Ecosystem Services Delivery in the Built Environment

Gaining a better insight into integration and assessment of green design solutions in buildings

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Preface

With a lot of enthusiasm and interest I have completed a Bachelor's degree in Biology focussed on Cell and Developmental Biology, at Utrecht University. After completing this degree I realised that I wanted to switch paths and contribute my education and future work to solving the current ecological crisis. With this motivation I started the Research Master Bio Inspired Innovation at Utrecht University.

I am very grateful for having met my current Master coordinator and Major Research Project examiner Jaco Appelman. He gave me the opportunity to do a research project on a topic I had no educational background in, but had my profound interest, being the topic of ecosystem services in the built environment. Together with the daily supervisor of my research project, Katharina Hecht, they gave me the experience of working in a healthy and therefore inspiring work environment. I am very grateful for this. I also want to thank Katharina for her clear and motivating feedback sessions each week. The feedback sessions helped me to stay confident about my own work, stay on track with the challenging research project, and develop new research skills.

I had a great time together with my fellow Master's student Leanne Haan, for which I want to thank her. It was really nice to explore together the new realms of performing your own first larger research project.

During the process of my research project I interviewed several people to gain background information and inspiration for further research. I want to thank Catalina Bustillo, Bonnie Chopard, Christine Lintott, Alex Ziegler, Real Estate and Campus Utrecht University, and the people of the military base in Amersfoort for their time and efforts.

Doortje Krekel
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Abstract

The concept of ecosystem services (ES) delivery can be used for the development of net-positive buildings, by integrating 'green' design solutions that deliver these ES. Indicators are used to measure the degree of ES delivery by the chosen design solution. Indicators to quantify ES in the biological context exist, however only a few have been translated to the building context. This research tries to develop knowledge that contributes to the completion of the indicator set for the building context. The biological structures and processes that deliver ES in the ecological environment are identified through a literature review and translated to the built environment. Indicators for the built environment are proposed based on these results and existing indicators for the ecological environment. Also, a new framework is proposed to describe the ecological system (Boerema *et al.*, 2017a) behind ES delivery. Based on this refined understanding of ES delivering infrastructures this research concludes that it is possible to formulate better indicators for the ecological environment and verify new indicators for the built environment. As a final step methodological triangulation, based on an interview and a literature review, was performed to verify the relevance and setup of a table proposed for communication of the knowledge developed in this research.

Layman's summary

In nature animals, plants, the soil, the atmosphere and water interact, forming an ecosystem. The interactions lead to the supply of, among other things, clean water to drink, food to eat, clean air to breath, and beautiful scenery to enjoy. The supply of these so called ecosystem services supports human lives. Current human activities destroy and pollute ecosystems. For example, much land is cleared to enable the construction of buildings. This threatens the ecosystem services supply. It is desirable that buildings will contribute to nature by also delivering ecosystem services. Many design solutions for buildings exist that facilitate this. Still, it is often unclear which specific ecosystem services these design solutions facilitate and how much. Indicators to measure ecosystem services in the biological context do exist, but not so many of these indicators have been translated to be used in the building context. The aim of this research is to complete the set of indicators for the building context.

In the first research step several lists of ecosystem services coming from different sources were compared. Not all scientific reports use the same list of ecosystem services, making it useful to understand their differences. In the second research step it is assessed which ecosystem services are already partly addressed via the requirements of sustainable building certification programmes. This creates an understanding of which ecosystem services are probably already partly delivered in buildings labelled sustainable.

For the third research step scientific articles or books were consulted to determine which parts of nature and the interactions between the parts contribute to delivering each of the ecosystem services defined in one of the lists. Next, it was determined how each part and the interactions between the parts could be mimicked in a building. There were three options: 1. Mimicking is not possible, this part of nature should be placed inside or on a building, 2. Design solutions can facilitate the desired interaction between these parts, or 3. The parts or interactions can be fully mimicked by design solutions. The results made it finally possible to also mimic the indicators found in scientific literature for measuring ecosystem services in the biological context, to measure the parts of nature or design solutions that deliver ecosystem services in a building.

The report also includes two other research items. The first item is a new description, also called a framework, of the ecosystem services and the ecosystem that delivers them, known as the ecological system. The framework describes how the aforementioned parts of an ecosystem can be grouped into 4 categories, each representing a stock; biosphere, lithosphere, hydrosphere and atmosphere. The framework also defines flows within and between stocks, which are the interactions between the parts. Finally, the

report proposes a means of communication for the results of this research to people involved in development of net-positive buildings, being a table including: questions, indicators, and requirements. The questions are meant to help persons developing a building to choose the right design solutions. The indicators are questions about the designs. The requirements are the required answers to the indicators. The design solutions should comply to these in order for ecosystem services to be delivered enough. An interview has been conducted and literature has been consulted to verify that the proposed set up of the table would work.

Glossary

Definitions of terms as used in this report. The definitions are either formulated specifically for this report or retrieved from a literature source.

Biological context	The biological realm as the setting.
Building context	A building as the setting.
Built environment	The human-made surroundings that provide the setting for human activity (adapted from Kaklauskas & Gudauskas, 2016).
Design equivalents for the built environment	A description of characteristics of a design solution for the built environment, that could provide similar characteristics as the structure or process delivering ES in the ecological environment.
Design solution	A design that fulfils a purpose.
Double-counting	Valuation of ES would result in counting the value of the benefits coming from nature more than once, as it is believed that individual ES defined in the MEA (2005) report overlap (Fu *et al*., 2010).
Ecological environment	The not human-made surroundings. Human activity may take place here. See Built environment.
Ecosystem	The complex of living organisms, their physical environment, and all their interrelationships in a particular unit of space (Britannica, 2021).
Ecosystem disservices	The result of ecological functioning that negatively impacts human health and/or well-being (adapted from Lyytimäki and Sipilä, 2009).
Ecosystem function	See Flow (Boerema *et al.*, 2017a).
Ecosystem property	Biophysical structure or stock (Potschin & Haines-Young 2011), see Structure, see Stock.
Ecosystem services	The benefits humans obtain from ecosystems, affecting human health and/or well-being (adapted from MEA, 2005)
Ecological system	The ecosystem properties and functions as a whole, see Ecosystem function and Ecosystem property (adapted from Boerema *et al.*, 2017a).
Flow	Material or energy stream from one stock to another (adapted from Constanza *et al.*, 1998), see Stock.

Framework	Textual structure in which keywords and definitions are organised (adapted from Oxford University, 2021a).
Indicator	An observed value representative of a phenomenon of study (EEA, n.d.).
Mimicking	The performance of a process by a substitute structure.
Nature	The phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to human creations (Oxford University, 2022).
Net-positive	When something has more positive than negative impact on its surroundings (adapted from Balch, 2013).
Process	The interaction between structures (see also Haines-Young & Potschin, 2010).
Regenerative design	Designing and developing the built environment to restore the capacity of ecosystems to function at optimal health for the mutual benefit of both human and non-human life (Pedersen Zari, 2018, p. 5).
Sustainable design	Implying a direction of improvement in design, i.e. continual improvement towards a generalized ideal of doing no harm, with an emphasis on reaching a point of being able to sustain the health of the planet's organisms and systems over time (Reed, 2007).
Stock	Collection of material (adapted from Costanza *et al.*, 1998). In this report 4 main stocks are defined: biosphere (all animals and plants), lithosphere (all the soil and rocks), hydrosphere (all the water on the planet) and the atmosphere (all the gasses and pollutants in the air) (adapted from Kumar & Mina, 2021, p. 43).
Structure	The physical parts out of which something is made up (see also Haines-Young & Potschin, 2010).
Urban environment	The area related to a town or city (adapted from Oxford University, 2021b).

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Introduction

This report describes research conducted around the topic of ecosystem services (ES) in the built environment. ES are defined as the benefits humans derive from nature (MEA, 2005). De Groot *et al.* (2002) describe how healthy ecosystems, including the presence of bio-geochemical (material) cycles and other biospheric processes, should be in place to facilitate the regulation of essential ecological processes and life support systems, the presence of refuge and reproduction habitat for organisms, the creation of biomass, and a fourth category of immaterial functions. The facilitation of these functions enables the provisioning of ES. This makes it clear that an ecological structure, or in abstract terms an infrastructure, needs to be in place in order for the ES to be provided. Throughout the years several typologies have been defined identifying individual ES (see Ehrlich & Ehrlich, 1981; Costanza *et al.*, 1998). Some of these typologies even categorise the ES into different groups, forming ES frameworks (see MEA, 2005; TEEB, 2010; Haines-Young, R., & Potschin, M., 2010).

Ecosystem services in the Building Context

In the current ecological crisis ecosystems are threatened (Walther, 2002), affecting their capacity to deliver these ES. The built environment is a great contributor of pressure on the ecosystems (Grimm *et al.*, 2008): Constructions take up space originally occupied by vegetation and other ecological elements, and obstruct waterways. Many greenhouse gasses are emitted in cities. Via its pressure on ecosystems the built environment also creates many disservices for humans, negatively affecting human health and well-being. On the other hand, in current construction practises buildings deliver benefits to humans by providing shelter and a place to live, work or meet other people. There is much to gain if buildings can be designed to provide (ecosystem) services and disservices are reversed. This leads towards net-positive buildings. Net-positive means that a building has more positive than negative impacts on its occupants and surroundings. This report builds on the understanding that this can be done by introducing ES delivery into the built environment through ES delivering designs. This practise can be combined with other sustainable building practises like nature inclusive design or the use of recycled materials to possibly increase the mitigation effect.

Many so called ‘green’ design solutions exist, having the potential to deliver ES in a building (Pedersen Zari & Hecht, 2020). However, it is not always clear which ES such designs deliver, to what extent and what the effect is of combining several design solutions. One way to gain more inside into this is by assessing ES delivery using indicators. However, only a few indicators for the built environment already exist

(Betzler, 2016). Even for the ecological environment, although many indicators are already used for ES assessment, an adequate set of indicators, standardised and uniting different approaches, has yet to be defined (Maes *et al.*, 2016). This report introduces a conceptual infrastructure for ES delivery in a building, based on the infrastructure behind ES delivery in a biological context. This understanding of how ES can be delivered in the built environment facilitates the definition of indicators for ES assessment in this context. It also gives clues on which 'green' designs can be combined to form one of possibly multiple conceptual ES delivering infrastructure setups in a building. To communicate these clues a tool for integration and assessment of ES delivery in a building is proposed in this report. The tool is a tabular structure meant to support the development of an ES delivering, and in that way net-positive, building. It includes questions to guide the design process and indicators with corresponding required values to ensure a correct setup of each part of an ES delivering infrastructure. A first set of indicators for ES delivery assessment in the built environment is proposed in this report. The proposed indicators are based on the conceptual ES delivering infrastructure and indicators for ES assessment in the ecological environment defined in literature. The research process also led to the formulation of a new framework describing the ecological properties and functions related to ES delivery, also known as the ecological system (Boerema *et al.*, 2017a). This framework has the potential to support a more adequate assessment of ES delivery in both the biological and building context.

In summary, the results presented in this report support a better understanding of how ES are delivered in the biological and building context and the integration and assessment of ES delivery in buildings. By integrating ES delivery into buildings they can become net-positive, contributing to ecological health and human health and well-being.

Defining scope of ecosystem services

The scope of this research are individual buildings, instead of the whole built or urban environment. The proposed ES delivering infrastructure is therefore applicable for individual buildings only. An urban ES delivering infrastructure would differ as multiple buildings are connected to it.

Many reports related to the topic of ES delivery talk instead about ES provisioning. For this report the choice has been made to use the term delivery to emphasize the difference between ES delivery and the ES category Provisioning Services (MEA, 2005; TEEB, 2010; Boerema *et al.*, 2017a).

The ecological infrastructure delivering so called "Cultural Services" (MEA, 2005) or a category of immaterial ES alike, will not be assessed in this report (except for Step 1). This choice is based on the understanding that Cultural Services are not only derived from nature, but also need human interaction with nature in order to be delivered, if not indirect (Pearsall, 1984). This makes it difficult to assess which components in the ecological ES providing infrastructure deliver the Cultural Services, something which is required for making the translation of the ecological ES delivering infrastructure to the built environment via the methods discussed in this report. ES in the category of "Provisioning Services" also need human interaction with nature in order to be harvested, but as these are material goods, it is possible to assess the degree of potential Provisioning Services delivery by the ecological or building infrastructure delivering them. From the biological context ES are described for both aquatic and terrestrial systems. As buildings are usually terrestrial, the scope of this research is limited to translating terrestrial ES to the building context. Therefore, ES delivering structures and processes of terrestrial ecosystems only have been defined and translated to the building context.

Research approach and research questions

As mentioned before, there exists a knowledge gap in research and industry regarding the assessment of ES delivery in buildings. For this reason this research aimed to address the following main research question: **How can ecosystem services be quantified in the building context?** This was done by performing design-led research. The research led to the development of concepts that support a possible future tool which can support researchers and building professionals to integrate and assess ES in buildings.

The aim of the first step was to validate whether there is enough consensus between existing ES typologies to be able to use the concept of ES as a standardised format for translation to the built environment. Depending on the degree of consensus a revised ES typology could be created bringing the various existing angles of the typologies together to one. Therefore, the following sub-question was answered: **1. What are the discrepancies between existing ecosystem services typologies?**

The second step was taken to assess whether the services covered by the ES typologies were already addressed through Sustainable Building Certificate Programmes. This, to verify that the concept of ES has a potential to contribute to the development of a net-positive built environment. This was done by researching the following sub-question: **2. Which ES are already (partly) addressed in common Sustainable Building Certificate Programmes?**

ES have largely not yet been assessed in the built environment, mainly because not enough indicators for ES assessment in the built environment do yet exist. The third research step was performed to tackle the perceived underlying cause of this problem which is a missing scientific understanding of what delivers ES in a building. Therefore, the following sub-question was addressed: **3. Which biophysical structures and processes deliver ecosystem services in the ecological environment?**

Step 4 was performed in tandem with step 3. The aim of step 4 was to determine which indicators are used to assess ES delivery in the ecological environment. The following sub-question was answered: **4. Which indicators are used to assess ES delivery in the ecological environment?**

The results of step 3 allowed the translation of the elements and processes that provide ecosystem services in the ecological environment to the built environment. This was done in step 5. In step 5 the following sub-question was addressed: **5. How can the biophysical elements and processes that provide ecosystem services in the ecological environment be translated to the built environment?** The results to this sub-question give an understanding of the elements that are required for ES delivery and what the built environment equivalents could be. This then led to the design of a conceptual ES delivering infrastructure for a building.

Step 6 was performed in tandem with step 5. The results of step 4 and 5 allowed the translation of these indicators for ES assessment in the ecological environment to the built environment. Therefore, step 6 addressed the sub-question: **6. Which indicators could be used to assess ES delivery in the built environment?**.

The combined generated understanding of ES typologies and ES delivery in this research led to the proposal of a new framework describing the ecological system of ES delivery (Boerema *et al.*, 2017a). This was done in research step 7.

The 8th and last step of the research was an effort to answer the research sub-question: **7. How can the results of this research project be communicated to building professionals wanting to integrate ecosystem services delivering designs in and on new buildings?** It led to the proposal of a table that guides the assessment and integration of ES delivery in a building. The table includes design guidelines, indicators and requirements. The relevance and setup of this table was verified through the process of methodological triangulation.

The action-led research approach is described in Chapter 2 Methodology. In Chapter 3 Results the research results and design deliverables are presented. In Chapter 4 Discussion and Chapter 5 Conclusion will be reflected on the results and their implications. Finally suggestions on Future Research will be proposed in Chapter 6 Future Research.

Methodology

The design-led research was divided into three phases. The research led to the development of several concepts related to the assessment of ecosystem services in buildings. For each phase the steps taken and the underlying motivation for each step are described in the methodology. An overview of the different phases, steps, and research questions answered is depicted in Figure 1.

1. The Theoretical framework phase encompasses research sub-questions 1 and 2. The aim of this phase was to create a broader theoretical understanding of the current state of ES assessment in the biological and building context and ES delivery in the building context. For these purposes systemic literature reviews have been performed: Existing ES typologies have been reviewed and revised and the prevalence of ES in building requirements of sustainable building certification programmes has been assessed.
2. The Translation phase covered research sub-questions 3, 4, 5, and 6. The aim of this phase was to generate concepts that support the development of a possible future tool for ES assessment in buildings. In the Translation phase the ecological structures and processes delivering ES and the indicators for ES assessment in the ecological environment, have been translated to the built environment. The results of the steps in this phase are based on the ES typology defined by Pedersen Zari (2018).
3. The Adaptation phase includes research step 7 and research sub-question 7. The results of the second phase led to the development of two more concepts. The first concept is the proposal of a new framework which describes both ES delivery and ecological functioning. The second concept gives some recommendations for science communication on the topic of ES delivery in the built environment.

Phase 1 includes research steps 1 and 2. Phase 2 includes research steps 3 to 6. Phase 3 includes research steps 7 and 8. The ES typology defined by Pedersen Zari (2018) has been used as reference typology in steps 2 to 6. In steps 7 and 8 this typology has been used as part of the theoretical framework on which the results are based. There are two reasons for using the Pedersen Zari (2018) ES typology in this research. 1. The Pedersen Zari (2018) typology is very similar to the revised typology defined in step 1 (see Figure 2). 2. ES sub-categories are defined in the Pedersen Zari (2018) typology. This allows in step 3 for a more detailed identification of structures and processes that in the ecological environment deliver ES. To use the same typology consequently in the entire report, the typology is also used in steps 4 to 6 and as a theoretical basis for steps 7 and 8.

Phase 1 – Theoretical framework

Step 1: Revision of current ecosystem services typologies

Before applying the ecosystem services concept to the building context, first the major existing ES typologies were analysed by means of a systematic literature review to find discrepancies between them. The results were then used to create a single ES typology. Analysing ES typologies allows identification of major points of debate around the defining of ES, knowledge that has been used in later steps of this research. Creating a revised ES typology based on analysing discrepancies between existing ES typologies, should allow results of future ES research in the building context to be better comparable with results from ES research in the biological context for which any of the in this report analysed typologies has been used.

Six ES typologies have been compared; Ehrlich & Ehrlich (1981), Costanza *et al.* (1997), MEA (2005), TEEB (2010), Haase *et al.* (2014), and Boerema *et al*. (2017b). The first typology comes from the book by Ehrlich & Ehrlich (1981), which is one of the first publications where the term "ecosystem services" has been used. The second typology comes from Costanza *et al.* (1997), which is the first publication that tried to calculate the total economic value of ES on the entire planet Earth. The second and the third typologies, MEA (2005) and TEEB (2010), are the first to categorise the typology in a framework. The purpose of the TEEB (2010) framework is specifically for economic valuation of ES. The fifth typology, Haase *et al.* (2014), is based on a literature review on ES assessment in the urban environment. The sixth typology, Boerema *et al.* (2017b), is a typology based on a literature review that covered all publications describing an ES assessment.

For the analysis all defined ES of each typology were compared, focussing on whether there exists an overlap between the names and the definitions of each individual defined ES. The names and the definitions of each ES used in each ES typology were obtained from the six abovementioned scientific publications introducing the individual typologies. To start the analysis the names of all the ES defined in the oldest ES typology, were listed in a table column. Next, the names of the ES defined in the second oldest ES typology were listed in a new column added to the table to the right, in the same row of the ES defined in the oldest ES typology in case the definitions of these ES overlapped. In case the definition of an ES of the newer ES typology did not overlap with one ES defined in the oldest typology, a row was added. A row was also added to include possible new or different categorisation headers. This approach was repeated with all the ES typologies analysed, from oldest to newest. In the end all the identified ES were combined, creating a revised ES typology. The ES names for the revised typology were based on the most common name for each ES between the six reviewed typologies. The

ES names for which this was not possible were based on the ES names used in the oldest typology of the six that included the ES.

Haines-Young and Potschin (2010) have introduced a cascade model to describe the delivery of an ES. The cascade consists of several phases. It can be that the definition of an ES by one of the typologies describes one or several phases of a specific cascade and the definition of an ES by the same or one of the other typologies describes one or several other phases of that same cascade. This can not be identified using the research approach of step 1. The research approach of step 1 also does not allow an identification of services supplied by ecosystems which are not yet described in the analysed ES typologies. These limitations are accepted as this approach does lead to the formation of a typology that allows comparison of research results based on this typology and any of the analysed ES typologies.

Step 2: Assessment of which ecosystem services are covered by Sustainable Building Certificate Programmes for the building context

Some principles behind some of the ecosystem services have already been included in existing sustainable building practices. To find out which ES are already (partly) dealt with in standardised sustainable building practices a literature review has been performed analysing the building requirements of several sustainable building certification programmes for new buildings, as published on the website of each programme. The analysed programmes have been selected based on their aspirations for buildings to make their surroundings a better place and based on a focus that covers a broader set of topics than only energy and water. Certification programmes can publish country specific versions of their requirements. If this was the case, the Netherlands specific version of the programme was chosen for the assessment performed in research step 2. The assessed certification programmes were: LBC 4.0 v13 (New Building) (International Living Future Institute, 2019), LEED v4.1 (Building Design and Construction) (U.S. Green Building Council, 2021), BREEAM-NL (Nieuwbouw 2020 v1.0) (Dutch Green Building Council, 2020), WELL v2 (International WELL Building Institute, 2020).

For the analysis, the descriptions of the building requirements of each certification programme were compared with the descriptions of ES as formulated by Pedersen Zari (2018). If their topics at least roughly overlapped, than this would count as a positive result and was noted down. The criterium of only needing a rough overlap between definitions made this a quick and dirty way of analysis. However, it allowed for a very clear determination of the ES that are left completely untouched when applying these certification programmes in building development.

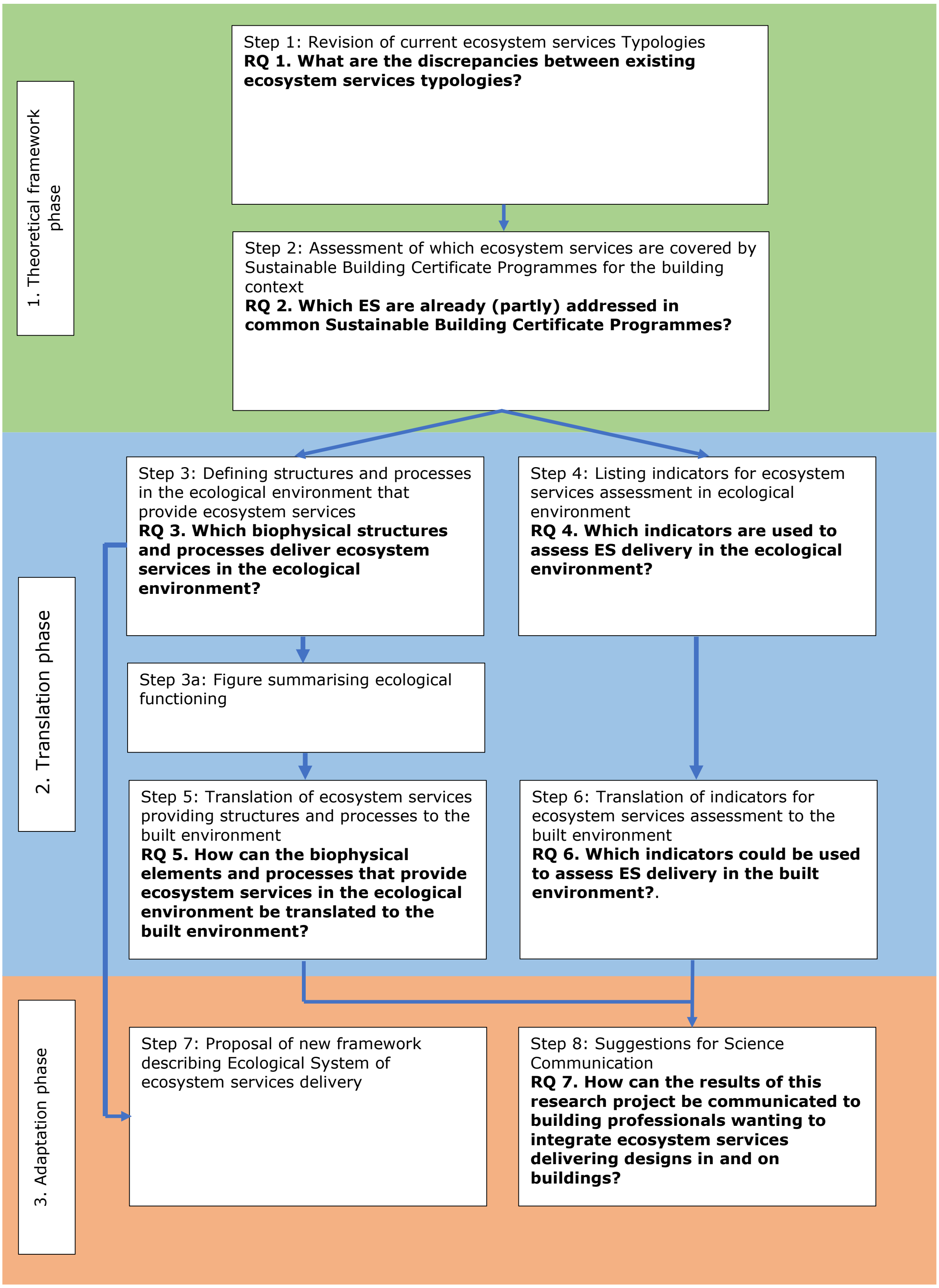

Figure 1. Timeline of research project, indicating research phases, research steps and research questions (RQ) answered. The blue arrows indicate which research question is answered using the results of the previous research step.

Phase 2 – Translation

Step 3: Defining structures and processes in the ecological environment that provide ecosystem services

The following two research gaps exist: 1. A lack of understanding how ES can be delivered by a building and 2. A lack of understanding how the ecological performance of ES deliverance by a building can be quantified. To address these two research gaps it should be determined what the characteristics of (bio)physical structures or processes are which deliver ES in a building context. In order to determine this, two consecutive research steps were taken, described here as step 3 (and 3a) and step 5.

For step 3 a systemic literature research has been performed to determine which (bio)physical structures or processes in a biological context deliver each ES listed in the Pedersen Zari (2018) typology. The typology of the Boerema *et al.* (2017) report has been aligned to the Pedersen Zari (2018) typology as a second reference typology. This typology has been chosen for comparison as it listed 21 ES selected based on 19 key reviews and meta-analyses of ES measures and indicators, regardless of which ES typology has been used. Literature review sources were scientific articles and (study) books on the topics of ecology, biology, environmental physics and biomimicry, describing ES or their underlying (bio)physical structures or processes, and functions. The results were summarised in a table, using keywords.

Step 3a: Figure summarising ecological functioning

Step 3 led to a list describing the structures and elements delivering ES in the ecological environment. The results allowed the creation of a figure summarising the current understanding of ecosystem functioning. In agreement with Costanza *et al.* (1997) it depicts an ecosystem consisting of stocks and flows. This summary has later in the research been used to base the design of the ES delivering infrastructure for a building on.

Step 4: Listing indicators for ecosystem services assessment in ecological environment

To create a reference list of indicators for ES delivery assessment in the ecological environment, a review has been selected that had selected single indicators for each individual ES. The review of Maes *et al.* (2016) was appropriate for this, as it had based the selection on an information quality review of many indicators currently used for ES assessment research in the EU. As Maes *et al.* (2016) have organised their data according to the multi-level CICIES (Haines-Young & Potschin, 2013) typology, the indicators selected were reorganised to match the equivalent ES from the Pedersen Zari (2018) typology. ES in table 3 in the Maes *et al.* (2016) report are described at the class or group level of the CICES typology (hierarchy: group > class). For the reorganisation the indicators were linked to the ES from the Pedersen Zari (2018) typology that corresponded with the 2013 CICES v4.3 group level description (European Environment Agency, 2021). The reference list has later been used in the research to formulate indicators for ES assessment in the built environment.

Step 5: Translation of ecosystem services providing structures and processes to the built environment

The results of step 3 and the summary of ecological functioning from step 3a led to the conceptual design of an ES delivering infrastructure for a building. First, the ecological structures and processes defined in step 3 were translated to design equivalents for the built environment. This has been done by describing the characteristics of a design solution for the built environment that could provide similar functions as the structure or process delivering ES in the ecological environment. This does involve the demand side of ES delivery, as the goal is to set up an ES delivering infrastructure that meets the demands of the building inhabitants. Secondly, these results and the principles behind ecological functioning were used to connect the different ES delivering structures and processes for a built environment to illustrate a conceptual ES delivering infrastructure for a building. This research approach follows the principles of biomimicry; mimicking shapes, processes and systems form nature to come to a regenerative design (The Biomimicry Institute, n.d.), and thus is based on a proven methodology.

Step 6: Translation of indicators for ecosystem services assessment to the built environment

The reference list of indicators for ES delivery assessment in the ecological environment from the Maes *et al.* (2016) report, as formulated in step 4, the indicators listed by Boerema *et al.* (2017b), and the list of structures and processes for ES delivery in the built environment, as formulated in step 5, were used to formulate indicators for ES delivery assessment in the built environment. Based on the results from step 4 and 5 and the Boerema *et al.* (2017b) report it has been determined what should be measured and what could be measured in the built environment, and thus how the indicators should be formulated. The Boerema *et al.* (2017b) report has been included, as it listed all the indicators used in all scientific papers explicitly assessing ES.

Phase 3 – Adaptation

Step 7: Proposal of new framework describing Ecological System of ecosystem services delivery

Working with existing ES typologies and frameworks during this research led to the hypothesis that these frameworks and typologies are insufficient for an adequate assessment of ES delivery in the ecological and built environment. This is confirmed by the statement in the Costanza *et al.* (1997) report saying that the infrastructure delivering ES is not but should be considered. Furthermore, too many different, and thus not strong, indicators have been defined per individual ES which also assess not all parts of the ES cascade equally much (Boerema *et al.*, 2017). Therefore, a consensus is missing which has to be defined (see results and discussion step 1).

Boerema *et al.* (2017) have proposed an ES framework describing an ecological system and a socio-economic system, urging that separately but both systems should be measured. The ecological system encompasses the ecosystem properties and ecosystem functions. Another way to describe the ecology of, and ecosystem services themselves is through the concepts of stocks and flows, where flows can transform or redistribute the stocks (Costanza *et al.*, 1997). Based on these understandings a new framework was developed, describing the ecological system using the concept of stocks and flows. To set up this framework the different stocks in nature were defined based on the results from step 3, subsequently categories have been defined based on the different ways flows can alter stocks. Stocks have been identified for the general biological context, not specifically for individual ES, to ensure that the framework describes all and not individual services.

Step 8: Suggestions for Science Communication

In step 7 indicators are proposed with the aim to allow for more insight in which ES are delivered by green designs, to what extent and what the effect is of combining several design solutions. This all has as purpose to choose the correct green designs in order for a building to deliver the desired ES. As a next step the indicators proposed in step 7 could be verified using case studies. Another approach to ensure the correct choice of green designs is by facilitating the implementation of the suggested conceptual setup of an ES delivering infrastructure for a new building. For research step 8 the decision is made to do the latter. Therefore, step 8 focussed on science communication.

In this step a suggestion has been formulated on how to communicate the scientific knowledge generated with this research project to actors involved in the development of ES delivering buildings. A table with guidelines, indicators and requirements was formulated. The goal was that a building infrastructure designed following the guidelines, matching the indicators and requirements, has similar characteristics as the conceptual design of an ES delivering infrastructure in a building proposed in this report. This will ensure that the infrastructure delivers the ES as defined by the Pedersen Zari (2018) typology. As a final step the guidelines, indicators and requirements have been divided into categories which are related to several ES, with the aim to create an intuitive understanding which parts of the infrastructure mainly contribute to the delivery of which ES.

Via methodological triangulation these suggestions and their relevance have been tested. A semi-structured interview has been conducted with a professional who has a combined background in architecture and biomimicry.

Choosing an interviewee with this background allowed asking questions that reflected on both the target group and the setup of the proposed table. Next to the interview, a scientific publication on negative feedback and a report on the psychology of sustainable behaviour have been consulted to complete the triangulation. No other interviews were analysed in this report.

As a preparation for the interview questions were formulated addressing the setup and relevance of the proposed table. During the interview the questions were either directly or indirectly addressed. The interview has been recorded. The recording was transcribed using the transcribing feature of Word Online 2019 and subsequently proofread manually. The protocol for analysing the interview was based on the protocol described by Van der Zee (2016). The transcript was divided into fragments of a few sentences long. Each fragment was then labelled with keywords indicating the topic, the same keywords were used for multiple fragments. All the keywords used were listed and grouped together into relevant categories. For each keyword, the core sentences from each fragment were listed together. Sentence fillers were left out. To gain an overview of the message belonging to each keyword a summary was made of the listed quotations. To gain an understanding of what were the answers to the formulated questions the summaries were pasted underneath the questions they answered. Summaries were only used once and not all summaries were used. The aforementioned scientific publication and report were used to perform a methodological triangulation, verifying one of the statements from the interviewee.

Results

Phase 1 – Theoretical framework

Step 1: Revision of current ecosystem services Typologies

The comparison of a total of 6 ES typologies (Ehrlich & Ehrlich, 1981; Costanza *et al.*, 1997; MEA, 2005; De Groot *et al.*, 2010; Haase *et al.*, 2014; Boerema *et al.*, 2017) revealed several quality differences between the typologies (see Appendix I).

Firstly, several typologies defined the same services, but differed in whether these services were defined as individual ES or sub-ES grouped under one ES. This was the case for services related to regulation of human diseases, and pest control, sometimes labelled as, or grouped together under, the ES Biological Control. The ES Raw Materials was in some typologies further specified into two individual ES related to fiber, and fuel. Also, not all typologies considered the water cycle part of the ES Nutrient Cycling, but defined it as an individual ES. For the ES in most typologies categorised under Cultural Services applied that many services appeared in most of the typologies, but were very often grouped together differently within the different typologies. These examples show a hierarchical problem addressed by the multi-level CICES typology (Haines-Young & Potschin 2010).

Secondly, there were several unique differences between the typologies. The MEA (2005) typology is the only one to include the category Supporting Services, as later typologies omit this category to prevent "double-counting" (Haines-Young & Potschin, 2010). Defined ES are believed to overlap and valuation of ES would thus result in counting the value of the benefits coming from nature more than once (Fu *et al*., 2010). The ES Life Cycle Maintenance defined in Boerema *et al.* (2017) had no clear equivalent within other typologies.

Also, not all typologies related waste treatment directly with the purification of water.

Lastly, Cultural Services related to social relations, mental and physical health, sense of place, and cultural diversity only appeared once between the several typologies.

The revised typology merges the points of view from the analysed ES typologies (see Appendix I). However, this revised typology is not used as a reference typology in upcoming research steps. Instead, the ES typology by Pedersen Zari (2018) has been used as a reference typology. As mentioned in the Methodology, there are two reasons for this choice. 1. The Pedersen Zari (2018) typology is very similar to the revised typology (see Figure 2). 2. ES sub-categories are defined in the Pedersen Zari (2018) typology. This allows for a more detailed identification of structures and processes that in the ecological environment deliver ES (see step 3).

	Revised typology	Pedersen Zari (2018)
Provisioning Services	Food	Food
		Human
		Forage
	Biochemicals	Biochemicals
		Medicines
		Other
	Raw materials	Raw materials
		Timber
		Fibre
		Stone
		Minerals/ores
	" (Raw materials)	Fuel/energy
		Biomass
		Solar
		Hydro
		Other
	Fresh water	Fresh water
		Consumption
		Irrigation
		Industrial processes
	Genetic resources	Genetic information
	Ornamental resources	
Regulating Services	Pollination	Pollination and seed dispersal
	Biological control, sub. Diseases, sub. Pests	Biological control
		Pest regulation
		Invasive species resistance
		Disease regulation
		Climate regulation
	Climate regulation	GHG regulation
		UV protection
		Moderation of temperature
		Moderation of noise
	Moderation of extreme events	Prevention of disturbance and Moderation of extremes
		Wind force mitigation
		/Wave force mitigation
		/Runoff force mitigation
		Mitigation of flood/drougth
	Erosion control	Erosion control

(Continues on next page)

(Continuing)

	Revised typology	Pedersen Zari (2018)
	Waste treatment, sub. Water purification	Decomposition Waste removal
	Air quality regulation	Purification Water /Air /Soil
	Water regulation	
Supporting (and Habitat) Services	Generation and Maintenance of soil	Soil Formation
	Primary production	Primary production
	Production of atmospheric oxygen through photosynthesis	Fixation of solar energy
	Nutrient cycling, sub. Water cycling	Nutrient cycling Regulation of biogeochemical cylces Retention of nutrients
	Refugia	Habitat provision Suitable habitat for organisms Suitable reproduction habitat
	Maintenance of genetic diversity Species biodiversity	Species maintenance Biodiversity Natural selection Self-organisation
Cultural services	N.A.	N.A.

Figure 2. Side-by-side comparison between the Revised ecosystem services typology as presented in Appendix I column 7 and the ecosystem services typology as defined by Pedersen Zari (2018). The ecosystem services from the category Cultural Services have not been included.

Step 2: Assessment of which ecosystem services are covered by Sustainable Building Certificate Programmes for the building context

Assessment of building requirements from common Sustainable Building Certification Programmes (LBC 4.0, LEED v4.1, BREEAM-NL, and WELL v2) revealed that the requirements did not address all the ecosystem services defined in the reference ES typology by Pedersen Zari (2018) (see Appendix II). The reference typology includes sub-ES (see Figure 2). Main services or sub-ES left untouched covered the topics of provisioning of biomass or water not related to consumption, or regulation of the composition of the exterior atmosphere, biosphere or lithosphere. The Supporting Services and sub-Supporting Services left out covered the topics soil formation and quality, primary production, nutrient cycling and species maintenance.

Phase 2 – Translation

Step 3: Defining structures and processes in the ecological environment that provide ecosystem services

Reviewing scientific reports and books resulted in Appendix III column 3 listing the structures and processes in the ecological environment that provide the ES defined in the reference ES typology (Pedersen Zari, 2018). Some structures or processes from Provisioning or Regulating Services were also related to one of the Supporting Services, this has been indicated by ", see [name of ES]" (see Appendix III column 3). Structures are the biophysical characteristics of an ecosystem. Processes are the interactions between these structures. The effects of these processes are the functions performed by an ecosystem. Structures can be categorised into groups called "stocks". If a process between structures alters the composition of a stock this is termed a "flow". This understanding of structures, processes, functions, stocks and flows has been defined by De Groot *et al.* (2002) and Costanza *et al.* (1997) and is used for step 3a.

Step 3a: Figure summarising ecological functioning

The stocks and flows described with the listed structures and processes allowed for the creation of a figure illustrating the current understanding of ecosystem functioning (see Appendix IV). It depicts that ecosystems are systems composed of stocks and flows. The illustrated stocks and flows are listed in the corresponding legenda. The defined stocks are Lithosphere, Soil, (Biomass of) Primary producers, (Biomass of) Consumers, Atmosphere, Ozone fraction of Atmosphere, Dead organic material, (Biomass of) Soil biology, Water, and Clouds. The flows are all based on the in Appendix III column 3 defined material (and energy) flows between these stocks.

Appendix IV is assimilated based on the information in Appendix III column 3, combining information coming from Kumar & Mina (2021) and Campbell *et al.* (2015). The basic outline of Appendix IV is based on the information in Appendix III column 3, under the ES S Nutrient Cycling. Here four reservoirs, or stocks, are defined: Living organisms; Coal, Peat and Oil; Water, Atmosphere and Soil; and Minerals in rock. Also the flows between these reservoirs are defined: Fossilisation, Burning/Combustion, Rock formation, Weathering and Erosion, Assimilation, Photosynthesis, Respiration, Decomposition, Excretion, Vulcanic eruption. For the construction of Appendix IV some flows are redefined and several new flows have been defined.

The reservoir Coal, Peat and Oil has been renamed Lithosphere, to indicate the fraction of which these materials are part.

The flow Weathering and erosion has been redefined as 1 Soil formation through rock weathering and Soil biology activity, based on Appendix III column 3, under ES S Soil.

The flows under 2.X describe Assimilation and Photosynthesis. Appendix III column 3, under ES S Fixation of solar energy, states that Photoautotrophs perform Photosynthesis. The flows under 2.X describe which flows Photoautotrophs need and produce when performing Photosynthesis to allow Assimilation.

Fixation of solar energy puts energy into the reservoir of Living organisms. Campbell *et al.* (2015, p. 950) indicates that this energy is eventually lost as heat. This is added to Appendix IV as 10 Heat loss. This is an energy flow rather than a material flow.

As Photosynthesis is performed by primary producers, stock D Consumers has been defined, as well as a flow between stock C and D, 3 Mass and Energy flow through Food web, to make a distinction between these two groups of Living organisms. The term Food web refers to Campbell *et al.* (2015, p.1290) as stated in Appendix III column 3, under ES P Food.

The flow between Living organisms and Water, Atmosphere and Soil is depicted with 4 Respiration, Transpiration/Excretion, Death. Soil exists partly of dead organic matter, for which a separate stock has been defined, F Dead organic matter, to show more clearly what happens to this fraction. As a consequence, Death is added as part of the definition of flow 4. Respiration is a two way process. Not only is gas excreted from the atmosphere, organisms also extract O_2 from the atmosphere to respirate (Campbell *et al.*, 2015, p.955). This is described as flow 4.1. Flows 6.1 and 6.2 are added to show to which stock the flows of Decomposition go, as the original reservoir described in Appendix III column 3, under ES S Nutrient Cycling, encompassed Water, Atmosphere and Soil.

Water cycles also through the Atmosphere. Appendix III column 3, under R Climate regulation – UV protection, and the corresponding references Science Land (2020) and Kumar & Mina (2021) indicate that a result of these two stocks coming together is eventually lighting, which leads to the creation of ozone. This is described as flow 7 Ozone cycle.

Step 4: Listing indicators for ecosystem services assessment in ecological environment

Meas *et al.* (2016) have reviewed 327 indicators for ES assessment in the ecological environment in the EU. Out of these 327 indicators they have selected 31 indicators for terrestrial and freshwater ecosystems based on their high information quality. For example, the selected indicator for the ES Biomass is *Area and yield of fibre crops*. For the purpose of defining indicators for the built environment, this set of 31 indicators of the Maes *et al.* (2016) report have been added in Appendix III column 4. These indicators have been reorganised to fit the single-level reference ES typology of Pedersen Zari (2018) used in this step. The indicators were in the Maes *et al.* (2016) report originally organised following the multi-level CICES typology. Indicators are missing for the ES Biochemicals, Genetic information, Ornamental resources, Biological control, Fixation of solar energy, and Species maintenance.

Step 5: Translation of ecosystem services providing structures and processes to the built environment

Ecological structures and processes from Appendix III column 3 were translated as design equivalents for the built environment (see Appendix III column 5). For the Provisioning Services the design equivalents indicate the production of similar resources, the need for space for this production and a consideration of the demand for these resources. For the Regulating and Supporting Services design equivalents indicate which ecological features should be integrated into or facilitated in the building design, or which processes should be mimicked with technological solutions. The material cycles, except the water cycle and air quality regulation, all form a closed loop inside a building itself (see cycle I, B, C, G in Appendix V). For the ES Water Cycling the design equivalent described how a building can be integrated into the water cycle. Thus not necessarily copying ecological processes, but expanding the natural water cycle with steps that happen inside a building (e.g. water being tapped from sanitare). Air quality regulation is an interaction between design equivalents and the in- and outside atmosphere.
These structures and processes were combined to design the conceptual characteristics of an ES delivering infrastructure for a building illustrated in Appendix V. The conceptual infrastructure shows a building as part of the natural water cycle, with an internal materials cycle, and air quality regulation. The formation of the materials cycle is the result of linking input and output of the structures and processes listed in Appendix III column 5. These two cycles continuously provide the water and materials required by a building, as described under the ES category Provisioning Services Appendix III column 2 (Pedersen Zari, 2018).

Step 6: Translation of indicators for ecosystem services assessment to the built environment

Concept indicators were defined based on the indicators of the Maes *et al.* (2016) framework as listed in Appendix III column 4, the indicators listed by Boerema *et al.* (2017b), and the structures and processes defined for the conceptual ES delivering infrastructure for a building as illustrated in Appendix V. These concept indicators have been listed in Appendix III column 6.

Phase 3 – Adaptation

Step 7: Proposal of new framework describing the ecological system of ecosystem services delivery

In Appendix VI a new framework is proposed which describes the ecological system of ES delivery, which encompasses the ecosystem properties and ecosystem functions (Boerema *et al.*, 2017a). The description of ecological functioning as a system of stocks and flows (Costanza *et al.*, 1997; Appendix IV) has been used to describe the ecological system of ES delivery, with the argument that ES describe what happens to these stocks. This so called Ecological System framework knows 4 categories; stocks, flows, mitigation (preserving stock integrity) and extraction. These categories describe the stocks and the different ways flows can alter these stocks: either transforming or redistributing stocks. The category *Stocks* consists of stocks and sub-stocks similar to the stocks depicted in Appendix IV. Only the sub-stock Clouds (Appendix IV) is not included as an individual sub-stock. Instead, the sub-stocks of the Hydrosphere are described as "Cycling through the different [main] stocks". The category *Flows* describes flows between stocks, focussed on the stocks and not between which stocks the flows go, therefore reducing the amount of sub-categories needed. Suggested is to only consider which flows leave the stock towards another stock. This prevents double counting that happens when also describing the flows that enter the stock, as this are flows already described as flows leaving a stock. The category *Mitigation* describes everything protecting stock integrity. Equalling ES like Prevention of disturbances and moderation of extreme events, this category is about the effects of the disturbances and extreme events on the stocks and thus their integrity. These first three categories encompass the ES from the categories Regulating Services and Supporting Services, as shown in Appendix III column 2 (Pedersen Zari, 2018). The category *Extraction* describes potential extraction from the stocks by human activity, not ensuring a material flow back to another stock. This last category equals the ES from the category Provisioning Services, as shown in Appendix III column 2 (Pedersen Zari, 2018).

Step 8: Suggestions for Science Communication

In Appendix VII is presented the conceptual setup of a questionnaire in table format. This table serves as a concept for a future tool for building professionals to assess the delivery of ES by design solutions, ensuring the correct integration of an ES delivering infrastructure into a new building (as described in Appendix V).

The table is divided into three columns and the rows grouped into seven categories. The table should be read from top down and left to right to answer the questions. The first column includes questions that function as guidelines regarding ES design solution integration to be answered during the building design process. The second column includes indicators, which are sub-questions to help answer the questions from column one. The third column states the required values for each indicator question. The questions and indicators of column one and two are no indicators for direct ES delivery assessment. However, the indicators are meant for assessment of the required ecological functioning for a building in order for it to deliver ES and whether the concept design solutions perform this. The goal of this questionnaire is to ensure sufficient ES delivery by the conceptual building ES delivering infrastructure.

Row category	**Related ES (Pedersen Zari, 2018)**	**Related design solution for building (see Appendix V)**
Provision of biomass	Food Biochemicals Raw materials Genetic information Fixation of solar energy	A B C D
Provision of renewable energy	Fuel/Energy	E F
Water cycling	Fresh water Prevention of disturbance and moderation of extremes – Mitigation of flood/drought Purification – Water	G H I J K
Enabling Nutrient cycling	Decomposition Purification – Soil Soil Nutrient cycling	(A) L (J)
Continuation of life	Pollination and seed dispersal Biological control Species maintenance Habitat provision	(B) M N
Mitigation	Climate regulation Prevention of disturbance and moderation of extremes – excl. Mitigation of flood/drought	(A) (D)
Atmospheric composition	Purification – Air	W X Y Z

Table 1. The relationship between the row categories of Appendix VII, the ES as defined by Pedersen Zari (2018), and the design solutions for a building as presented in Appendix V.

The categories in which the rows are divided represent groups of ES. In step 5, for each ES defined in the reference typology by Pedersen Zari (2018) design solutions were defined for the generation of that ES in a building (see Appendix III column 5). Next, these design solutions were put together to form a conceptual setup of an ES delivering infrastructure for a building (see Appendix V). Several parts of the conceptual ES delivering infrastructure setup are related to not one but multiple ES. For example, the ES Food, Biochemicals and Raw materials all include the infrastructure parts A, B, and C (see Appendix III column 5). Infrastructure parts can also be related with each other because they are in sequence (see for example Appendix V, parts H, I, and J). The rows are divided in categories that each address such a set of ES with related infrastructure parts (see Table 1). The questions formulated in one row category ensure the correct setup of the corresponding parts of the infrastructure.

The transcript of the interview with Catalina Bustillo on the relevance and setup of this proposed table is added in Appendix VIII. Based on the transcript from Appendix VIII, Appendix IX lists the keywords and corresponding core sentences identified during interview analysis. The core sentences which answer the interview questions are summarised in Appendix X. Figure 3 depicts the subjects of several interview questions and adapted fragments of core sentences from the interview answering these interview questions as described in Appendix X.

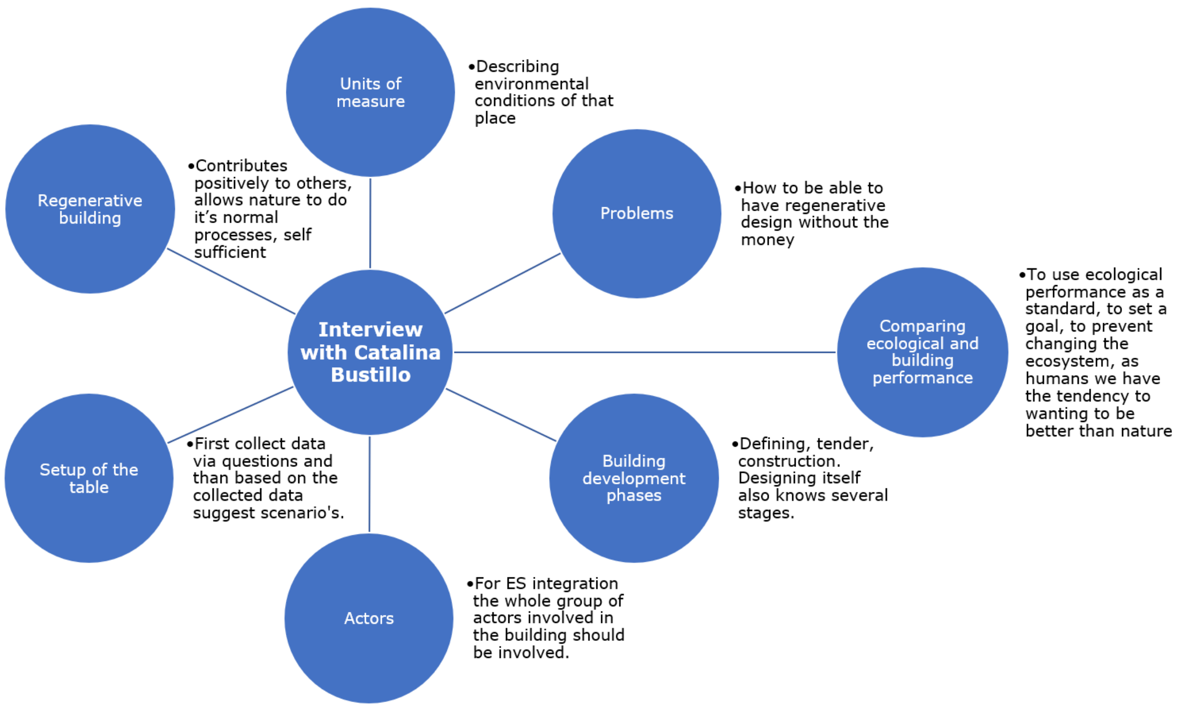

Figure 3. Subjects of interview questions from the interview with Catalina Bustillo (in the blue circles) and adapted fragments of core sentences as spoken by Catalina Bustillo which answer these interview questions.

The interviewee recommended to set up the questionnaire table in such a way that *first data is collected via questions and that the data is used to suggest (design) scenarios* (see Figure 3, Setup of the table). This recommendation was based on the believe that *Asking questions the wrong way will make people defensive, offended or reject your suggestions. Questions should not be too difficult or implicating a right way to do it that is possibly different from what the practitioner is currently doing* (see Appendix X, What is your opinion on the overall setup?). This corresponds with the report of Manning (2009) on psychology of sustainable behaviour, which states that "[…] negative cues should be used with more caution. Negative cues are likely to generate a negative response: a direct challenge, a rebellious continuation of the behavior, or reactance: deliberate thwarting of efforts toward a sustainable alternative".
Also, the conclusions of the report of Ilgen and Davis (2000) on Negative Performance Feedback are in line with the statement of the interviewee. They state that "In our opinion, the most critical issue for delivering negative feedback is the balance between making it possible for performers to accept responsibility for substandard performance and, at the same time, not lower their self-concept." This implicates that stating that an actor acts in a non-desired way can affect their self-concept, which can be the underlying reason for the defensiveness, offensiveness and rejection referred to by the interviewee. The answer from the interviewee, the report of Manner (2009) and the report of Ilgen and Davis (2000) together form three perspectives underlining the statement that negative feedback on behaviour can lead to a negative response.

Discussion

This report aimed to address the research question: How can ecosystem services be quantified in the building context? This research question is based on the lack of ES delivery assessment in buildings. Several research sub-questions have been answered to generate knowledge that contributes to answering this research gap. The results generated for answering these sub-questions, and several developed concepts will be discussed in the following sections.

Phase 1 – Theoretical framework

Step 1: Revision of current ecosystem services typologies

The first research step addressed the research sub-question: What are the discrepancies between existing ecosystem services typologies? The comparison of major ES typologies showed no consensus concerning on which level ES should be defined, therefore differing in whether services where defined as individual ES or grouped together under one ES. Also, not all typologies covered the same services or ES categories.

The results of step 1 could be an indication that the definition of ES is possibly insufficient for unambiguously defining individual ES. This is backed up by the report of Nahlik *et al.* (2012) which discusses how the definition of ES differs between several reports on the topic. The lack of unambiguous definitions of individual ES could play a role in the fact that there is a lack of indicators that measure ES in the ecological context to a sufficient extent (Maes *et al.*, 2016; Boerema *et al.*, 2017a; Boerema *et al.*, 2017b).

Step 2: Assessment of which ecosystem services are covered by Sustainable Building Certificate Programmes for the building context

Assessment of the ES addressed via the building requirements of Sustainable Building Certificate Programmes addressed the research sub-question: Which ES are already (partly) addressed in common Sustainable Building Certificate Programmes? It showed that a very diverse range of (sub-)ES are not addressed via these building requirements. Therefore, the concept of ES can be used as a guiding principle when aiming for sustainability or net-positive in the built environment. This assessment indicates that communication around ES and working standards still needs to be developed to make sure the concept of ES can be fully applied in the building context.

This way of comparing ES definitions and the requirements of Sustainable Building Certificate Programmes does not indicate to what extent the addressed ES should be delivered according to the building requirements and how ES can be quantified.

Phase 2 – Translation

Step 3: Defining structures and processes in the ecological environment that provide ecosystem services

The third research step addressed the research sub-question: Which biophysical structures and processes provide ecosystem services in the ecological environment? The ES cascade model described by Potschin & Haines-Young (2011) and adapted by Boerema *et al.* (2017) indicates that there is a biophysical element involved in the delivery of ES. However, none of the ES typologies describe which are the biophysical elements related to each ES. Information on the biophysical structures and processes related to ES delivery had to be abstracted from 30 sources to create Appendix III column 3.

This indicates that for many ES the full ES cascade is inadequately defined. This is in line with the paper of Barnaud & Antona (2014), which states that ecosystem functioning is currently poorly understood and that much is uncertain. This probably contributes to the inadequate indicators used for ES assessment (Boerema *et al.*, 2017), as an incompletely defined ES cascade can lead to a bias in measure types towards the cascade phases of each ES that are better defined and understood.

As ES are the result of complex ecosystem functioning, Appendix III column 3 highly likely indicates only some and not all structures and elements involved in the delivery of each ES. For example the dynamics underlying Biological Control are difficult to identify and summarise.

Step 3a: Figure summarising ecological functioning

Appendix IV indicates that the ecological infrastructure that supports the delivery of ES constitutes material cycles. This implicates that for continuous delivery of ES these cycles should not be broken or extracted from to the point of depletion. As mentioned before the concept of ES can be used as a guiding principle when aiming for sustainability or net-positive in the built environment. The results depicted in Appendix IV show that in this case there should be a focus on whether and how a building disturbs or depletes the natural material cycles, whether a building can be integrated in such a cycle in case this is beneficial to the inhabitants or the integrity of such a cycle, and whether mimicking of such cycles within a building can deliver desired ES.

As Appendix IV is constructed based on the structures and processes listed in Appendix III column 3, some structures and processes might be missing in this full, however summarised, representation of ecological functioning (see Discussion Step 3).

Step 4: Listing indicators for ecosystem services assessment in ecological environment

Step 4 answered the research sub-question: Which indicators are used to assess ES delivery in the ecological environment? The Maes *et al.* (2016) and Boerema *et al.* (2017) reports make it clear that at least 327 indicators for the EU and 1625 indicators worldwide have been defined to assess ES, multiple for each individual ES. As the purpose of this report is not to (re)define indicators for the ecological environment a set of indicators has been selected which were reviewed in the Maes *et al.* (2016) report. The indicators are meant to form the reference indicators from the ecological environment to be used for the formulation of indicators for the built environment. The set of 31 indicators from Maes *et al.* (2016) has been chosen as these indicators have been reviewed for their information quality and the list presented a maximum of only one indicator per ES. The Maes *et al.* (2016) report used CICES (Haines-Young & Potschin, 2013) as a reference typology. The presented research reorganised these indicators to match the Pedersen Zari (2018) typology. This reorganisation is justified as this is a translational step from a multi-level typology to a single-level typology. In a multi-level typology ES are described using several description levels, this is not the case for single-level typologies. However, this does not imply that the defined ES in a single-level typology have the same characteristic level. Translating from a multi-level typology to a single-level typology is possible as the number of descriptive levels and thus the information quality is reduced. The reorganisation from the CICES (Haines-Young & Potschin, 2013) typology to the Pedersen Zari (2018) typology is also justified as they are both historically based on the same preceding typology (MAE, 2005). Not all ES of the Pedersen Zari (2018) typology know a matching indicator as these were not identified as an ES in the Maes *et al.* (2016) report. Also, not for all ES of the CICES (Haines-Young & Potschin, 2013) typology Meas *et al.* (2016) have chosen an indicator. The implications of these two givens will be discussion in the section on Step 6.

Step 5: Translation of ecosystem services providing structures and processes to the built environment

The research sub-question: How can the biophysical elements and processes that provide ecosystem services in the ecological environment be translated to the built environment?, was addressed with the fifth research step.

There is not yet a consistent definition of ES (Nahlik *et al.*, 2012; see Appendix I). This makes it possible that the ES listed in the Pedersen Zari (2018) and Boerema *et al.* (2017) typologies are not all the ES delivered by nature, meaning that some ES are not yet defined, and the consequence of this is, among other reasons, that these lists of ES might not cover the complete functioning of ecosystems. This design research approach however, does ensure the design of a system delivering the desired ES. If new ES are

defined in the future, research steps 3 and 5 can be repeated and the design can be revised.
The formulation of design equivalents for ecological structures and processes resulted in the identification of some ecological features that could not be mimicked, as technological solutions were too complex or non-existent, but instead should be integrated into the design of a building. This is especially true for many of the services delivered by vegetation. This makes it clear that some ecological functions cannot be easily delivered by technological solutions, and thus that green elements should be welcomed into buildings that should deliver ES. The feasibility of this paradigm shift has already been demonstrated by the works of Stefano Boeri and Ken Yeang, who both designed high-rise buildings (Stefano Boeri Architetti, 2019; Stefano Boeri Architetti, 2021; Yeang & Threipland, 2021), and the construction of autonomous houses (Earthship Biotecture, n.d.), as all these examples have vegetation integrated into their design.
When formulating the design equivalents for the Provisioning Services, the demand of resources was taken into account as an indication for features of the design, as this correlates with the space needed for resource production and thus in the end with the potential resource provisioning. This also led to the space needed for resource production to become an indication for features of the design. This makes it clear that ecological features cannot be mimicked without taking into account the spatial aspect.
For many of the Regulating Services technologies are proposed not to mimic but facilitate ecological processes, for example Decomposition, as facilitation forms the easiest technical solution. Technical solutions have been chosen as design equivalents for the sub-ES Runoff force mitigation, Mitigation of flood/drought, and Erosion control of ES Prevention of disturbance and moderation of extremes as technical solutions can mimic the delivery of these services. For the sub-ES Wind force mitigation and Wave force mitigation of ES Prevention of disturbance and moderation of extremes no design equivalents were selected, as building practises for these services are already common practise in wind- and floodprone areas. For the sub-ES Climate regulation – UV protection, a technical solution delivering the same service but via design and not via a similar atmosphere quality regulating process has been proposed as design equivalent. This design equivalent has been chosen as this was a translation from the original system level of the ES to the level of the research scope which are individual buildings. Technical mimicking of ES delivering ecological features thus can happen in different ways, from facilitating to replacing.
Appendix IV and the proposed ES delivering infrastructure for a building show that when mimicking ecological structures and processes to facilitate ES delivery, the key likely lays in the cycling of materials. All ecology based ES (stating that provisioning of electricity is a technology based ES) are a result of an ecological complex system (Fu *et al.*, 2010). As

ES delivery is the result of the functioning of a complex system, a system, an infrastructure, should be designed for a building to provide ES.
All proposed design equivalents were based on indications that suggested integration of green elements, facilitating ecological processes with technology, or mimicking services with technology was the most fitting approach. However, there is no evidence yet indicating that another setup of an ES delivering infrastructure for a building won't deliver similar ES. As the proposed infrastructure is constructed based on the structures and processes listed in Appendix III column 3, which was compiled in research step 3 and might not be complete as stated in the discussion, it cannot be guaranteed to what extent this infrastructure could potentially deliver ES.

Step 6: Translation of indicators for ecosystem services assessment to the built environment

The research continued with step 6 addressing the research sub-question: Which indicators could be used to assess ES delivery in the built environment? Not all proposed indicators for the built environment have been based on a reference indicator from the ecological environment, because not all ES of the Pedersen Zari (2018) typology know a matching indicator as these were not identified as an ES in the Maes *et al.* (2016) report, no indicator was selected in the Maes *et al.* (2016) report for that specific ES, or no suitable reference indicator was listed in Boerema *et al.* (2017b). Indicators were newly formulated in case some ES delivering structures or processes of the building context were not addressed by the translated indicators. For the Provisioning Services, when reference indicators lacked, proposed indicators were based on the indicator type proposed for other Provisioning Services. This is justified as all Provisioning Services, except Fresh water, deliver a form of biomass and therefore have a similar ecological basis. For other ES, e.g. Biological control, the proposed indicators were based on which ecological structures and processes are required according to the information in Appendix III column 3. This is justified, as the indicators need to represent the structures and elements providing ES. Lacking reference indicators may result in future problems comparing results of ES assessment in the built environment with results from the ecological environment.
The proposed indicators are a first step towards identifying indicators for ES assessment in the built environment, using conventional single-level ES typologies. Even though verification of the proposed indicators is still necessary, the first step of defining possible indicators has now been performed.

Phase 3 – Adaptation

Step 7: Proposal of new framework describing the ecological system of ecosystem services delivery

The proposed framework shows a way for researchers to describe the ecological system behind ES delivery (Boerema *et al.*, 2017a), thus covering the Ecosystem Properties and Ecosystem Functions (ES supply). The categories of the framework allow for a simultaneous description of the ecosystem infrastructure delivering ES and the "benefits humans obtain from nature" (as is the definition of ES defined by MEA (2005)) (see Appendix VI column 3). The framework addresses problems arising from the missing consensus on which ES categories should be taken into account, what are the individually defined ES, and the disproportional representation of parts of the ES cascade when it comes to defining indicators for individual ES. This allows for the indentification of stronger indicators for ES assessment in the ecological environment and can also benefit the further process of defining indicators for the built environment. For a less ambiguous description of the benefits humans obtain from nature individual ES can be redefined as the flows between, the mitigation processes of, and the extractions from stocks. This way of redefining ES removes the risk of "double-counting" when addressing the former ES category Supporting Services, since there is no liniair relationship anymore between the categories in the framework. In the MEA (2005) framework the Supporting Services enabled the Regulating Services, which in turn enabled the Provisioning Services, forming a liniair relationship.

The category *Extraction* describes the potential material extraction. If the realised resource extraction is described, this category can be used to describe sections of the socio-economic system of ES delivery (Boerema *et al.*, 2017). The materials under the category *Extraction* can be reintroduced into the system after being extracted by human. In this case the category *Extraction* specifically describes *flows* between *stocks* due to human intervention. Reintroduction can play an important role in stock maintenance.

Step 8: Suggestions for Science Communication

Research step 8 aimed to address the research sub-question: How can the results of this research project be communicated to building professionals wanting to integrate ecosystem services delivering designs in and on new buildings? This resulted in the proposal of a table that guides the correct integration of an ES delivering infrastructure in a new building (see Appendix VII). The table includes guidelines regarding ES design solution integration, and indicators and corresponding required values to assess and ensure correct integration. These guidelines, indicators, and requirements formulate the characteristics of the conceptual ES delivering infrastructure formulated in research step 5 (see Appendix V).

Through methodological triangulation involving an interview discussing Appendix VII, a scientific publication on negative feedback, and a report on the psychology of (sustainable) behaviour, it has been determined that negative feedback on behaviour can lead to a negative response. The table's guidelines steer towards a predetermined setup of an ES delivering infrastructure in a building. However, with a freedom in which design solutions to choose. The implication of the steering guidelines is that actors involved in building development might give up on integrating ES in a building in case preliminary project requirements or design ideas do not match the requirements as formulated in the table.

The research focussed on the setup of the table. It has not been validated whether the formulated guidelines, indicators and requirements are understood by actors in building development in such a way that they result in a functioning ES delivering infrastructure in a new building. The proposed table requires a basic understanding of ecosystem services, for example it does not include an explanation of the term biochemicals. Using the table also requires basic knowledge on the ecological situation of the buildings surroundings. This includes information of local vegetation, natively occurring animals and their diets, and precipitation. The required background knowledge limits the application scope.

The table is a first proposal for science communication to building professionals on the topic of ES integration in new buildings. It is meant to be used during the design phase for a new building, in a collaborative manner by all actors involved in this phase. It is a demonstration of the impact science can make when the translational step to real life application is made.

Conclusion

With the current ecological crisis it is important to find ways in which it is possible to contribute to nature with human activities. As buildings play an important role in human civilisation, there is a great potential for using buildings to generate this positive impact. Integrating the ecosystem services concept into the built environment promises to be an effective way to have buildings contribute to their surroundings. It is necessary to be able to assess ES delivery by a building to gain inside in the effects of integrating existing green designs with the purpose of ES delivery. It also gives the opportunity to compare the ES delivery to that of a reference natural site, to attune the ES delivery by a building to what is required by its surroundings.

The main research question was **How can ecosystem services be quantified in the building context?** This has been answered to the extent that 1. an understanding has been created on how ES can be delivered in a building, 2. indicators for ES delivery assessment in the built environment have been suggested based on this understanding, 3. a new framework has been proposed to better describe ES delivery in both the biological and building context.

This research had as aim to generate knowledge that allows for the identification of indicators for ES delivery assessment in the built environment, specifically individual buildings. To start of, a selection of existing ES typologies has been revised, to define their consensuses and discrepancies. Subsequently, the design of a conceptual infrastructure for ES delivery in a building created an understanding of how ES can be delivered by a building. This allowed for a first suggestion of indicators for ES delivery assessment in the built environment, using conventional single-level ES typologies. ES delivery assessment in the built environment supports the correct integration of ES delivering design solutions, which positively impact human health and well-being and mitigate pollution and climate change.

It is important that scientific knowledge is not only generated, but also that steps are taken to have science be applied. In this way science can truly fulfil its promise of contributing to solving society's big problems. The design of the conceptual infrastructure for ES delivery in a building was succeeded by the formulation of suggestions for communication of these research findings to actors involved in the design phase of a new building development. This is a first important step towards applying the scientific knowledge generated in this report. For these actors having the knowledge on which type of ES delivering designs to choose can lead to a higher cost-effective positive ecological impact and more social support for a proposed building design.

A new framework for describing the ecological system of ES delivery has been proposed in this report. The framework promises to describe ES delivery more all-encompassing, stepping away from the drawbacks of describing ES delivery based on single-level ES typologies. The framework would not only be a contribution to the research concerning ES delivery in the built environment, but also towards the standardisation of the ES concept in ecological research.

Future research

Conforming to Sustainable Building Certificate Programmes is a popular way of practise for developing sustainable buildings. Conforming also to the concept of ES delivery to achieve not only sustainability but even net-positive could be seen not as a substitute to these sustainable building practices, but as an expansion. Via the original Sustainable Building Certificate Programmes mainly the development and end phases of a building's life cycle are addressed (see International Living Future Institute, 2019; International WELL Building Insititute, 2020). However, as ES in the building context are something that is generated by design solutions, ES delivery is focussed on the use phase of a building's life cycle. Therefore, there might lay great potential in integrating indicators (step 6) and requirements (step 8) for ES delivery into the Sustainable Building Certificate Programmes requirements. In this way building developers can work with familiar certificate programmes, while integrating the new net-positive concept of ES delivery.

In this report a conceptual infrastructure for ES delivery in a building has been proposed, (see Appendix V). It shows the structures and processes necessary in a building to provide ES, but no link has yet been made to many of the already existing green design strategies that could embody these structures and processes. An interactive tool for design strategies addressing ES delivery in urban environments has already been developed (Pedersen Zari & Hecht, 2020). A next step could be to develop a similar tool for the building context, using the database of ES delivering structures and processes in the biological and building context as a basis (see Appendix III). The tool will link the same design strategies to the identified required structures and processes instead of the ES.

Cultural Services are immaterial benefits derived from ecosystems (MEA, 2003). They thus cannot be described by the material stocks and flows principles in the framework. However, the stocks and flows framework does describe the context that could provide these services. The framework could possibly be expanded to include immaterial flows.

Having identified what the structures and processes required for a building to deliver ES are, now brings the opportunity to verify and revise the list of proposed indicators for ES delivery in the built environment. Future research can also focus on how to identify and communicate requirements for the development of an ES delivering building infrastructure in the form of a questionnaire-based tool, a research process of which the very first steps have already been discussed in this report. Appropriate indicators should be identified for the proposed framework that describes the ecological system behind ES delivery (see Appendix VI).

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Appendices

Appendix I – Revision of current ecosystem services typologies

Ehrlich and Ehrlich (1981)	Costanza *et al.* (1997)	MEA (2005, p. 40)	TEEB (2010)	Haase *et al.* (2014)	Boerema *et al.* (2017)	Revised typology
		Provisioning Services	**Provisioning Services**		**Provisioning Services**	**Provisioning Services**
Direct Supply of Foods	Food production	Food	Food	Food	Food production	Food
	Water supply	Fresh water	Water	Fresh water	Water Provision	Fresh water
	Raw materials	Fuel	Raw materials	Raw materials	Energy & Fuel	Raw materials
		Fiber			Materials & Fibre	
	Genetic resources	Biochemicals, natural medicines, and pharmaceuticals	Medicinal resources		Medicinal Resources	Medicinal resources
Maintenance of a Genetic Library		Genetic resources	Genetic resources		Genetic Resources	Genetic resources
		Ornamental resources	Ornamental resources		Ornamental Resources	Ornamental resources
		Regulating Services	**Regulating Services**		**Regulating Services**	**Regulating Services**
Maintenance of the Quality of the Atmosphere	Gas regulation	Air quality regulation	Air quality regulation	Local climate/air quality regulation	Air quality regulation	Air quality regulation
Control and Amelioration of Climate	Climate regulation	Climate regulation	Climate regulation	Carbon sequestration/storage	Climate Regulation	Climate regulation
Regulation of Freshwater Supplies	Water regulation	Water regulation	Regulation of water flows		Water Regulation	Water regulation
	Erosion control and sediment retention	Erosion control	Erosion prevention	Erosion prevention/maintenance of soil fertility	Soil Retention	Erosion control
(2) Regulation of Freshwater Supplies		Water purification and waste treatment	Waste treatment	Waste water treatment	Water Purification	Waste treatment, sub. Water purification
Disposal of Wastes and Cycling of Nutrients	Waste treatment					
Pest and Disease Control		Disease regulation	Biological control	Biological (pest) control	Biological Control	Biological control, sub. Diseases, sub. Pests
	Biological control	Pest regulation				
Pollination	Pollination	Pollination	Pollination	Pollination	Pollination	Pollination
	Disturbance regulation	Natural hazard regulation	Moderation of extreme events	Moderation extreme events		Moderation of extreme events
		Supporting Services			[Omitted, double-counting]	**Supporting (and Habitat) Services**
		Primary production				Primary production
		Photosynthesis				Photosynthesis

(continuing)

Ehrlich and Ehrlich (1981)	**Costanza *et al.* (1997)**	**MEA (2005, p. 40)**	**TEEB (2010)**	**Haase *et al.* (2014)**	**Boerema *et al.* (2017)**	**Revised typology**
Generation and Maintenance of Soils	Soil formation	Soil formation	Maintenance of soil fertility	(2) Erosion prevention/maintenance of soil fertility	Soil Quality Regulation	Maintenance of soil fertility
(2) Disposal of Wastes and Cycling of Nutrients	Nutrient cycling	Nutrient cycling				Nutrient cycling, sub. Water cycling
		Water cycling				
					Life Cycle Maintenence	Life Cycle Maintenence
			Habitat Services			
	Refugia		Maintenance of life cycles of migratory species	Habitat for species		Refugia
			Maintenance of genetic diversity	Maintenance of genetic diversity		Maintenance of genetic diversity
				Biodiversity		Biodiversity
		Cultural Services	**Cultural & Amenity Services**		**Cultural Services**	**Cultural Services**
		Knowledge systems			Scientific & Educational Services	Knowledge systems
		Educational values	Information for cognitive development			Educational values
		Aesthetic values	Aesthetic information	Aesthetic appreciation/inspiration	Aesthetic Services	Aesthetic appreciation
		Inspiration	Inspiration for culture, art and design		Heritage, Cultural, Bequest, Inspiration & Art	Inspiration
		Cultural heritage values				Cultural heritage values
		Cultural diversity				Cultural diversity
		Spiritual and religious values	Spiritual experience	Spiritual experience/Sense of place	Symbolic, Sacres, Spiritual & Religious Services	Spiritual experience
		Sense of place				Sence of place
		Social relations				Social relations
				Mental and physical health		Mental and physical health
	Recreation	Recreation and ecotourism	Oppertunities for recreation & tourism		Recreation & Tourism	Recreation
				Tourism		Tourism

Appendix II – Assessment of ecosystem services addressed by Sustainable Building Certificate Programmes Requirements

(Legend: green = ES is addressed by programme, orange = ES is not addressed by programme)

ES typology (Pedersen Zari, 2018)	LBC 4.0 New Building	LEED v4.1 Building Design and Construction	BREEAM-NL Nieuwbouw 2020 v1.0	WELL v2	Covered by at least 1 certification (green = Yes, orange = No)
Provisioning					
Food					
> Human (land/fresh water/marine)	green	orange	orange	green	green
> Forage	orange	orange	orange	orange	orange
Biochemicals					
> Medicines	orange	orange	orange	orange	orange
> Other	orange	orange	orange	orange	orange
Raw materials					
> Timber	orange	orange	orange	orange	orange
> Fiber	orange	orange	orange	orange	orange
> Stone	orange	orange	orange	orange	orange
> Minerals/ores	orange	orange	orange	orange	orange
Fuel/energy					
> Biomass	green	green	orange	orange	green
> Solar	green	green	orange	orange	green
> Hydro	green	green	orange	orange	green
> Other	green	green	orange	orange	green
Fresh water					
> Consumption	green	green	orange	orange	green
> Irrigation	orange	orange	orange	orange	orange
> Industrial processes	orange	orange	orange	orange	orange
Genetic information	orange	orange	orange	orange	orange
Regulating (human time scale)					
Pollination and seed dispersal	orange	orange	orange	orange	orange
Biological control					
> Pest regulation	orange	orange	orange	green	green
> Invasive species	orange	orange	orange	orange	orange
> Disease regulation	orange	orange	orange	orange	orange
Climate regulation					
> GHG regulation	orange	orange	orange	orange	orange
> UV protection	orange	orange	orange	orange	orange
> Moderation of temperature	orange	green	green	green	green
> Moderation of noise	green	green	green	green	green
Prevention of disturbance and moderation of extremes					
> Wind/wave/runoff force mitigation	green	green	green	orange	green

(Continuing)

ES typology (Pedersen Zari, 2018)	LBC 4.0 New Building	LEED v4.1 Building Design and Construc-tion	BREEAM-NL Nieuwbouw 2020 v1.0	WELL v2	Covered by at least 1 certification (green = Yes, orange = No)
> Mitigation of flood/drought	orange	green	green	orange	green
> Erosion control	orange	green	green	orange	green
Decomposition					
> Waste removal	orange	orange	orange	orange	orange
Purification					
> Water	green	green	orange	orange	green
> Air	green	green	green	green	green
> Soil	orange	orange	orange	orange	orange
Supporting (long time scale)					
Soil					
> Formation	orange	orange	orange	orange	orange
> Retention	green	orange	orange	orange	green
> Renewal of fertility	orange	orange	orange	orange	orange
> Quality control	orange	orange	orange	orange	orange
Fixation of solar energy					
> Primary production/plant growth	orange	orange	orange	orange	orange
Nutrient cycling					
> Regulation of biogeochemical cycles	orange	orange	orange	orange	orange
> Retention of nutrients	orange	orange	orange	orange	orange
Habitat provision					
> Suitable habitat for organisms	green	green	green	orange	green
> Suitable reproduction habitat	orange	orange	green	orange	green
Species maintenance					
> Biodiversity	orange	green	green	orange	green
> Natural selection	orange	orange	orange	orange	orange
> Self-organisation	orange	orange	orange	orange	orange
Cultural					
N.A.	green	green	green	orange	green

Appendix III – Description of structures, processes and indicators of ecosystem services delivery in the ecological and built environment

ES typology – Biological context **(Boerema *et al.*, 2017)**	**ES typology– Building context** **(Pedersen Zari, 2018)**	**Ecological structures and processes related to ES delivery** **[X] = source**	**Indicators ES assessment ecological environment (terrestrial)** **(Maes *et al.*, 2016)**	**Translation of ecological structures and processes to building context** **[X] = reference to Appendix V**	**Indicators ES assessment building environment** **[X] = reference to Appendix V** **(Translated from Maes *et al.* (2016) or Boerema *et al.* (2017b), [Author] indicates indicator newly formulated)**
P Food Production	**P Food**	All forms of life that are not top predators [1, p.1290] Organic compounds/Detritus [1, p.710, 1306] Mineral nutrients/Dissolved compounds [1, p.637-638, 650], [2, p.119] see Nutrient cycling, see Fixation of Solar energy	Area and yield of food and feed crops Livestock Distribution of wild berries (modelling) Population sizes of species of interest	[A] Area used for food production [B] Food production with vegetation [C] Food consumption/demand	Land use • [A] Land use area for food (m^2) Food harvest • [B] Crop yield (kg/m^2, GJ/m^2 gross energy, g/kg protein yield) • [C] Food demand and consumption *Harvest should be sustainable, not depleting.
	- Human (land/fresh/water/marine)				
	- Forage				
P Medicinal Resources	**P Biochemicals**	Chemicals coming from organisms [3] Materials extracted from the lithosphere [4, ch. 1]		[A] Area used for biochemical production [B] Biochemical production with vegetation [C] Biochemical use/demand	Land use • [A] Land use area for biochemicals (m^2) Biochemicals harvest • [B] Crop yield (g/m^2) • [C] Biochemical demand and use

(Continuing)

ES typology – Biological context (Boerema *et al.,* 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
	- Medicines				*Harvest should be sustainable, not depleting.
	- Others				
P Materials & Fibre	**P Raw materials**	Extracted primary production (not destined as food) [5], [6], [7, section 1] see Nutrient cycling, see Fixation of Solar energy Materials coming from animals [7, section 1] Materials extracted from the lithosphere [7, section 2 and 3]		[A] Area used for raw materials production [B] Raw materials production [C*] Raw materials use/demand [B*] Raw materials sustainable sources, Raw materials use/demand, Raw materials separated in recycle streams	Land use • [A] Land use map (m^2) as proxy for productivity • OR [B*] Import products that can be dismantled into recyclable waste streams. Biomass or volume • [B] OR [C*] ton or m^3, per year, per m^2 *Harvest should be sustainable, not depleting.
	- Timber		Timber production and consumption statistics		
	- Fibre		Area and yield of fibre crops		
	- Stone				
	- Minerals/ores				
P Energy & Fuel	**P Fuel/energy**	Biomass [8, 9 p.35], see Nutrient cycling, see Fixation of Solar energy Technologies for renewable energy [10]		[E] Energy production [F] Energy use/demand	Energy production • [E] Theoretic produced energy (kWh/ha) • [F] Energy supply/energy use-demand (%) [Author]
	- Biomass		Fuel wood statistics		
	- Solar				
	- Hydro				
	- Other				

(Continuing)

ES typology – Biological context (Boerema *et al.*, 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
P Water Provision	**P Fresh water**	Water [11], see Nutrient cycling		[G] Water collection [I] Water use/demand	Water availability • [G] Precipitation (as indicator of how much will be collected) • OR [G] Collected precipitation Water provision -percent • [I] Water supply/water use-demand (%)
	- Consumption		Water abstracted		
	- Irrigation				
	- Industrial processes		Water abstracted Total supply of water per forest area (modelling)		
P Genetic Resources	**P Genetic information**	(Genetic diversity of) organisms [12, p.12-19], [13, p.153], see Species maintenance		[M] Organism inter- and intraspecies diversity	Diversity • [M] Species richness • [M] Intraspecific Diversity (Genome characteristics)
P Ornamental resources					
R Pollination	**R Pollination and seed dispersal**	Organisms (seed producing, pollinators (insects, birds, mammals)) [2, p.633], see Species maintenance Wind [2, p.633] Water [2, p.633]	Pollination potential	[D] Plants in need for pollination [M] Pollinators (matching with vegetation) [D]/[N] Habitat for pollinators	Habitat • [D] Number of plants in need for pollination [Author] Number of bees or species • [M] Number of pollinators and species (matching the vegetational pollination needs)

(Continuing)

ES typology – Biological context (Boerema *et al.,* 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
R Biological Control	**R Biological control**	E.g.: - Species diversity (leaving fewer resources for invader, decreasing survival) [1, p.1289] - Soil biology (supporting succession state, therefore preventing weeds) [14, 40:18-57:43] - Hypothesis: Species richness in relation to ecosystem size [35, p.159] - Hypothesis: Minimal disturbance of ecosystems [15, p.159] - Hypothesis: High environmental heterogeneity [15, p.159]		[D] Native vegetation cover [M] Pest-controlling species (Soil biology and higher order)	Organisms • [M] # Pests • [M] # Pest-Controlling Species, e.g. Cover of weed preventing cover crops (%) [14, 40:18-57:43] [Author]
	- Pest regulation				
	- Invasive species resistance				
	- Disease regulation				
R Climate Regulation	**R Climate regulation (Note 5)**				
	- GHG regulation		Carbon storage and sequestration by forest		
	- UV protection	(Formation of) Ozone [16], [15]		[not in image] Physical shading against UV radiation	UV [not in image] Amount of UV radiation to which the building residents are exposed.
	- Moderation of temperature	Vegetation (local scale) [17]	Forest area	[D] Native vegetation	Temperature [not in image] Minutes building residents are exposed to extreme temperatures inside (> maximum temperature advised by local health organisation or government)

(Continuing)

ES typology – Biological context (Boerema *et al.,* 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
	- Moderation of noise	Vegetation (local scale) [17]		[D] Native vegetation [not in image] Physical shading against sound coming from outside or inside the building	Sound [not in image] Amount of dB to which building residents are exposed
	R Prevention of disturbance and moderation of extremes				
	- Wind force mitigation	Physical barriers like vegetation cause wind speed to drop below a certain threshold (e.g. erosion initiation prevention starts at a threshold of 5 m/s, 0,3m above ground) [13, p.359-360]		Construction solutions protecting buildings against high wind forces are already common practice in windprone areas. [28]	N.A.
R Water Regulation (1)	^ Wave force mitigation	Dense vegetation barriers like tidal marshes [18], mangroves [19], floodplain forests and wetlands [13, p. 156]	Coastal protection capacity	Construction solutions protecting buildings against wave forces are already common practice in floodprone areas. [29]	N.A.
R Soil Retention (1)	^ Runoff force mitigation	Soil structure and texture with low erodibility, good soil infiltration and storage and vegetation cover [13, p.294]		[A] Good soil quality [not in image] Sufficient drainage of vegetated areas and impermeable areas on building.	Water retention • [G] Precipitation • [A] Retention potential
R Water Regulation (2)	- Mitigation of flood/drought	Dense vegetation barriers like tidal marshes [18] and mangroves [19] Wetlands [20, p. 539] Interception [21]	Floodplains areas (and record of annual floods) Area of wetlands located in flood risk zones	[H] Storage tank (can be several small for vegetation) for mitigating storm precipitation and droughts [not in image] Basement/Ground floor resistant to flooding	Water storage • [I] Amount of water needed in a potential drought period • [H] Capacity of storage tank Water resistance • [not in image] Water column resistance of each item in the basement/ground floor

(Continuing)

ES typology – Biological context **(Boerema *et al.*, 2017)**	**ES typology– Building context** **(Pedersen Zari, 2018)**	**Ecological structures and processes related to ES delivery**	**Indicators ES assessment ecological environment (terrestrial)**	**Translation of ecological structures and processes to building context**	**Indicators ES assessment building environment**
R Soil Retention (2) (Note 8)	- Erosion control	Ground cover by vegetation, causing roots to hold the ground [13, p.156]	Soil erosion risk or erosion protection Coastal protection capacity (2x)	[D] Vegetation or manmade (compost) cover	Erosion • [A]/[D] Erosion potential (how much soil can be washed away or compacted with the present wind and precipitation impact, and the vegetation cover)
	R Decomposition	Micro-organisms in soil and water [1, p. 643], see Nutrient cycling		[L] Decomposition of organic wastes	Decomposition • [L] Decomposition rate (in Boerema *et al.* (2017b) seen as part of Water purification)
R Water Purification (1)	- Waste removal		Area occupied by riparian forests Nitrogen and Sulphur removal		
	R Purification				
R Water Purification (2)	- Water	Biophysical filtration by soil [22, p.2]	Chemical status	[J] Purification of collected or used water to quality level required for (re)use or infiltration	Water quality • [J] Quality of water meant for use • [J] Quality of water destined for infiltration Water purification • [J] Filtering rate [Author] Sewage • [x] Amount of water destined for sewage → Should be ZERO!
R Air Quality Regulation	^ Air	Air pollution removal by vegetation [23], [24]	Amount of biomass	[X]/[Y]/[Z] Ventilation of indoor air [W]/[Z] Purification of indoor air	Vegetation • [D]/[W] Vegetation cover as estimate for vegetation cleaning capacity …

(Continuing)

ES typology – Biological context **(Boerema *et al.,* 2017)**	**ES typology– Building context** **(Pedersen Zari, 2018)**	**Ecological structures and processes related to ES delivery**	**Indicators ES assessment ecological environment (terrestrial)**	**Translation of ecological structures and processes to building context**	**Indicators ES assessment building environment**
					Natural air flow • [X] Natural ventilation (m3/h) Electric air flow • [Y] Electric ventilation (m3/h) Air quality [Z] Air quality
	^ Soil	Soil food web, see Nutrient cycling [25]			
R Soil Quality Regulation	**S Soil**				
	- Formation	Rock weathering creating mineral particles [17], [35, p. 3] Soil biology activity [17], [26], [15, p. 4] Detritus as input [15, p. 4] Humus as product [15, p. 4] Enabling soil containing water [15, p. 4-5] Enabling soil containing air [15, p. 4] see Nutrient cycling	Share of organic farming Soil organic matter content pH of topsoil Cation exchange capacity Area of nitrogen fixing crops		
	S Fixation of solar energy	Photoautotrophs (plants, algae, cyanobacteria) > Photosynthesis (Light reaction (=fixation) and Calvin cycle (=primary production)) [1, p271], see Nutrient cycling		[B] Fixation of Solar energy by vegetation or other primary producers to create biomass	Synthesis • [B] CO_2 uptake • [B] Increase of biomass
	- Primary production/plant growth (above ground, below ground, marine, fresh water)				

(Continuing)

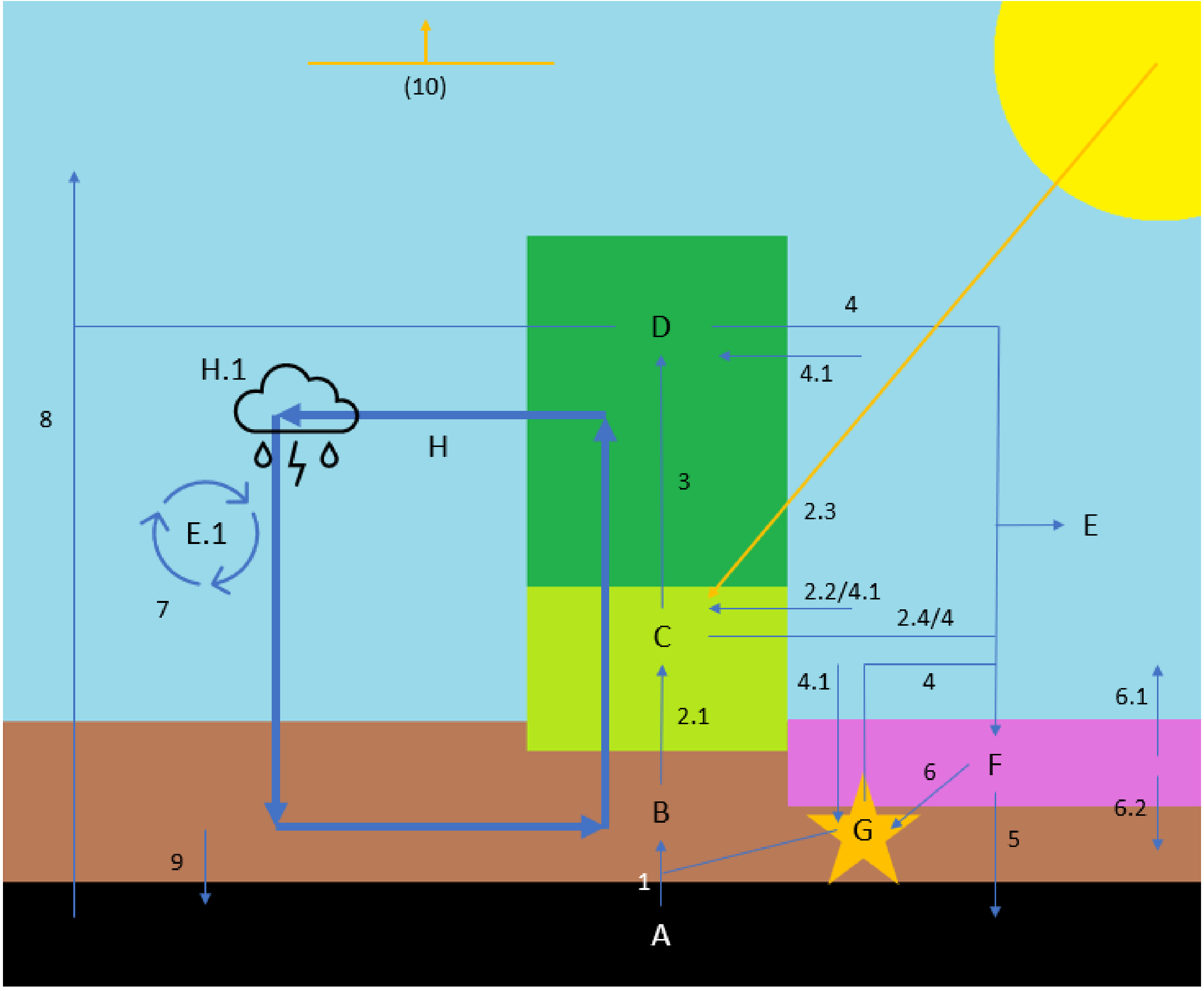
ES typology – Biological context (Boerema *et al.,* 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
S Nutrient Cycling	**S Nutrient cycling**	Water [26]: Precipitation (Intake by organisms) [Author] Evaporation Transpiration Infiltration Runoff (Collection) [Author] Subsurface water Cloud formation Other terrestrial mineral cycles [15, p.42-50]: *C = Carbon cycle* *N = Nitrogen cycle* *O = Oxygen cycle* *S = Sulphur cycle* *P = Phosphorus cycle* Pools [27, p.351] Fluxes between pools [27, p.351] Reservoir (A) = Living organisms Flux (A>B): Fossilisation [C, S] Reservoir (B) = Coal, Peat, Oil Flux (B>C): Burning/Combustion [C, S] Reservoir (C) = Water, Atmosphere, Soil Flux (C>D): Rock formation [P, S] Reservoir (D) = Minerals in rock …	Carbon storage and sequestration by forests	Water: [G] Water precipitation/collection (Use/reuse phases assessed by P Fresh water and R Purification - Water [H] Water storage [K] Infiltration Other terrestrial mineral cycles: [D]/[C] Reservoir (A) [I] Reservoir (C) [C*] Products [B], [L], [J] Fluxes	Water: • [I] Irrigation as indicator for Evapotranspiration aka water “loss” [Author] • [H] Storage capacity for flood events and drought mitigation [Author] • [K] Amount of water destined for infiltration [Author] • [K] Infiltration capacity Other terrestrial mineral cycles [Author]: [B] Harvest (kg/year) [C] Demand for harvest (kg/year) [I] Water demand (L/year) [L] Decomposing (kg/year) [D] Biomass (kg)
- R Water Regulation (2)	- Regulation of biogeochemical cycles				
	- Retention of nutrients				

ES typology – Biological context (Boerema *et al.,* 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
		Flux (D>C): Weathering, Erosion (and Leaching) [P, S] Flux (C>A): Assimilation [Plants: P], Photosynthesis [Light reaction: O; Carbon cycle: C] Flux (A>C): Respiration [by ALL organisms: C, O; by soil organisms: N; non-biological nitrogen fixation: N], Decomposition [by Soil Food Web: C, O; Abiotic: C, O], Excretion [by Soil Food Web: N, S, P], Precipitation [S], Volcanic eruption [S] [15, p.42-50], [adapted from 15, Figure 2.9 p. 44, Figure 2.10 p.45, Figure 2.11 p.47, Figure 2.12&2.13 p.48]			
S Habitat	**S Habitat provision**	The place where an organism usually lives; the environment in which the life needs of an organism are supplied [27, p.457]	Share of High Nature Value farmland Ecological Status of water bodies	[N]/[D] Habitats for organisms	Habitats [N] # and area of habitats created for (native) species, including pollinators
	- Suitable habitat for organisms				
R Life Cycle Maintenance	- Suitable reproduction habitat				
	S Species maintenance	The presence of species that together provide the ecosystem services. This presence is formed by evolution based on genetic information and natural selection, and the provisioning of ecosystem services …			
S Biodiversity (Note 2)	- Biodiversity			[M] Species introduced and attracted	Species [D]/[M] # (Native) species present

(Continuing)

ES typology – Biological context (Boerema *et al.,* 2017)	ES typology– Building context (Pedersen Zari, 2018)	Ecological structures and processes related to ES delivery	Indicators ES assessment ecological environment (terrestrial)	Translation of ecological structures and processes to building context	Indicators ES assessment building environment
		on self-organisation. [inspired by 17]			
	- Natural selection			Natural selection/Evolution is an inherent process within populations, happening over generations. Therefore, no translation towards a building context is necessary. [30, p.7, 8, 59-65, 166]	N.A.
	- Self-organisation			Facilitation of relationships between buildings, components, people and ecosystems [17, p.93]	N.A. (outside scope)
C [Cultural ES]	**C [Cultural ES]**	N.A. (Outside the scope of this report)			

Appendix IV – Summary of ecological functioning in the ecological environment



Stocks

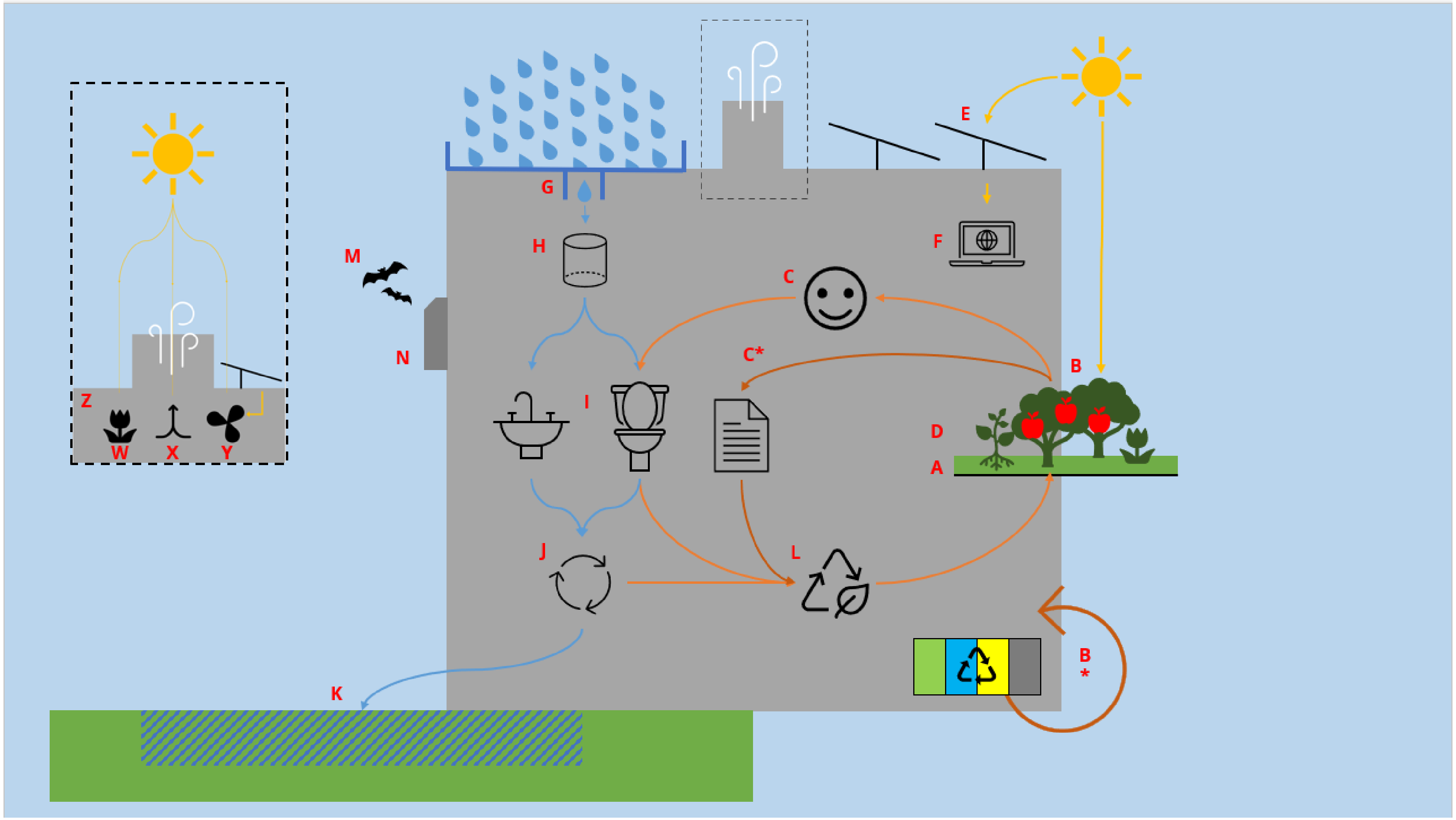
A	Lithosphere
B	Soil
C	(Biomass of) Primary producers
D	(Biomass of) Consumers
E	Atmosphere
E.1	Ozone fraction of Atmosphere
F	Dead organic material
G	(Biomass of) Soil biology
H	Water
H.1	Clouds

References for Stocks and Flows classification: Campbell *et al.* (2015) and Kumar & Mina (2021, p. 42-50)

Flows

1	Soil formation through rock weathering and Soil biology activity
2.1	Material and Water extraction from Soil
2.2	CO2 extraction from Atmosphere
2.3	Fixation of Solar Energy
2.4	Excretion of O2 to Atmosphere
3	Mass and Energy flow through Food web
4	Respiration, Transpiration/Excretion, Death
4.1	O2 extraction from Atmosphere
5	Fossilisation
6	Decomposition
6.1	Gasses coming from abiotic decay
6.2	Material coming from abiotic decay
7	Ozone cycle (under influence of lightning)
8	Combustion
9	Rock formation
10	Heat loss from all parts of the system

Appendix V – Conceptual setup of ecosystem services delivering infrastructure for a building



Legenda: See Appendix III column 5

Appendix VI – Framework describing the ecological system of ecosystem services delivery

ECOLOGICAL SYSTEM FRAMEWORK		Definition	Link to ES from typology Pedersen Zari (2018)	Matching ecosystem structures and processes (from Appendix III column 3)
Stocks				
Lithosphere	Crust/Rock	“	N.A.	
	Soil	“	N.A.	
Biosphere	(Biomass of) Primary producers	“	N.A.	
	(Biomass of) Consumers	“	N.A.	
	Death organic material	“	N.A.	
	(Biomass of) Soil biology	“	N.A.	
Atmosphere	General	“	N.A.	
	Ozone fraction	“	N.A.	
Hydrosphere	Cycling through the different stocks	“	N.A.	
Flows				
Lithosphere/Soil composition regulation		Flows between stocks that influence the composition of the soil or the entire lithosphere	**R Purification** - ~~Water~~/~~Air~~/Soil **S Soil** - Formation - Renewal of fertility - Quality control **S Nutrient cycling** - Regulation of biogeochemical cycles - Retention of nutrients	Soil food web, see Nutrient cycling [25] Rock weathering creating mineral particles [17], [35, p. 3] Soil biology activity [17], [26], [15, p. 4] Detritus as input [15, p. 4] Humus as product [15, p. 4] Enabling soil containing water [15, p. 4-5] Enabling soil containing air [15, p. 4] see Nutrient cycling ***Nutrient cycling*** Water [26]: Precipitation (Intake by organisms) [Author] Evaporation Transpiration Infiltration Runoff (Collection) Subsurface water Cloud formation Other terrestrial mineral cycles [15, p.42-50]: *C = Carbon cycle* *N = Nitrogen cycle* *O = Oxygen cycle* *S = Sulphur cycle* *P = Phosphorus cycle …*

(Continuing)

			Pools [27, p.351] Fluxes between pools [27, p.351] Reservoir (A) = Living organisms Flux (A>B): Fossilisation [C, S] Reservoir (B) = Coal, Peat, Oil Flux (B>C): Burning/Combustion [C, S] Reservoir (C) = Water, Atmosphere, Soil Flux (C>D): Rock formation [P, S] Reservoir (D) = Minerals in rock Flux (D>C): Weathering, Erosion (and Leaching) [P, S] Flux (C>A): Assimilation [Plants: P], Photosynthesis [Light reaction: O; Carbon cycle: C] Flux (A>C): Respiration [by ALL organisms: C, O; by soil organisms: N; non-biological nitrogen fixation: N], Decomposition [by Soil Food Web: C, O; Abiotic: C, O], Excretion [by Soil Food Web: N, S, P], Precipitation [S], Volcanic eruption [S] [15, p.42-50], [adapted from 15, Figure 2.9 p. 44, Figure 2.10 p.45, Figure 2.11 p.47, Figure 2.12&2.13 p.48]
Biosphere composition regulation	Flows between stocks that influence the composition of the biosphere	**R Decomposition** - Waste removal **S Fixation of solar energy** - Primary production/plant growth (above ground, below ground, marine, fresh water) **S Nutrient cycling** - Regulation of biogeochemical cycles - Retention of nutrients	Micro-organisms in soil and water [1, p. 643], see Nutrient cycling Photoautotrophs (plants, algae, cyanobacteria) > Photosynthesis (Light reaction (=fixation) and Calvin cycle (=primary production)) [1, p271], see Nutrient cycling **…**

(Continuing)

					See ***Nutrient cycling*** column 4, row 13
Atmosphere composition regulation			Flows between stocks that influence the composition of the atmosphere	**R Climate regulation** - GHG regulation **R Purification** - ~~Water~~/Air/~~Soil~~ **S Nutrient cycling** - Regulation of biogeochemical cycles - Retention of nutrients	Air pollution removal by vegetation [23], [24] See ***Nutrient cycling*** column 4, row 13
Hydrosphere composition regulation			Flows that distribute water between the different stocks	**R Purification** - Water/~~Air~~/~~Soil~~ **S Nutrient cycling** - Regulation of biogeochemical cycles - Retention of nutrients	Biophysical filtration by soil [22, p.2] See ***Nutrient cycling*** column 4, row 13
Mitigation					
Soil regulation			Factors that influence soil retention/erosion and the prevention of landslides	**R Prevention of disturbance and moderation of extremes** - Erosion control	Ground cover by vegetation, causing roots to hold the ground [13, p.156]
Biology regulation	Life cycle	Habitat, Species maintenance (Biodiversity/Natural selection/Self organisation), Pollination	Factors that ensure the ongoing presence of the biosphere	**R Pollination and seed dispersal** **S Habitat provision** **S Species maintenance** - Biodiversity - Natural selection - Self-organisation	Organisms (seed producing, pollinators (insects, birds, mammals)) [2, p.633], see Species maintenance Wind [2, p.633] Water [2, p.633] The place where an organism usually lives; the environment in which the life needs of an organism are supplied [27, p.457] The presence of species that together provide the ecosystem services. This presence is formed by evolution based on genetic information and natural selection, and the provisioning of ecosystem services on self-organisation. [inspired by 17]
	Pests/ Diseases	Different existing hypothesis and strategies (Kumar & Mina, 2021, p. 159)	- Factors that that influence the abundance of human pathogens or disease vectors	**R Biological control** - Pest regulation - Invasive species resistance - Disease regulation	E.g.: - Species diversity (leaving fewer resources for invader, decreasing **...**

(Continuing)

			(carriers, like mosquitoes) - Factors that influence the prevalence of crop and livestock pests and diseases		survival) [1, p.1289] - Soil biology (supporting succession state, therefore preventing weeds) [14, 40:18-57:43] - Hypothesis: Species richness in relation to ecosystem size [35, p.159] - Hypothesis: Minimal disturbance of ecosystems [15, p.159] - Hypothesis: High environmental heterogeneity [15, p.159]
Climate regulation			(Meaning not the atmosphere composition, but) mitigation of temperature, UV, noise	**R Climate regulation** - UV protection - Moderation of temperature - Moderation of noise	(Formation of) Ozone [16], [15] Vegetation (local scale) [17]
Water regulation			Factors that influence runoff, flooding and aquifer recharge	**R Prevention of disturbance and moderation of extremes** - Wind/~~wave~~/runoff force modification - Mitigation of flood/drought	Physical barriers like vegetation cause wind speed to drop below a certain threshold (e.g. erosion initiation prevention starts at a threshold of 5 m/s, 0,3m above ground) [13, p.359-360] Soil structure and texture with low erodibility, good soil infiltration and storage and vegetation cover [13, p.294] Dense vegetation barriers like tidal marshes [18] and mangroves [19] Wetlands [20] Interception [21]
Coastal protection			Factors that influence the size of damage caused by hurricanes or large waves	**R Prevention of disturbance and moderation of extremes** - ~~Wind~~/wave/~~runoff~~ force mitigation	Dense vegetation barriers like tidal marshes [18], mangroves [19], floodplain forests and wetlands [13, p. 156]

(Continuing)

Extraction (more detailed categorisation is optional following CICES)			
Food	Biomass that can be eaten	**P Food**	All forms of life that are not top predators [1, p.1290] Organic compounds/Detritus [1, p.710, 1306] Mineral nutrients/Dissolved compounds [1, p.637-638, 650], [2, p.119] see Nutrient cycling, see Fixation of Solar energy
Biochemicals	Biomass that can be used as/to manufacture medicines and other biochemicals	**P Biochemicals**	Chemicals coming from organisms [3] Materials extracted from the lithosphere [4, ch. 1]
Raw materials	Biomass that can be used as raw material	**P Raw materials**	Extracted primary production (not destined as food) [5], [6], [7, section 1] see Nutrient cycling, see Fixation of Solar energy Materials coming from animals [7, section 1] Materials extracted from the lithosphere [7, section 2 and 3]
Fuel/energy***	Biomass that can be used as fuel	**P Fuel/energy**	Biomass [8, 9 p.35], see Nutrient cycling, see Fixation of Solar energy Technologies for renewable energy [10]
Water	Water that can be consumed	**P Fresh water**	Water [11], see Nutrient cycling
Genetic information	Genetic material, coming from organisms, that can be used for gene editing	**P Genetic information**	(Genetic diversity of) organisms [12, p.12-19], [13, p.153], see Species maintenance

Appendix VII – Science communication table with guidelines, indicators and requirements for buildings designed for building developers

Design guidelines	Indicators	Requirements
Provisioning of renewable energy		
Is all of the energy required by the building generated renewable?	Amount of energy required by the building and the building's inhabitants (kWh/year)	
	Amount of renewable energy produced by the building (kWh/year)	Amount of renewable energy produced by the building should be more or equal to the amount of (renewable) energy required by the building and the building's inhabitants
	Energy storage capacity in the building (kW)	Should at least match the maximum temporal differences between energy generation and demand
Provisioning of biomass		
What is the size (m^3) of the area that is covered with vegetation?	Area size (m^3) covered with vegetation	
Is this area equal to or larger than the building's parcel size?	Building's parcel size (m^3)	
	Vegetated area < / = / > Building's parcel size	Vegetated area should be larger than or equal to Building's parcel size
Does the vegetation grow on either soil beds or other substrates?	Types of growth bed (soil bed, hydroponics, on a wall, etc.)	
	Area size soil beds (m^3)	
	Area size substrates (m^3)	
Is the vegetation native?	Location where every species of vegetation in and on the building natively occurs	Native location should be local for every species of vegetation that is in or on the building
Does the vegetation type and quantity provide all the by the building inhabitants required food?	Type of food that is required by the building inhabitants	
	Amount of food that is required by the building inhabitants (kg)	
	Type of food that is provided by the planted vegetation	Type of food provided by the building should be equal to the type of food required by the building inhabitants

(Continuing)

Design guidelines	Indicators	Requirements
	Amount of food that is provided by the planted vegetation (kg / kcal / g protein)	Amount of biochemicals provided by the building should be equal to or more than the amount of biochemicals required by the building inhabitants
Does the vegetation type and quantity provide all the by the building inhabitants required biochemicals?	Type of biochemicals that is required by the building inhabitants	
	Amount of biochemicals that is required by the building inhabitants (kg)	
	Type of biochemicals that is provided by the planted vegetation	Type of biochemicals provided by the building should be equal to the type of biochemicals required by the building inhabitants
	Amount of biochemicals that is provided by the planted vegetation (kg)	Amount of biochemicals provided by the building should be equal to or more than the amount of biochemicals required by the building inhabitants
Does the vegetation type and quantity provide all the by the building inhabitants required raw materials?	Type of raw materials that is required by the building inhabitants	
	Amount of raw materials that is required by the building inhabitants (kg)	
	Type of raw materials that is provided by the planted vegetation	Type of raw materials provided by the building should be equal to the type of raw materials required by the building inhabitants
	Amount of raw materials that is provided by the planted vegetation (kg)	Amount of raw materials provided by the building should be equal to or more than the amount of raw materials required by the building inhabitants

(Continuing)

Design guidelines	Indicators	Requirements
Does the vegetation type and quantity provide all the by the building inhabitants required fuel/energy?	Type of biomass that is required by the building inhabitants as fuel	
	Amount of biomass that is required by the building inhabitants as fuel (kg)	
	Type of biomass for fuel that is provided by the planted vegetation	Type of fuel biomass provided by the building should be equal to the type of fuel biomass required by the building inhabitants
	Amount of biomass for fuel that is provided by the planted vegetation (kg)	Amount of fuel biomass provided by the building should be equal to or more than the amount of fuel biomass required by the building inhabitants
Is harvesting of all the biomass done is a regenerative way?	YES/NO	Should be YES This means that harvesting practises do not degrade the capacity of the vegetation (also the quality of the soil) to grow the same amount or more harvestable biomass the next growing season
Does the vegetation provide all the by the building inhabitants required vegetational genetic information?	Plant species of which a genetic bank is required	Required genetic bank EQUALS Species present
Is the vegetation diverse and heterogenous?	YES/NO	Should be YES
Is the soil inoculated with Effective Microbes matching the Soil biology needs of the planted vegetation?		
Does the soil have the right quality? *+ Monitoring guidelines: What is the quality of the soil? → To enable maximum water storage, soil retention, nutrient cycling*	Amount of bacteria present in the soil (individuals g/cm^3)	Should match the requirements of the vegetation present, can differ between vegetation patches - inoculated soil with Effective Microbes if necessary

(Continuing)

Design guidelines	Indicators	Requirements
	Ration bacteria/fungi present in the soil (g:g)	Should match the requirements of the vegetation present, can differ between vegetation patches - inoculated soil with Effective Microbes if necessary
	The amount of water the soil can hold/Water retention capacity of the soil (l water per m^3 soil)	Should match the requirements of the vegetation present, can differ between vegetation patches - inoculated soil with Effective Microbes if necessary
Is all the dead vegetation/organic material left on top of the soil or collected and composted?	YES/NO	Should be YES
Does the vegetation receive the required amount of sunlight?	The amount of sunlight required by every vegetation species planted (lumen / sun hours a day)	
	Amount of sunlight reaching every area covered with vegetation (lumen / sun hours a day)	Should match the requirements of the vegetation present
Water cycling		
Is the amount of water required by the building and the building's inhabitants (or more) collected from the atmosphere (precipitation, condensation)? *Water could also be collected from streams, but this could lead to depletion	Amount of water required by the building inhabitants (l/day / l/year)	Amount of water collected and (re)claimed should be more or equal to amount of water required by the building inhabitants
	Amount of precipitation per year (mm/m^2 on building's parcel)	
	Amount of precipitation that is collected (l/year)	
	Amount of water that is (re)claimed (l)	
	Amount of water that can be stored in the building (l)	

(Continuing)

Design guidelines	Indicators	Requirements
Is all the collected and (re)claimed water filtered to purity standards?	Filtering capacity for collected water (l/day)	Filtering capacity should match the amount of water collected or (re)claimed
Is all grey water filtered to purity standards?	Amount of grey water (l/day / l/year)	
	Filtering capacity for grey water (l/day)	Filtering capacity should match the amount of grey water created
Is grey water reused?	Percentage of water that is reused	Will be used to fill the water shortage gap
Is all used water infiltrated into the ground or used for irrigating the buildings vegetation? *Can water leave the soil beds to prevent flooding?	Infiltration capacity infiltration area ($mm/m^2/day$ / $mm/m^2/year$)	Infiltration capacity should match size of water body
	Amount of water lead to infiltration area ($mm/m^2/day$ / $mm/m^2/year$)	
	Amount of water used for irrigation (l/day / l/year)	
	Amount of water lead to the sewage (l/year)	Should be ZERO
Enabling Nutrient cycling		
Is all human excretion collected in recyclable/compostable waste streams?	Amount of human solid excretion collected (kg/year / m^3/year)	
	Amount of human liquid excretion collected (l/year)	
	Percentage of human solid and liquid excretion ending up in the sewage (kg/year)	Should be ZERO
Are all used materials collected in recyclable/compostable waste streams?	Types of material streams	
	Amount of material per stream (kg/year)	
	Amount of material to landfill or incinerator (kg)	Should be ZERO
Are no toxic chemicals released in the building's water system?	YES/NO	Should be YES
Are all materials filtered out of (used) water collected in a compostable waste stream?	Amount of filtration residue (kg/year)	
Are all compostable waste streams being composted?	Composting capacity (kg/year)	Should match material streams sizes

(Continuing)

Design guidelines	Indicators	Requirements
Is all the compost annually distributed over the soil beds? (No tillage!!!!)	Amount of compost distributed over the buildings soil beds (kg/year)	
	Thickness of compost layer distributed over the buildings soil bed once a year (cm)	Aim should be around 2 cm
Is all imported material recyclable?	Percentage of imported material that is recyclable	In case of imported materials should be 100%, but import of materials should be 0 kg/year
Are all the recyclable waste streams being recycled?	Percentage of material recycled per type of recyclable material stream	Should be 100%
Atmospheric composition		
Does the vegetation fixate as much or more CO_2 than is produced by the building's inhabitants through breathing or the combustion of biomass/materials?	Amount of CO_2 respirated by building inhabitants (kg/year)	
	Amount of CO_2 emission through combustion (kg/year)	
	Amount of CO_2 fixated (kg/year)	CO_2 fixation should be more or equal to CO_2 respiration/emission
Does the vegetation replenish as much or more O_2 than is consumed by the building's inhabitants through breathing or the combustion of biomass/materials?	Amount of O_2 needed by building inhabitants (kg/year)	
	Amount of O_2 needed for combustion (kg/year)	
	Amount of O_2 replenished by vegetation (kg/year)	O_2 replenishment should be more or equal to O_2 respiration or combustion
Does the vegetation fixate as much or more [gas] than is produced by the building's inhabitants through the combustion of biomass/materials?	Amount of [gas] emitted (kg/year)	
	Amount of [gas] fixated (kg/year)	[gas] fixation should be more or equal to [gas] respiration/emission
Does the vegetation replenish as much or more [gas] than is consumed by the building's inhabitants through the combustion of biomass/materials?	Amount of [gas] consumed (kg/year)	
	Amount of [gas] replenished (kg/year)	[gas] replenishment should be more or equal to [gas] respiration or combustion

(Continuing)

Design guidelines	Indicators	Requirements
Can the building be ventilated?	YES/NO	Should be YES
Continuation of life		
Which animals are native in the buildings surroundings?	List of animals natively occurring locally	
Are habitats present for the native animals in and on the building (nature inclusive building practises)?	Habitats present per natively occurring animals species (# / m^2 / m^3)	
What are the food types eaten by the native animals?	Food types eaten per native animal species	
Is vegetation present providing the food types/requirements of the native animals?	Vegetation occurring in or on building that provides food type required by native animals	If it is correct the pollinators of the vegetation present in and on the building are part of the native animals.
Are regenerative agriculture practises used to mitigate diseases/pests/weeds?	YES/NO	Should be YES
Mitigation		
Are all the soil beds covered with vegetation? / Is no soil left bare?	YES/NO	Should be YES
Is a part of the vegetation perennial, so that roots can continually hold the soil?	YES/NO	Should be YES
Does strategically placed vegetation/barriers provide a shelter against UV?	Maximum amount of UV radiation exposure for building inhabitants ($mW/cm^2/nm$)	Should be below by local health organisation or government recommended UVI
Does strategically placed vegetation/barriers provide a shelter against extreme temperatures?	Temperature reduction through vegetation/barriers (degrees Celsius)	
	Maximum temperature experienced inside the building	Temperature experienced inside the building should be less than by local health organisation or government recommended maximum temperature
Does strategically placed vegetation/barriers provide a shelter against disturbing levels of sound?	Maximum sound level experienced inside the building (dB)	Maximum sound level experienced inside the building should be less than local health organisation or government recommended $L_{Ar,LT}$ and L_{Amax} (NAB, 2017)

Appendix VIII – Full transcript of interview with Catalina Bustillo on the 26th of October 2021

Due to the large size of this Appendix, the transcript of the interview can be obtained as a separate document via the author of this report.

Appendix IX – Text fragments from interview with Catalina Bustillo ordered using keywords

BIOMIMICRY

ELEMENTS

00:00:30 Speaker 2

ethos is going to be the wrapping of the whole thing. The ethos part, because that's the whole.

00:00:36 Speaker 2

You know, like that's the whole create conditions conducive to life element of it. Like everything in nature, creates conditions for other lives to continue to thrive.

00:02:33 Speaker 2

then bringing the reconnect piece is just being, Just being very conscious and and creating activities that actually reconnect you to the place, because right now the discovery process and the, you know, it's ideal if you go out into nature and look, but it may not be ideal, it needs to be part of the bio mimicry thinking process, to go out and connect with nature.

00:08:39 Speaker 2

To me, is how do I how can I integrate the two other elements into that bio mimicry thinking process in a way that it doesn't become a burden for the process, but it's already hard. Because, you know. We can do whatever we want, but it's like if people are going to look at it and be like oh, then it's like it's not gonna work. No too much work.

00:10:49 Speaker 2

So like that's that's one side of the coin and the other side is OK, So how do we integrate the other two elements. And I think ecosystem services are the key to integrating the ethos or creating conditions conducive to life into the bio mimicry thinking framework and how to do.

01:22:06 Speaker 2

You know, that's why I want to integrate the other elements in a very visible way in the framework because. It's not like. Yes, if we create a design that is closer to the way that nature designs, then it's going to be more efficient than in a way we are contributing to the environment, right. We could do more. So, so it's it's so it to me it's like we generate bio mimicry. Like we need regenerative biomimicry, not only biomimicry

QUESTIONS ABOUT DESIGN / ecosystem services

00:00:46 Speaker 2

So how do we. How do we make sure. That our designs are part of that same rhythm, right, so, and and to me the way that I find that we can do that is the ecosystem services and the ecosystem services thought. Like yes, they serve us, but then how do we.

How do we transform them. So that we understand that we also need to provide the ecosystem services.

00:01:50 Speaker 2

So anyway, so my hope is that in that bio mimicry thinking framework, when we are in the context part, when we're in the scoping part of the process, we figure out what ecosystem services Are being affected by whatever we're designing and we figure out what ecosystem services we're we wanna affect. Like, either, It's either because we are affecting them in a negative way or because we see a possibility of providing a positive effect.

ACCESSABILITY OF BIOMIMICRY

00:09:06 Speaker 2

And and, uhm, and one of the things that's interesting to me is how how to make Bio mimicry accessible not only from the language perspective but also from the complexity perspective. Like how do we, how how can we make bio mimicry understandable to anybody. Anybody that it's not a you know client even if they don't get to that depth you could still. Practice bio mimicry.

00:10:29 Speaker 2

But anyway the the whole thing is like I want those people to value the knowledge that they have and I want them to be able to transform that knowledge into a practice using bio mimicry into a practice that they can apply so. It's all about making bio mimicry simple and easy to use.

BIOMIMICRY 3.8

01:21:30 Speaker 2

I think that the 3.8 perspective is Ecocentric in its roots. I think that in the practice it's still far from it, it tends to be attributes.

01:24:26 Speaker 2

I I think you make a really good point and for example bio mimics like me that have been like for a long time in bio mimicry, we've been taught that we can mimic forms process or systems. Commercially bio mimicry is known for forms. So yeah, so that's why I say the root yes, because the way that that we are being taught and the way that we have been thaught. You know it has to do with processing systems too and form is like the shallow level of application of bio Mimicry,

01:25:36 Speaker 2

Because process and system is harder to do

EFFECT OF QUESTIONS ON ACTORS

AVERSION

00:01:20 Speaker 2

I feel like the way to get people sometimes into things, it's through the sides and not directly up

00:01:24 Speaker 2

...how do you ask a set of questions [...] Without, without maybe generating a first reaction or negative reaction.

00:14:33 Speaker 2

People don't wanna feel bad or people don't wanna feel… People tend tend to feel defensive in the questions.

00:18:14 Speaker 2

I make a comment right now that is offensive to you. And it's not because I want to be offensive. It's like I have no idea, you know, if you grew up with X or Y. You know, and I made a comment and it hurt.

00:22:05 Speaker 2

If you approach somebody like I feel like if I was approached with many questions with a lot of data and complex questions that are outside of my comfort zone. All of this. It sort of creates, uh, rejection.

00:24:24 Speaker 2

So I feel like this information you can get out without saying equal to or larger than the building's parcel side because there's a hidden message somehow in that collection, like, is it good that it's bigger, or is it good that it's smaller like.

00:25:35 Speaker 2

So that's that's why I think that that's the tricky part, because do people feel nudged or do people feel this defensive and I. People feel defensive because that's the way that we are set up as humans.

00:26:26 Speaker 2

Well, I think you can nudge, but but I think it's when to nudge.

00:36:33 Speaker 1

Oh yeah, so if you leave it to free you say you have all the design freedom in the world. It's like "no, this is too difficult."

00:37:09 Speaker 2

...the vegetation type and quantity provide all the building habitats required biochemical. And I'm gonna go like. Second question, I don't know what you're talking about, and I'm not sure like I'm ever going to provide that for my habit, like I have no idea if that's a question. The first question that I read, I'm gonna go like, no. It doubles that, yeah.

POSSITIVE

00:35:02 Speaker 2

And because like everybody knows, solar panels and everybody. [...] So so those things people already feel like, yes, it's something that they can do.

00:35:48 Speaker 2

If people feel like if you say oh solar panels and people say yes and then you say what effect you know collect water, yes. Then people start feeling good and like, Oh yes, I'm we're generous. And then the other things. Want to set up in a way that people are like happy, happy, happy and like I can do that. Yeah, like it doesn't feel like a long stretch and I have to do like this whole like I have to relearn how to do my whole process again.

00:37:43 Speaker 2

Uhm, after I already know that I'm putting solar panels that I'm gonna, you know, collect water and recycle the water and I'm going to do like have this vegetation incorporated and you know increase the vegetation inside the building and you know all other stuff. And then you ask me that and that. And then I'm gonna make a like "I'm not sure what you mean but I tackled all the other things, so this will work, it might work. Yeah, and you know I don't, you know, just tell me what this means and maybe I can get it."

AH MOMENT

00:41:00 Speaker 2

because I'm I'm looking for an Ah moment.

00:41:10 Speaker 2

Once you tell once people say like, OK, I'm gonna I can do this, this, this and this and you start like OK you know you are providing this ecosystem service. This is how much you're giving. This is how much you're contributing. Then it's like, oh, like you know it's it's like. I'm doing it. And it's a instead of. I feel like if you go like. If it, if the if if it's the goal is something that they see very big, it's like. Unachievable, but if you say only by doing these five things, you're gonna get here. People are gonna probably want to Get there and So then how can we get a little bit farther. You know, and then you give them the answer For that, it's it's. It's a positive reinforcement positive feedback loop.

01:09:45 Speaker 2

We don't need to do much like, we just need to allow nature to do it.

LACK OF MONEY IS A DIFFICULTY

00:08:10 Speaker 2

So bio mimicry, it's not a simple process like actual practice of bio mimicry is very complex. Uh, in it's whole process, but it's also because of the research that goes into it, and translating that that nature knowledge into something that we can use in other disciplines.

00:52:41 Speaker 2

Now from the logistics perspective, having those ecosystem like political performance standards, it's not easy like. It's a whole process. It's a whole research. Yeah, you need to you know, hire a huge team and do a huge project, that's why you know it's Ford, it's Microsoft, It's those kind of companies that can actually do it.

00:53:56 Speaker 2

If I don't have anything and that you're not, you don't have the money. I don't have the money, so it's like, but you still want to have regenerative design. How do we make sure that we integrate that and how do we make sure that we use the ecosystem next door so.

THE IMPACT OF ARCHITECTURE

ARCHITECTURE

00:04:57 Speaker 2

So when I went to study architecture and at some point I had issues with the fact that we were those you know as architects, great contributors to climate, Uhm, problem and climate change and were, like, responsible for a lot of the state of the planet. So that created, you know, that that was a conflict for me.

CLIMATE PROBLEMS

01:01:19 Speaker 2

We are not contributing in a positive way. We are only generating negative effects, so that's not. You know that's not a way of being a good team player.

BIOMIMICRY/CONTRIBUTE TO NATURE

00:06:11 Speaker 2

Heard this talk about bio mimicry and it was like I saw the light. And because I saw how, How I could finally integrate those two sides of of me but also of you know of doing things. And I thought and I sort of like made peace with the fact that as architects, we didn't have to destroy the planet, so we could contribute positively in a positive way.

00:06:35 Speaker 2

As architects, we didn't have to destroy the planet, so we could contribute positively in a positive way.

POSITIVE CONTRIBUTION TO NATURE

REGENERATIVE BUILDING DEFINITION

01:05:26 Speaker 2

So it would be something allowed along the lines of. Does it contribute positively to other species besides humans? And maybe the environment. But I would say others because it contributes possibly.

01:10:09 Speaker 2

So I think a way to contribute and to be regenerative is to generate the conditions for nature to be able to do its normal processes.

[SELF SUFFICIENT:] 01:10:32 Speaker 2

And of course, uhm and well, no, there's another way is that just. Being self sufficient or as much as self sufficient as you can without so that you don't extract more from nature, right?

01:10:57 Speaker 2

Is I think there's very different perspectives like like one is allowing for the processes we talk about. Let let's give space, don't interrupt the process. Let them flow. That's one, then the other one is OK I have needs and I've been getting those needs from nature like energy OK, is there a way that I cannot like I don't get them from nature and I get them from another source. Solar panel, that's another option.

[definition regenerative building:] 01:06:03 Speaker 2

To me it's all about the role. Does it play a positive role. In the environment. And does positive mean extra or not not deplete not destructive. Positive is beyond beyond zero, like it's not not destructive, it means purposely contributing, contributing. Like to me we what ever means purpose. Is purposefull and it's positive.

SYSTEM DESIGN

DESIGN CONNECTED

01:31:55 Speaker 2

... they have like gardens all over the house and they set it up in a way that the roots of the plants throughout the whole house connect the roots. OK, because you know to promote mycelium networks so they did not do isolated pots. You know, but yeah, it's a whole connected system. It's a completely different way of designing with that very simple act. That's what I mean of creating the conditions for nature to do its work.

BUILDINGS CONTRIBUTE TO THEIR SYSTEM

01:11:34 Speaker 2

What is my. What is that building's role. [...] In that production, or that or those services, because I may have the conditions to produce a lot of energy that it's beyond what I need. So if I'm if I'm extrapolating like if I'm if I'm being more metaphorical about that ecosystem, it's my ecosystem is the other or my system is the other buildings around me and maybe I'm a great generator of energy, so I provide that to myself and to the other one you know to the building next door, but I'm really bad at the water cycle and then that other building helped me out with the water cycle.

01:12:29 Speaker 2

Understanding your part of the system, yes, and contributing to it because it's a way that nature works like not one Organism does all the jobs like they they are spread and they. Each contribute in a different way. So it's like we all need to contribute in a different way, we don't have to contribute in the same way, yeah.

01:13:27 Speaker 2

And I think a question that I'm using a lot is like What other organism can I have an effect on? Like what other Organism can I help out.

EGO-LOGIC VS ECO-LOGIC

01:16:56 Speaker 2

[SHOWING A POWERPOINT PRESENTATION]

Yeah, yeah, so this this shows us like these are all and this is the same. You know mindset man on top and everybody else on the bottom. And what I'm saying is. We cannot see each other this way because we also play a role in the system, so we are contributing… This is a nest. So we are contributors of raw materials for other species, so that's it. This is what I'm saying. We contributed raw materials to these species and this is what they build. You know we play a role.

QUESTIONS

LEVELS OF QUESTIONS (related to aversion)

00:13:58 Speaker 2

And I think there's going to be different levels of questions...

00:21:45 Speaker 2

I think that there needs to be sort of like levels or stages like.

00:22:29 Speaker 2

So so I'm so I'm wondering if it could be like this entry level questions that would give a first a first glimpse and then you can go into more in depth questions and sort of like guide the process.

00:38:36 Speaker 2

One thing is to ask the question and the other rhing is, what do you do with the data.

SUGGESTION SCENARIOS

00:38:40 Speaker 2

So if you ask the question and I can answer you truthfully and I can say no My my you know this is the size of my building parcel up and then you like after in the analysis page it says like OK greater that or less than or equal then then. If it's equal then this. Is what you do. If it's the same, you know if. It's smaller then this is what you do. Like that becomes a strategy, it doesn't become a question at the beginning.

00:39:54 Speaker 2

So so and and at the end if I'm doing, if I'm incorporating and this is because technically I want to do it, so I just want you to tell me what to do. I don't and it's what we talk about. We are either they don't care or most people don't care to know about the ecosystem services. Just tell me what do I have To do.

LIFE'S PRINCIPLES IN QUESTIONS

01:27:28 Speaker 2

Trying and use Bio mimicry or the life principles in the design of the questions, not as a not as a theory, in a way, but as a practice.

01:27:56 Speaker 2

Like try to see like if you take a life principle and see how that principle can play out into the questions. In a way. Umso, for example, adapt to changing conditions.

01:28:22 Speaker 2

How can I make my questions adapt to changing conditions.

NEW INTERVIEW

00:35:28 Speaker 2

Side note, my suggestion is that if you can again somebody from, you can get a psychologist or somebody with experience in questions

REQUIRED KNOWLEDGE

IMPLICATIONS OF QUESTION TYPE

00:12:45 Speaker 2

So I I did some trial with more open questions.

00:13:07 Speaker 2

Having any effect on or any relationship to raw materials produced by nature. And then this person that I was interviewing he was like no I I don't have anything to do with raw material. I'm like OK. And then as we continue through that through the questions, Uhm, he ends up talking about, you know, using a bunch of raw materials, and I'm like, they did it like, in his head he was not using raw materials.

CONNECTION TO/WITH NATURE

00:09:41 Speaker 2

People that work with us there a lot of them had very basic formal education. Exactly don't even know how to read or write.

00:09:58 Speaker 2

But these people have a lot of knowledge about the environment, because that's where they grew and it usually is at least here in Latin America, that the people that have less financial resources are more connected to nature.

00:15:51 Speaker 1

Uh, from the person answering "I have nothing to do with raw materials". Do you think that it's, uh, that he just doesn't understand that he does not understand the definition of raw materials, or do you think that he looks at nature in our connection with nature, completely different. 00:16:16 Speaker 2 I think it's more about not even realizing it.

00:16:20 Speaker 2

Not that they don't know the definition. It's like they. Like they don't. They don't even see the connection. [...] Like for example, you go to the supermarket and you pick up an apple. You have no connection, no idea where that apple is coming from no.

00:19:10 Speaker 2 * Author's note: her goal of how to connect people again to nature following the biomimicry principle of Reconnect

So it's like how can you ask questions to create that relationship to to? So my my goal what I want to do like I still don't know how but what I want to do is throughout the questions create that bridge or that connection without people being aware that we're creating the connection, yeah. So you start and it's sort of like it starts building the connection, building the connection. And at the end you you sort of transform the persons view just by asking the questions.

KNOWLEDGE REQUIREMENTS

00:15:14 Speaker 2

I think it needs to be things that are very easy to respond without having to explain what ecosystem services are, because many people are not interested in knowing what the ecosystem services are.

SCOPE

TARGET GROUP

00:42:39 Speaker 2

I think that everybody that is involved in the building. Design and indeed should be involved in this. Because yeah, yeah, I think it's something that but the whole team should know in order to be aligned.

00:43:02 Speaker 2

So the engineer. The you know engineer, meaning the the structural engineer, the engineer, the landscape. Uhm architect the the I don't know if one can be the designer and the other can be the construction constructor so if they're different then both of them need to be involved.

00:43:42 Speaker 2

Because the building doesn't work otherwise, like even for you know I as an architect, I can design whatever I want, but if I if I if I don't integrate the electrical engineer needs then my design is not gonna work, yeah.

00:46:26 Speaker 1

So everybody needs to continue talking with each other all the time, yeah, so it's a combined process. Combined meetings.

DESIGN STAGES "phases"

[Questioning Speaker 1 on when to integrate ES into a design]

00:27:47 Speaker 2

Do I go ahead and answer those questions now before I start on the design? Or I'm like up, do I already have like a preliminary design. And then I try to integrate those ecosystem services into that preliminary design.

00:28:59 Speaker 2

Well, I I think that ideally it would be at the beginning, but in reality. It would probably be much farther into the process

00:29:07 Speaker 2

The problem, yeah, unless you know, unless for example if I'm gonna do it as an architect because I already am involved in this. You know in this world. Yeah, you are already in. So if but if I'm not and I'm trying to, you know. Get you involved in it. I will do it. Probably when the design is already set, and if I already have a uh building like the like, the project that Katharina is in my understanding. So like it's already. An existing building. So how do you. How do you integrate it to an existing building.

00:29:52 Speaker 2

Important in these type of questions to identify what questions fit all parts of the process and what questions are do not apply if the design is already underway and what questions don't design if don't apply if the project already physically exists

PERFORMANCE STANDARD

ECOLOGICAL PERFORMANCE STANDARD

00:49:12 Speaker 2

Everybody project positive so that project is that they're working with different companies like Ford, Microsoft Interface and they are doing what they call project positive and what it's called, they also call it like factory at the forest, which means taking the ecological performance standards from the ecosystem close to the site and using them as standards for what they're doing.

00:49:50 Speaker 2

Yes, it makes sense to set to set a standard, you know it, it makes sense. Uhm, because I have a goal and then I can try to achieve that goal.

DON'T TRANSFORM THE ECOSYSTEM

00:50:21 Speaker 2

Uh, like an ethical but not ethical ecological part, which is like. You want the ecosystem to provide guidance on what and how it should happen, right. Because if., if you don't have that guidance, then we may end up transforming the ecosystem into something that it's not naturally what it is.

00:52:16 Speaker 1

So, so we have the tendency instead of making like the six month dry period also in the city to move to we have never water shortage. 00:52:25 Speaker 2 And we are better than nature.

ACCESSABILITY

00:53:14 Speaker 2

Like we create standards for every place in the world, and then people can just go and see a graph and say hey, this is what I have to do here.

00:54:30 Speaker 2

But if that becomes a common thing and maybe with time then yes, we should have some kind of standard to follow or. Or sometime kind of data that is like OK, like sort of like law like you know like we want data. So yes, you know the whole city needs to store this amount of water. OK, this is my contribution. What's your contribution then? All contribution OK, we reach that level then we don't need to store more kind of thing, but it's a but I feel like we are

USING A STANDARD IS FAR OUT OF REACH

00:55:22 Speaker 2

Ideally we would have the logical performance standard from the ecosystem next or in reality. Right now. For this time we need to work with alpha. Then maybe have maybe just have a general guide of what it means, like because something very easy. What Biome are you like. What then OK or what ecosystem are you OK. I'm a tropical dry forest, yes, so these are the main characteristic that that means translate that into your building

ANYTHING BETTER THAN NOTHING

00:54:12 Speaker 2

So I feel like. At this point, anything is better than nothing like whatever we can accomplish in our building. I'm sure it's gonna because the rest of the of the place it's not doing anything. Anything that we can do, it's going to be a huge contribution, right.

01:00:17 Speaker 1

Yeah, no standard, no reference point yet. Only a starting point.01:00:20 Speaker 2 ...at this point in time The starting point is enough because anything at this point anything that we can contribute because the amount of people that are contributing is so small than anything that we can contribute, it's.

01:01:07 Speaker 2

So it's not whether we had climate change like take away climate change that we're still we're still taking over the environment, and we are not doing anything we are not contributing.

GUIDANCE

00:11:15 Speaker 2

Could could there be a set of questions that are easy enough for anybody that's doing a scoping process to fill out and have that set off questions show where the leverage points are in regards to the ecosystem service. So that those ecosystem services can be established as intentions, or can be purposely, you know, incorporated into the design.

LEVERAGE POINTS

00:58:40 Speaker 1

To finding leverage points, I would say if you found them, you create created a certain understanding of your ecological environment. 00:58:55 Speaker 2 Yes, well. And no, you created a certain understanding of where you could easily act upon.

00:59:27 Speaker 2

It it it shows you where you can act, but it doesn't show you what the ideal or what the standard is.

UNITS
00:55:52 Speaker 1
But like the but in in like ecological units, measurement units, but. 00:55:57 [??] Or just or.
00:55:58 Speaker 2 Just context units, you know. OK, even even as architects we sometimes forget to understand that we are in a place. So you need to understand that place and understanding that place means what are the environmental conditions of that place.

Appendix X – Summarised answers of Catalina Bustillo to the interview questions

From your point of view, what is a regenerative building?
A building is regenerative if it contributes positively to others, if it allows nature to do it's normal processes/we do not interrupt nature's processes, if a building is self sufficient and thus does not extract from nature, does it play a positive role?

Is there any situation where you would want to compare the ecological performance of a building with that of a natural site?
With Project Positive from Biomimicry 3.8 they are taking the ecological performance standards from the ecosystem close to the site and using them as standards for what they're doing. It makes sense to set a goal.
Have the ecosystem provide guidance for what should happen to prevent changing the ecosystem. Usually as humans we have to tendency to wanting to be better than nature.

If so, in which units of measurement would you prefer to do this?
Context units should be used, describing the environmental conditions of that place.

What is the main existing problem when trying to develop regenerative buildings?
Biomimicry is a complex process, largely because of the large amount of necessary research into nature. A large amount of money is necessary for this much research. The question is how to be able to have regenerative design without the money.

Are there sustainability certifications of which you are a fan and what are there ups and downsides?
N.A.

Would you prefer the integration of such a design guide with an already existing certification matrix?
N.A.

In the international field: does a building development phase know 3 phases (defining, tender, construction)
YES, but also designing itself knows several stages:
Preferably integration happens already in the first phase, but realistically, for example because you are renovating and not building a building, integration happens in a later

design phase and design is already set. Identify which questions fit all design phases and which questions do not fit if the project is already on the way or already physically exists.

Which actors of these phases are concerned with the ecological performance of a building

Whole group involved in the building should be involved (with the ES integration process). It is a combined process.

What is your opinion on the overall setup?

Asking questions the wrong way will make people defensive, offended or reject your suggestions. Questions should not be too difficult or implicating a right way to do it that is possibly different from what the practitioner is currently doing.

Their could be different levels of questions. Split questions concerning data collection and what should be done based on the data.
First collect data via questions and than based on the collected data suggest scenario's.
People just want to be told what to do (added: and not judged for the values given).
Try incorporate the life's principles in the formulation of your question, for example make questions that adapt to changing conditions.
Talk with a psychologist for further development of the questions.

Would open guiding questions be preferred above closed directing questions?

(She has tried open questions) People can have much knowledge about the environment without fully realising their connection to the environment. Via the right formulation of questions she wants to guide the reconnection process.

Do you work with indicators and requirements?

N.A.

Extra relevant information received:

Ecosystem services concept used to create conditions conducive to life

To have our designs create conditions conducive to life we should use the ecosystem services thought. When in the biomimicry process we should figure out which ecosystem services we want to affect.

Allow positive reinforcement

People are already familiar with some solutions, this makes them confident that they can do this stap and possibly also the next step with which they are not so familiar.

Show that something they can do contributes ecosystem services to a specific extent, gives positive reinforcement.

Design a connected system, all parts contribute (differently) to each other
Creating conditions for nature to do its work also means design a connected system instead of in this example isolated pots.
Buildings can produce resources needed by nearby buildings and receive resources produced by these other buildings. In this way buildings are part of a system and contribute to it, no single building has to contribute in the same way.
We should see ourselves as part of the system, because we do contribute to it. For example we contribute raw materials (plastics) to other species for nest building.

Ideally one uses a standard, realistically to start with one finds leverage points
Standards/data for every place in the world should be created (making further research not necessary anymore).
Currently we should use general easy questions about the main characteristics of the environment.
A standard is not yet necessary. Because nobody contributes yet to nature, using only a starting point instead of a whole standard already has a huge impact.
Can questions be set up in such a way that it shows where the leverage points are (instead of needing a whole standard).
By finding leverage points it shows where you can act, but not what the ideal or the standard is.