidelines Blatchford West - Stage One Green Building Codes

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#	Project	Documents titles
4	Living Building Challenge: Enhancing the local environment Landscape Plan Site plan – Final Owners Corporation Rules “The Paddock” Ecovillage Castlemaine Fair Share	Paddock The Paddock – About
5	SORGEM : Clause-Bois Badeau Projet de modification n°2 du PLU – 2. OAP Clause Bois Badeau modifié Fiche n°38 Brétigny-sur-Orge/Essonne ZAC Clause Bois-Badeau Clause – Bois-Badeau, un quartier qui évolue Amenagement Durable En Essonne: Quelles Avancées Du Label Écoquartier ? Comment Produire Du Logement Durable Abordable ? Bienvenue à Clause-Bois Badeau Votre livret d'accueil Germe et Jam : Clause Bois Badeau plans et visuels Germe et Jam : Clause Bois Badeau plan masse Germe et Jam : Clause Bois Badeau projet urbain tissu Projet d'Amenagement Des Terrains Clause Bois Badeau - Zac Clause Bois Badeau Et Zac Des Sorbiers - Cahier General Des Prescriptions Paysagères Et Ecologiques Projet d'Amenagement Des Terrains Clause Bois Badeau - Zac Clause Bois Badeau Et Zac Des Sorbiers - Cahier General Des Prescriptions Paysagères Et Ecologiques pour les Ilôts Du Mesnil Tribu : ZAC Clause Bois Badeau – Brétigny-sur-Orge (91) Assistance à la maitrise d'ouvrage et suivi de la conception des projets architecturaux Projet urbain, Clause Bois Badeau - germe&JAM Nature en ville La nature comme élément du projet d'aménagement urbain BRÉTIGNY-SUR-ORGE / Essonne L'écoquartier Clause-Bois Badeau EcoQuartier Clause Bois Badeau, Brétigny-sur-Orge (91) Retour d'expérience synthétique INTEGRATION DES ENJEUX DE BIODIVERSITE DANS LES ÉCOQUARTIERS Analyse des pratiques d'ÉcoQuartiers labellisés « étape 3 » en 2016 et 2017 et recommandations Label EcoQuartier et biodiversité Evaluation de 7 EcoQuartiers Plan Local d'Urbanisme Commune de Brétigny-sur-Orge 2b- Justifications des choix et impacts sur l'environnement	Clause Ekopolis: EcoQuartier Clause-Bois Badeau
6	Cahier Des Charges En Vue De La Création De La Cite De La Gastronomie Dossier de candidature – La cité internationale de la gastronomie à Dijon – Présentation La cité internationale de la gastronomie à Dijon – Dossier de candidature – Compléments d'informations Partie 1 La cité internationale de la gastronomie à Dijon – Dossier de candidature – Compléments d'informations Partie 2 La cité de la gastronomie à Dijon Etude d'impact – Evolutions du projet Dijon Le projet de territoire Grand Sud PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 1–2–3–4–5–6–7–9 DOCUMENT PRINCIPAL PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 2–4–5 ANNEXES DOCUMENT PRINCIPAL PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 8 : ANNEXES PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 8 : NOTICE ASSAINISSEMENT PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 8 : NOTICE VRD PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 11 : GFA PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 14 : ETUDE D'IMPACT PERMIS D'AMÉNAGER Cité internationale de la gastronomie et du vin DIJON (21,000) PA 14 : EVALUATION APPROPRIÉE DES INCIDENCES	CIGV A.M.I. Réalisation du projet de la cité internationale de la gastronomie sur e site de l'hôpital général

Appendix C. Identified Urban solutions and their classification following the research criteria

#	Project	Solution	1. Goal	2.Type	3.Ecosystem component
1	Lloyd	Implementation of mixed conifer forest "patches" within the district through urban parks	Reinforce ecosystem structure	NBS	Biological structure
2	Lloyd	Create a green corridor connecting Sullivan's gulch to habitat "islands" within the study area	Reinforce ecosystem structure	NBS	Biological structure
3	Lloyd	Design of green corridor streets using understory and three-level vegetation	Reinforce ecosystem structure	NBS	Biological structure
4	Lloyd	Creation of rooftop gardens	Reinforce ecosystem structure	NBS	Biological structure
5	Lloyd	Creation of two pocket parks	Reinforce ecosystem structure	NBS	Biological structure

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#	Project	Solution	1. Goal	2.Type	3.Ecosystem component
6	Lloyd	Implementation of bioswales on the street corners	Reinforce ecosystem structure	NBS	Material flows
7	Lloyd	Stream Restoration along Sullivan's Gulch Wildlife Corridor	Reinforce ecosystem structure	NBS	Physical structure
8	Lloyd	Create the Sullivan's Gulch Wildlife Corridor	Reinforce ecosystem structure	NBS	Biological structure
9	Lloyd	Efficiency Upgrade on existing installations to reduce water consumption	Reduce pressure over the ecosystem	Technological	Material flows
10	Lloyd	Stormwater harvesting, detention facilities and treatment plant	Reduce pressure over the ecosystem	Technological	Material flows
11	Lloyd	Blackwater harvesting and treatment plant	Reduce pressure over the ecosystem	Technological	Material flows
12	Lloyd	Efficiency Upgrade on existing installations to reduce energy consumption	Reduce pressure over the ecosystem	Technological	Energy Flows
13	Lloyd	Efficiency by design strategies for new buildings - Water	Reduce pressure over the ecosystem	Urban code and policy	Material flows
14	Lloyd	Efficiency by design strategies for new buildings - Energy	Reduce pressure over the ecosystem	Urban code and policy	Energy Flows
15	Lloyd	Implementation of a district thermal sharing system	Reduce pressure over the ecosystem	Technological	Energy Flows
16	Lloyd	Installation of photovoltaic capacity	Reduce pressure over the ecosystem	Technological	Energy Flows
17	Lloyd	Installation of wind turbine capacity	Reduce pressure over the ecosystem	Technological	Energy Flows
18	Lloyd	Biogas production from waste processing	Reduce pressure over the ecosystem	Technological	Energy Flows
19	Lloyd	Purchase of wind power for 100% of imported electricity	Reduce pressure over the ecosystem	Technological	Energy Flows
20	Lloyd	Purchase of carbon offset credits for remaining imported fossil fuels	Reduce pressure over the ecosystem	Compensation	Material flows
21	Lloyd	Encourage urban agriculture at residential developments with raised planters on terraces	Both	Urban code and policy	Material flows
22	Lloyd	Implementation of vegetated plazas on open spaces	Reinforce ecosystem structure	NBS	Biological structure
23	Lloyd	Create pedestrian and bicycle-friendly streetscape using livability structures as benches, gathering spaces, playgrounds	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
24	Lloyd	Optimise solar access to all buildings and open spaces through a solar massing study and zoning changes	Reduce pressure over the ecosystem	Urban code and policy	Energy Flows
25	Lloyd	Preserve urban density near infrastructure by utilising as much of allowable FAR as possible, avoiding urban sprawling and reducing transport-related emissions	Reduce pressure over the ecosystem	Urban code and policy	Material flows
26	Lloyd	Implement a sustainable materials strategy to help the choice of high-performance materials, durable and with low maintenance (Use LCA as a tool for choice, reduce materials consumption, use renewable resources, upgradable components, materials that contribute to indoor air quality)	Reduce pressure over the ecosystem	Urban code and policy	Material flows
27	Lloyd	Source building materials from 500 miles only	Reduce pressure over the ecosystem	Urban code and policy	Material flows
28	Lloyd	Education program to reduce energy consumption	Reduce pressure over the ecosystem	Education	Energy Flows
29	Lloyd	On-site parking displacement to the underground, to release surface for the other strategies and facilitate modal shift	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
30	Lavasa	Masterplan and zoning developed using local ecosystem information aiming to protect green areas (landscape suitability analysis)	Reinforce ecosystem structure	Urban code and policy	Biological structure
31	Lavasa	Design of tiles shapes to collect rainwater and slow down runoff and facilitate evaporation	Reduce pressure over the ecosystem	Technological	Material flows
32	Lavasa	Construction of underground reservoirs tanks to manage and reuse rainwater	Reduce pressure over the ecosystem	Technological	Material flows
33	Lavasa	Design of a drainage system with radiating grooved earth dams to redirect water away in multiple directions	Reduce pressure over the ecosystem	Technological	Material flows
34	Lavasa	Design of infiltrations solutions (Nalla bunding, contour trenching)	Reduce pressure over the ecosystem	NBS	Material flows
35	Lavasa	Hydroseeding for erosion control through revegetation	Reinforce ecosystem structure	NBS	Biological structure
36	Lavasa	Rooflines designed to create wind turbulence and facilitate evaporation	Reduce pressure over the ecosystem	Technological	Material flows
37	Lavasa	Use of green roofs to manage rainwater and prevent soil erosion	Reduce pressure over the ecosystem	NBS	Biological structure
38	Lavasa	Application of polymer on the soil to slow down the erosion process	Reduce pressure over the ecosystem	Technological	Physical structure
39	Blatchford	Bioreactors for energy production based on organic waste recycling	Reduce pressure over the ecosystem	Technological	Energy Flows
40	Blatchford	District Stormwater collection using natural systems and low-impact development strategies (culverts -daylight streams)	Both	NBS	Material flows
41	Blatchford	District stormwater treatment using lake systems and water reuse	Both	NBS	Material flows
42	Blatchford	Restoration of native aspen parkland ecosystem through a green park	Reinforce ecosystem structure	NBS	Biological structure

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#	Project	Solution	1. Goal	2.Type	3.Ecosystem component
43	Blatchford	Urban zoning includes a major agricultural area	Both	Urban code and policy	Material flows
44	Blatchford	Geothermal energy production	Reduce pressure over the ecosystem	Technological	Energy Flows
45	Blatchford	Zoning for urban density increase	Reduce pressure over the ecosystem	Urban code and policy	Material flows
46	Blatchford	Transport orientated Development strategies to reduce CO ₂ emissions	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
47	Blatchford	Promote green ecological connectivity using furrows and stormwater gardens	Reinforce ecosystem structure	NBS	Biological structure
48	Blatchford	Prevision of climate-responsive built form with staggered blocks and windrows that break the dominant winds and allow for massing variation and sunlight	Reduce pressure over the ecosystem	Urban code and policy	Energy Flows
49	Blatchford	Waste management strategies and recycling using pneumatic systems	Reduce pressure over the ecosystem	Technological	Material flows
50	Blatchford	Green streets design	Reinforce ecosystem structure	NBS	Biological structure
51	Blatchford	Exigence for high-performance building envelopes on the masterplan and construction codes	Reduce pressure over the ecosystem	Urban code and policy	Energy Flows
52	Blatchford	Education program for sustainability and lower energy consumption	Reduce pressure over the ecosystem	Education	Energy Flows
53	Blatchford	On-site wastewater treatment system and wastewater reuse	Reduce pressure over the ecosystem	Technological	Material flows
54	Blatchford	Irrigation systems reusing rainwater	Reduce pressure over the ecosystem	Technological	Material flows
55	Blatchford	Reuse existing buildings for cultural and recreational uses	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
56	Blatchford	Design of a walkable community - Active transportation strategies to reduce CO ₂ emissions	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
57	Clause	Renewable energy production for heating using wood biomass (partial production)	Reduce pressure over the ecosystem	Technological	Energy Flows
58	Clause	Design for active mobility - pedestrian streets, bike lanes, near local train network station	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
59	Clause	Bioclimatic design prescriptions for construction phase - optimisation of solar inputs, massing and building design	Reduce pressure over the ecosystem	Urban code and policy	Energy Flows
60	Clause	Design of a main park, recreating local ecosystem and linking the project to local green network and creating diversity of habitat for identified local species	Reinforce ecosystem structure	NBS	Biological structure
61	Clause	Design for high urban density and mixed-use zoning	Reduce pressure over the ecosystem	Urban code and policy	Material flows
62	Clause	Collective gardens	Reinforce ecosystem structure	NBS	Biological structure
63	Clause	Private gardens	Reinforce ecosystem structure	NBS	Biological structure
64	Clause	Transversal parks/alleys	Reinforce ecosystem structure	NBS	Biological structure
65	Clause	Green streets design	Reinforce ecosystem structure	NBS	Biological structure
66	Clause	Bioswales to manage rainwater on the surface and reuse for irrigation	Both	NBS	Material flows
67	Clause	Reuse local soil during the construction phase	Reduce pressure over the ecosystem	Technological	Material flows
68	Clause	Partial energy production on buildings using solar panels	Reduce pressure over the ecosystem	Technological	Energy Flows
69	Clause	Car parking reduction and car-sharing strategy	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
70	Clause	No phytosanitary products allowed on the green area management	Reduce pressure over the ecosystem	Urban code and policy	Material flows
71	Clause	Elaboration of design prescriptions to integrate biodiversity at the building/plot scale (mostly flora)	Reinforce ecosystem structure	Urban code and policy	Biological structure
72	Clause	Elaboration of design prescriptions to assure building energetic performance	Reduce pressure over the ecosystem	Urban code and policy	Energy Flows
73	Clause	Elaboration of design prescriptions to assure high water use performances on buildings	Reduce pressure over the ecosystem	Urban code and policy	Material flows
74	Clause	Soil unsealing	Reinforce ecosystem structure	Urban form and infrastructure	Physical structure
75	Clause	Utilisation of three states of vegetation and local species whenever possible, creating complex ecosystems	Reinforce ecosystem structure	NBS	Biological structure
76	Clause	Prescriptions to avoid PVC and prefer wood structures in buildings	Reduce pressure over the ecosystem	Urban code and policy	Material flows
77	Clause	Creation of a green network connecting to a local park (Jonc marins)	Reinforce ecosystem structure	NBS	Biological structure
78	Paddock	Active mobility infrastructure (walking paths + bike parking)	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
79	Paddock	Collective food gardens and orchards	Both	NBS	Material flows
80	Paddock	Wetlands design	Reinforce ecosystem structure	NBS	Physical structure
81	Paddock	Design of native gardens		NBS	

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#	Project	Solution	1. Goal	2.Type	3.Ecosystem component
82	Paddock	Design of energy-efficient buildings (insulation, isolation on wall and windows)	Reinforce ecosystem structure Reduce pressure over the ecosystem	Technological	Biological structure Energy Flows
83	Paddock	Use of local materials and reused wood for buildings construction	Reduce pressure over the ecosystem	Technological	Material flows
84	Paddock	Use of materials that are safe for human health and ecosystems	Reduce pressure over the ecosystem	Technological	Material flows
85	Paddock	100% Solar energy with smart grid	Reduce pressure over the ecosystem	Technological	Energy Flows
86	Paddock	Rainwater collection on roofs and storage for reuse	Reduce pressure over the ecosystem	Technological	Material flows
87	Paddock	On-site composting	Reduce pressure over the ecosystem	NBS	Material flows
88	Paddock	Private gardens	Reinforce ecosystem structure	NBS	Biological structure
89	Paddock	Biophilic approach on buildings to improve air flows and natural lighting	Reduce pressure over the ecosystem	Urban form and infrastructure	Energy Flows
90	Paddock	Use of native species of flora on green areas	Reinforce ecosystem structure	NBS	Biological structure
91	Paddock	CO2 offset for project embodied carbon	Reduce pressure over the ecosystem	Compensation	Material flows
92	Paddock	Link project green area with the outside green network	Reinforce ecosystem structure	NBS	Biological structure
93	Paddock	Wastewater treatment plant	Reduce pressure over the ecosystem	Technological	Material flows
94	Paddock	Bioswales for stormwater management	Both	NBS	Material flows
95	Paddock	Reuse of greywater on garden irrigation	Reduce pressure over the ecosystem	Technological	Material flows
96	Paddock	Fixtures to assure low energy consumption on buildings and urban space	Reduce pressure over the ecosystem	Technological	Energy Flows
97	CIGV	Walkable district design (Human scale and active mobilities without parking)	Reduce pressure over the ecosystem	Urban form and infrastructure	Material flows
98	CIGV	Use of diverse vegetation schemes with local species	Reinforce ecosystem structure	NBS	Biological structure
99	CIGV	Bioswales all the long of pathways to manage rainwater	Both	NBS	Material flows
100	CIGV	Design of a humid zone using natural topography (V-shaped garden)	Reinforce ecosystem structure	NBS	Physical structure
101	CIGV	Protection of semi-dense vegetated area (EBC)	Reinforce ecosystem structure	NBS	Biological structure
102	CIGV	Ornamental gardens	Reinforce ecosystem structure	NBS	Biological structure
103	CIGV	Vegetable gardens	Both	NBS	Material flows
104	CIGV	Living "fences" associated with bioswales to delimitate the separation amongst public and private areas	Reinforce ecosystem structure	NBS	Biological structure
105	CIGV	Low impact transitions between private and public space avoiding barriers and topography alterations	Reduce pressure over the ecosystem	Urban form and infrastructure	Physical structure
106	CIGV	Grass covered paving	Both	NBS	Material flows
107	CIGV	Artificial bird nests	Reinforce ecosystem structure	NBS	Physical structure
108	CIGV	Connection to municipal heat network	Reduce pressure over the ecosystem	Technological	Energy Flows
109	CIGV	Green roofs	Reinforce ecosystem structure	NBS	Biological structure
110	CIGV	Waste management strategies and recycling using voluntary segregation systems	Reduce pressure over the ecosystem	Technological	Material flows

Appendix D. Identified strategies on each case study

Class	Subclass	Strategy family	Total	1. Lloyd	2. Lavasa	3. Blatchford	4. Paddock	5. Clause	6. CIGV
Energy Flows	Electricity	1.On site renewable energy production	9	4	*	2	1	2	*
		2.Reduction of energy consumption	8	3	*	2	1	*	
	Heat and light	3.Optimisation of solar input on buildings	4	1	*	1	1	*	
		4.Opmisation of on-site heat and energy transfers	2	1	*	*	*	1	
Material Flows	Water	5.Reduction of on-site water consumption	3	2	*	*	*	*	
		6.Onsite stormwater management (reuse/drinking)	6	1	1	2	2	*	
		7.Onsite stormwater management (infiltration/ evaporation)	11	1	5	1	1	1	2
		8. On-site wastewater management	3	1	*	1	1	*	*
	Building materials	9.Reuse demolition materials	1	*	*	*	*	1	*

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	10.Reuse existing buildings and infrastructure (renovation)	1	*	*	1	*	*	*
	11.Use building materials with low impact on human/ecosystem health	3	1	*	*	1	1	*
Carbon	12.Source building materials locally	2	1	*	*	1	*	*
	13.Offset CO2 embodied emissions - building phase	1	*	*	*	1	*	*
	14.Offset CO2 emissions - using phase	1	1	*	*	*	*	*
	15.Promotion of urban densification	3	1	*	1	*	1	*
	16.Design for Transit-orientated development (TOD)	1	*	*	1	*	*	*
Food	17.Design for active and low carbon urban mobility	7	2	*	1	1	2	1
	18. On-site food production in small scale (education)	3	1	*	*	1	*	1
	19. On-site food production in large scale (for local food provisioning)	1	*	*	1	*	*	*
Chemical products	20.Phytosanitary products restrictions	1	*	*	*	*	1	*
Waste	21. On-site organic waste management	1	*	*	*	1	*	*
	22.Recycling and waste management	2	*	*	1	*	*	1
	23.Water body restoration	1	1	*	*	*	*	*
Physical structure	24.Water body design	2	*	*	*	1	*	1
	25.Erosion control	2	*	2	*	*	*	*
	26.Avoid soil sealing	1	*	*	*	*	1	*
	27.Avoid topography changes	1	*	*	*	*	*	1
	28.Design artificial abiotic habitat structures	1	*	*	*	*	*	1
Biological structure	29.Design of major green area using native species	3	1	*	1	*	1	*
	30.Protect existing vegetation area	2	*	1	*	*	*	1
	31.Green streets design	3	1	*	1	*	1	*
	32.Design of in-building vegetation	3	1	*	*	*	1	1
	33.Promote connection with local green network	3	1	*	*	1	1	*
	34.Design of minor public green areas	9	3	*	1	1	2	2
	35.Design of minor private green areas	2	*	*	*	1	1	*
	36.Use of complex vegetation schemes	3	*	*	*	1	1	1

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