HOW CAN A BUILDING ACT AS A HEALTHY LANDSCAPE LAYER AND THUS CONTRIBUTE TO THE BIODIVERSITY OF THE CITY?

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ABSTRACT

With the emerging climate change and nature degradation, solutions to the environmental challenges have to be implemented in various industries. The experiment method was undertaken to study symbiotic human and nature connection possibilities through the water and nutrient cycle. The purpose was to elevate the role of the building in enhancing biodiversity in the urban settlement and merge it with the context. The scope of the research paper touches on the building scale to decentralize the existing sanitation treatment in the Netherlands as an alternative solution for the water and nutrient cycle and create a more circular system. The result of the schematic diagram indicates the combination of flows that could benefit both humans and nature.

KEYWORDS: *Architecture, Human, Skin, Ecosystem, Cycles, Nature, Water, Nutrient, Sanitation system, Decentralization*

I. INTRODUCTION

Nowadays, the urban settlement is designed with priority and comfort for people. Humans are disconnected from the natural environment as the knowledge of processes is deficient and fragmented. The artificially engineered infrastructures extract and utilise resources avoiding naturally occurring ecosystems. The traditional architectural projects either reduce impacts on nature or compensate for any residual effects - it seems like the natural ecosystem is perceived as a necessary burden in the design process. (de Vriend, an Koningsveld, 2012, p.9) The decreasing biodiversity occurs in the cities because of, among the others, a lack of space for biota and linear water flows. A healthy ecosystem enhances biodiversity, which is crucial for nature to withstand climate change or any other threats. (Costanza, Mageau, 1999 pp 105-114) There is a potential connection between human and natural cycles in the urban settlement to have a circular flow so that both can gain. **[See appendix 1]**

With all of the threats of decreasing biodiversity and climate change the focus is back on climate adaptation and energy transition. One of the approaches of sustainable urban planning is focusing on closing the linear flow of energy and materials. This research paper aims to study the opportunity to create nature-based urban settlements through utilizing flows of human and domestic waste. Maintaining the circulation of resources on the local scale allows for creating value on the site instead of relocating "waste" where it is impossible to convert and absorb through natural processes because of the volume and time. (Reefsgard, Jenssen, Magid, 2006) Urban waste creates problems on a global scale. The most growing proportion of waste is produced in urban agglomerations, and half of the population are city residents. The threat of the urban management system is that all of the waste flow is directed into one location, avoiding all of the steps of natural processes. As a result, no organisms can gain from the wastewater, which eliminates the possibility to process it efficiently with natural processes.

There are already publications which focus on the topics of biodiversity enhancement. The studied concepts of improving or changing ecosystems look at the vast region to intervene as a landscape rule, for example, sandy coasts or muddy coasts. It is more regional planning than architecture intervention. (van Eekelen, E., Bouw, M. (Eds), 2020, p. 266) The aim of this research paper is to study the integration of human and nature in the building scale on ecosystem level, so that it can complete the existing research on nature based solutions. The scope of research paper covers the service of the building and the surrounding site, studying the possibility to have the closed nutrient and water cycle in the building and its surrounding. It follows the Nature Based solutions principles, which means to " be proactive, utilizing natural processes and providing opportunities for nature as part of the infrastructure development process". (de Vriend, an Koningsveld, 2012, p.9) To answer the question *"How can a building act as a healthy landscape layer and thus contribute to the biodiversity of the city?"* the supporting service of ecosystem is studied in the urban environment with consideration of human well-being and biodiversity benefits. The focus is on altering the infrastructural water system in the urban environment which can embed the natural processes in engineering solutions.

The water cycle is a complex system which can be analysed form landscape to micro level. **[See appendix 2]** The regularity and abundance of its supply are the basis for the society and maintaining ecosystems. (NOAA, 2019)Soil moisture controls the availability of resources to organisms by modifying abiotic processes. Water is a key element influencing the dynamics of an ecosystem. Unfavorable conditions for the limited availability of moisture in the soil slowing down the rate of transpiration, photosynthesis, microbial decomposition and mineralization in plants and microorganisms (eg Baldocchi et al. 2004, Rodriguez-Iturbe, Porporato, 2005). On the other hand, when the soil is saturated with water creating anaerobic conditions, microbial processes such as denitrification and biogenic methane emissions increase (eg D'Odorico, Porporato, 2006). The nutrient cycle is related to the water, as the latter serves as transport and minerals distribution in the land by e.g. washing away or providing certain elements such as nitrogen. The indication of nutrient flow is practical to identify the environmental condition of the suitable type of landscape. In the research paper the role of the water flow is evaluated with the acknowledge of nutrient input as the latter is the persistent element of water cycle.

In the Netherlands, wastewater treatment plants treat 93% of industrial and 98% domestic wastewater. Sometimes the rainwater is also conveyed to the central water system. It means that most of the wastewater flow is directed to one location, treated and released to rivers. (Leenaers, (Ed.) 2012, p. 73) Even effectively treated wastewater can have extensive effects on stream ecosystem structure and function as it unnaturally introduce the water with different chemistry levels than the one in the output location. (Gucker, Brauns, Pusch, 2006) In order to transfer from the regional water purification system, it was assumed that the collection and use of waste locally could contribute to a more local circular model of sanitation and create a connection between human action and the natural environment. To properly dispose of output and reintroduce it into the natural cycle, decentralization of the existing water and sanitation treatment in Western Europe is studied (Tjallingii, 1996) Research paper takes the direction of radical intervention, even though there are still few doubts about introducing the system locally in the Netherlands on a regional level. (Matos, Pereira, Amorim, Bentes, Briga-Sáab, 2014). The hypothesis does not propose replacing the existing water system but showing the alternative pin-application which can contribute to the nature in the city. To proceed with the research the three topics are studied; people's potential for contribution to the nutrient and water cycles, healthy terrestrial ecosystem and integrations of those into the urban settlement on a building scale. In the ideal scenario all of the water and nutrient flow from the building is utilized an introduced into the local site with no harm to the existing nature and human well-being.

II. METHODOLOGY

2.1. General overview of the method

The appropriate method is required to answer the research question "How can the design of a building act as a healthy landscape layer and thus contribute to the biodiversity of the city?". The methodology for this research paper is following the strategy research-by-design which in this case experimental strategy is supported by literature review to gather relevant data for schematical prototype. The research paper elaborate and extend the existing ecological, architectural theories and simulates potential solutions based on parameters drawn from theories of other sciences related to the landscape for example water management.

2.2. Framework with subquestions

The main question is divided into three subquestions to create the framework in which the research paper is maintaining the logical research order and cover all of the relevant data required to test the hypothesis. The tactics are briefly described while elucidating on each subquestion.

- How can people contribute to the supporting service of ecosystem?
- What are the cycles of healthy terrestrial ecosystems in the city?
- How can a natural ecosystem be integrated within the skin layer of the building?

The first and second subquestions require using qualitative research tactic - the goal is to gather the relevant data to set up the schematic model for the living wall and roof. Taken steps for the first subquestion is to understand nutrient and water cycles in human settlements to have an overview of supporting service of the ecosystem and have a foundation to elicit further data. Because of the limited space, the results of the first subquestion show only relevant data of the amount and type of components which has to be introduced in circulation locally and the relevant technical systems. Estimating the amount of water and nutrient per person per day allows embedding data in a timeframe that \to have a proper understanding of flows and later can be used for defining the suitable landscape. For the data collection, the online resources are completed with basic calculations. The results are presented in the table of quantitative data.

In turn, the second subquestion requires outlining characteristics of the natural landscape by gathering information from online resources of academic publications, lectures by specialists from the relevant studies or reliable literature. The natural landscape is analyzed at the ecosystem level through the prism of the results from the first question. The choice of landscape types is determined by their ability of input absorption, weather conditions and soil requirements. The result is a list of landscapes types and their relevant characteristics to the research paper.

The experimental method for the third question aims to replicate in a holistic manner all the relevant parameters in an isolated setting in order to study the essential causal linkages within the phenomenon of study. The isolation and segregation of a few parameters - within the human cycle and natural flow - allows for better construction of a schematic model that could eliminate inaccuracy and errors at the system level. The choice of the data was conducted by their doability of regulation in a real-life setting where human action plays a crucial role. Limiting the variable factors allows for careful observation and adjustment of the model in the theoretical stage. Combining relevant components with an emphasis on finding common aspects on a supplementary basis ensure the consistency of water and nutrients circulation in the model, thus combining nature and human actions. The decision on connection between various cycles are based on not only the similarities of elements but also on the relevant principles described in Ecological Sanitation publication (Vinblad, (Ed) 1998, p.5), which are:

- Prevent disease
- Affordable
- Protect the Environment
- Acceptable
- Simple

The human and natural ecosystem is represented in the building scale, through the section as for Shearing Layers concept **[see Appendix 3]** In the current situation of centralized sanitation, all of the flows are connected to the city piping system. The Visionary scenario implies that all of the flows can be connected to the local nature proving circular management of flows.

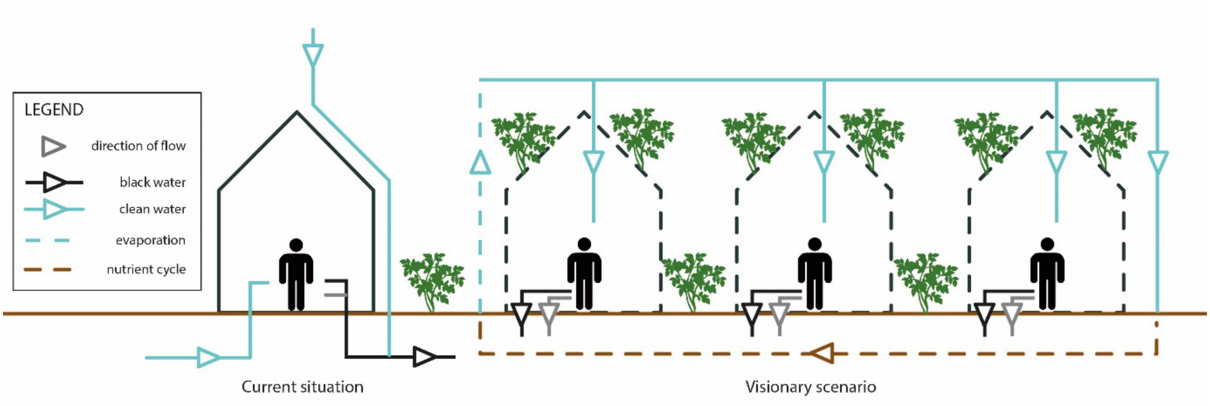

Figure 1. Current situation and visionary scenario schemes

III. Results

3.1. How people can contribute to the supporting service of ecosystems?

Although the Shearing Layer diagram presented earlier draws attention to the building by showing the scale of the intervention, the research subject in this paragraph is human. People actively participate in the water and nutrient cycle while influencing the changes in the proportions of microelements. Healthy soils and plants gain valuable nutrients from humans and other animals waste. (Heinonen-Tanskia, Wijk-Sijbesmab, 2005) Conventional approaches to sanitation, mostly in cities, misplace these components, dispose of them in high amounts in one area and break the cycle. (Conradin, n.d.) The human as a component of the water and nutrient cycle is studied through the input and output, and through these elements can be connected to the local ecosystem.

The human requirements are drinking water and nutritious food. The quantity is respectively 2,5 kg of food, 3 liters of water for drinking and 275 liters for house related activities. **[see Appendix 4]**

The human waste was divided into four categories: urine, excreta, greywater from home-related activities and bio-waste. The separation of the inputs allow for use the potential of each stream and use appropriate treatment.

The urine is full of nitrogen (N), potassium (K) and phosphorus (P) which are also ingredients in common mineral fertilizers. There is already excessive research proving that urine with good microbiological quality can be utilized for plant production and used in soils with the high phosphorus content. Moreover, the preservation phase is not required (Heinonen-Tanskia, Sjöblom, Fabritius, Karinen, 2007, p. 214-217) although, storage for six months is recommended according to the investigation by Stockholm Environment Institute (Richert, Gensch, Jonsson, Stenstrom, Dagerskog, 2009). The urine has to be applied directly into the soil, preferably 1-4 cm deep (or even deeper) to avoid the evaporation of ammonia, losing the nitrogen, which can be noticed as an unpleasant smell. (Richert Stintzing, Rodhe, Akerhielm, Steineck, 2002).

Human excreta, as well as urine, contain components that are valuable for the natural environment: nitrogen (N), potassium (K) and phosphorus (P; in the form of phosphates). It also carries micronutrients vital for plants but cannot be found in artificial fertilizers, including iron, chlorine, boron, copper and zinc (Andersson, Rosemarin, Lamizana, Kvarnström, McConville, Seidu, Dickin, Trimmer, 2016, p.21) Carbon from the excreta can improve the soil condition, although the nutrient content of these products is not as high as in urine. The proper treatment can exclude spreading pathogens (Harder, Wielemaker, Larsen, Zeeman, Oberg, 2019 , Chapter 2.2). Separated faeces from urine and grey-water can be processed with dehydration or composting. In dehydration, most pathogens from excrete die out in the drying process by adding lime to raise the pH above nine. The formed crumbly material is still rich in organic matter (Tilley, Ulrich, Luethi, Reymond, Zurbruegg,

2014) and can be post-treated through co-composting with other organic materials or added directly as a soil conditioner. According to the “Closing the loop” paper, no further action is required for pathogen destruction (Esrey, Andersson, Hillers, Sawyer, 2001, p.19). In the case of composting, the process should occur at temperatures of 55°C for at least two weeks or at 60°C for one week for sanitation. After that stage, the material can be introduced to the landscape (Berger, 2011, p.7).

Greywater depending on the source - kitchen or bathroom - varies in contaminants. It contains salts, food materials, household detergent and bacteria and other disease-causing microbes. The water laundry rinse or shower water is low risk compared to kitchen water with a higher number of contaminants. Using specially designed detergents phosphate-free or low-phosphate and filters in washing machines improves the quality of the greywater (Better Health Channel, 2013). Removal of suspended matter from greywater is required for both lawn/garden irrigation and toilet flushing. The cleaning process includes three stages: strainer in laundry, shower or bath; a mesh filter in collection tanks and a fine filter for precipitates and settled material. The filters require servicing at least once a week. (Christova-Boala, Eden, McFarlanec, 1996) There are already existing case studies with the implementation of DESAR - decentralised sanitation and reuse system - that treat greywater and release it on the site with no harm to nature. (Koetse, 2016)

The bio-waste from the kitchen, similarly to human waste, can be processed, and the output reintroduced into the natural cycle enhances the soil condition. The kitchen waste can be turned into a nutrient-rich material through independent three composting methods; Aerobic (oxygen using process), Anaerobic (fermentation) and Vermicomposting (combination of microbes and worms). The first and the last one is the most suitable for the building environment because of time, space efficiency and smell. (The Department of Public Worms, n.d.) On-site composting reduces the significant amount of biowaste and logistics costs (Bhave, Kulkarni, 2019).

3.2. What are the cycles of healthy terrestrial ecosystems in the city?

A healthy ecosystem has to preserve vigour, organization and resilience in its fully expected lifespan. The first one refers to the activity and productivity of the elements, for example, the consistency of energy flow. The organization relates to the diversity and number of components of the system. For example, generalist feeders with multiply connections are valued lower than the same number of two specific prey elements with fewer connections because a disease can wipe out one species destroying the ecosystem. (Costanza, Mageau, 1999 pp 105-114) And last, resilience is the ability to preserve the ecosystem structure and pattern of behaviors in the situation of stress occurrence (Holling, 1986).

Based on these parameters, there is no healthy ecosystem in cities. Urban environment is dominated by humans spatially, which breaks the flows of the cycles of supporting services. However, there is a potential of strengthening the ecosystem by making the flows circular and outlining spaces for greenery. The nutrient and water cycles are studied to defines key elements to maintain the ecosystem, so that they are included in the schematic model in paragraph 3.3.

The model demonstrates complex patterns occurring in green water flows that dependence on soil, climate, and vegetation characteristics in the section of terrestrial habitat. The root profile, soil type and density determine the vertical water penetration and storage. (D'Odorico, Laio, Porporato, Ridolfi, Rinaldo, Rodriguez-Iturbe, 2010) Implementing biotas mechanics in water cycle model, e.g. transport of water to the surface by deep-rooted plants during dry seasons (Caldwell, Richards 1989) are an evidence of plants and soil regulating the climate by hydraulic redistribution enhances dry-season transpiration (Lee, Oliveira, Dawson, Fung, 2005).

The nutrient cycle demonstrate the linkage between organisms, soil and organic matter. The natural waste in form of fallen leaves or root tips are broken down to simpler compounds by soil organisms. Next macronutrients, for example N,K,P, are stored in soil to be later taken up by plants. I case of having more nutrients than soil and plants can process, the excess by water flow enter river and lakes influencing these ecosystems or pollute the groundwater (Europe Environment Agency, 2019)

To ensure a healthy ecosystem, based on the parameters presented in the first paragraph, it is worth ensuring the balance of the ratio of each component and the diversity. As a result, they have adequate resources to process water flow and nutrients, and the risk of loss and outbreaks to other ecosystems is minimized. Based on the foundations of a natural ecosystem, there are already existing patterns sustaining the cycles and components without which the ecosystem would not exist. To mimic the water cycle occurring in the natural environment, the model should include;

- Soil with microorganisms
- Vegetation
- Exposition to sun and precipitation

Depending on the conditions created by amount of water and nutrient flow, the biota can be designed accordingly. In case of high salination output, the plants which can prefer it can be introduced to the urban greenery. **[See Appendix 5]** In the case of high nitrogen in soil the chosen plants should be Kale, pac choi, mustards, lettuce, spinach, and most chicories. (Macdonald, 2019) The preference would be to choose the type of biota with plant species which prefer the environment with human output and observe and adjusted the choice if required following the Building with nature principles.

3.3. How can a natural ecosystem be integrated within the skin layer of the building?

The schematic diagram **(See Fig. 2)** suggests the water and nutrient cycle connection between the human and natural environment. The prototype is based on the information gathered from the studies in previous chapters and altered based on principles described in Ecological Sanitation publication (Vinblad, U. (Ed), 1998). Human flows after the treatment can be directed into the natural landscape in the urban environment. There is no risk of ecosystem disturbance with provisioning an adequate amount of vegetation, soil and an appropriate irrigation system. Thus introducing the human cycle into nature is possible with the preservation of vigour, organization and resilience values.

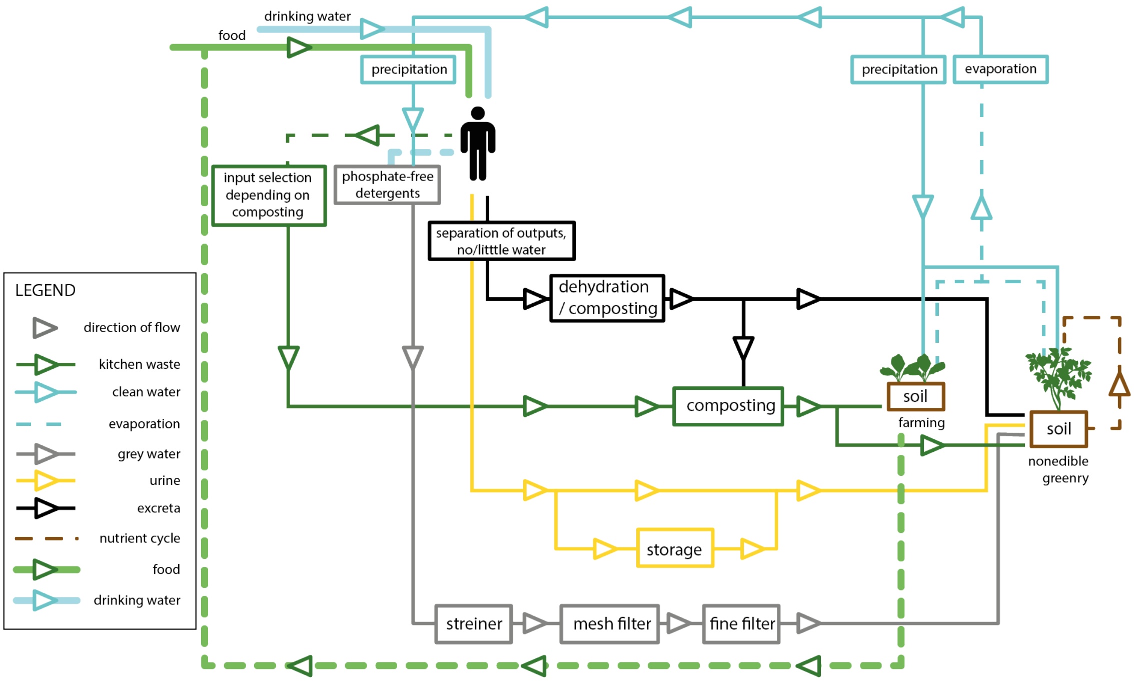

Figure 2. The diagram showing the circular flow cycles of a human and nature

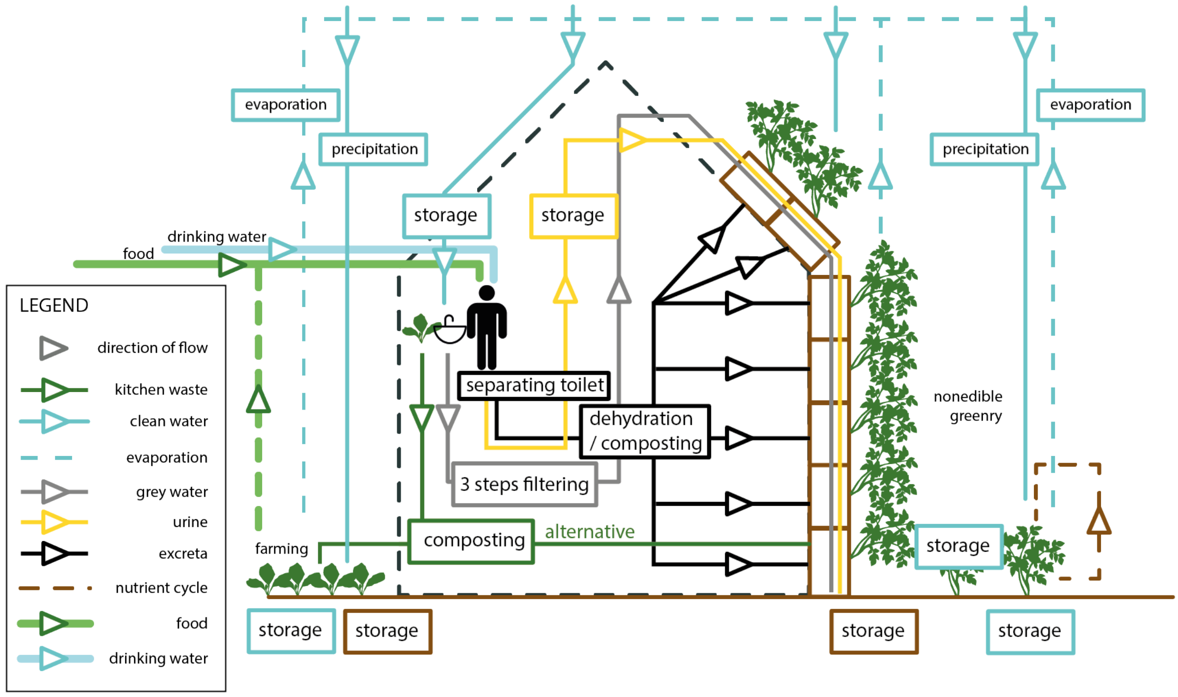

Figure 3. The circular flow cycles positioning inside and outside of the building

The schematic diagram **(See Fig. 3)** shows the previous human and nature collaboration through cycles in the spatial arrangement. The prototype studies the possibilities of connection through the skin layer of the building based on the Shearing layers concept. The location of biota on the facade enhances the surface for nature without trading off human space. (Medl, A., Stangl, L., Florienth, F. 2017) The treated grey and urine flows go through the system pipes in the exterior continuous living wall, whereas the dehydrated/composted human excreta is applied directly to the soil. The living wall does not have to be arranged vertically - the horizontal works as well. For achieving a healthy ecosystem, it is crucial to maintain the greenery and soil organisms through a continuous soil network.

IV. CONCLUSIONS

How can the design of a building act as a healthy landscape layer and thus contribute to the biodiversity of the city?

The design of a building can act as a healthy landscape layer by sustaining the proper conditions for terrestrial habitat and maintaining the ecosystems. The skin layer of the building provides extra surface for soil and vegetation network without taking that much space from the urban environment. The schematic diagram has already shown that emerging totally human and nature circulation with consideration of principles described in Ecological Sanitation while maintaining a healthy ecosystem is impossible. It is limited by human resistance to pathogens and the rules of drinking water. Due to the intensity of inputs, the selection of plants that favors soil full of nutrients should be introduced in the urban environment. Therefore, more terrestrial habitats are needed to process constant water and nutrient flow. More space for nature contributes to the expansion of biodiversity, but the artificial design of nature with respect to different plant species is required to ensure vigor, organization and resilience of ecosystem.

The method with schematic diagram eliminated inaccuracy and errors on the system level, but more knowledge on water sanitation and waste treatment technologies could introduce different solutions on moving components into the natural cycles. The prototype does not take into account the physical transportation of the waste, as in the liquid one, the pipes are the obvious choice in the solid-state human action is probably involved. Moreover, as already stated in the introduction chapter, the result cannot be the only option for the water system. It runs with the support of the city water treatment system. The method investigates theoretical solutions, but further investigation is required to use the system in a real-life setting. More literature reviews or specialist interviews would increase the reliability of the schematic diagram.

The results are general, as they can be applied in almost any building typology and site. The boundaries are the space, money investment and the climate. No particular vegetation and soil types were introduced on purpose so that the schematic diagram can be altered depending on the site of intervention. No doubt, the results need further research. However, they serve as a starting point or rise a discussion about human and nature connection in the building environment.

The challenge is to take a step further to transform the schematic diagram into a real-life system. The process requires involvement of various actors, starting from specialists opinions through the help of prototyping real-life objects to feedback from users.

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Appendix 1

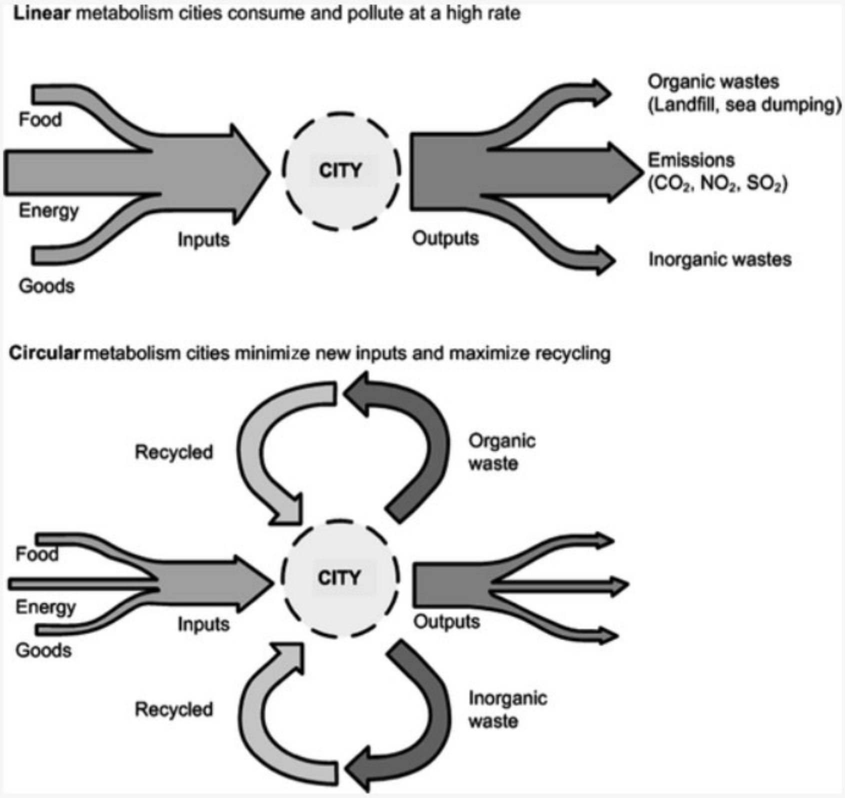
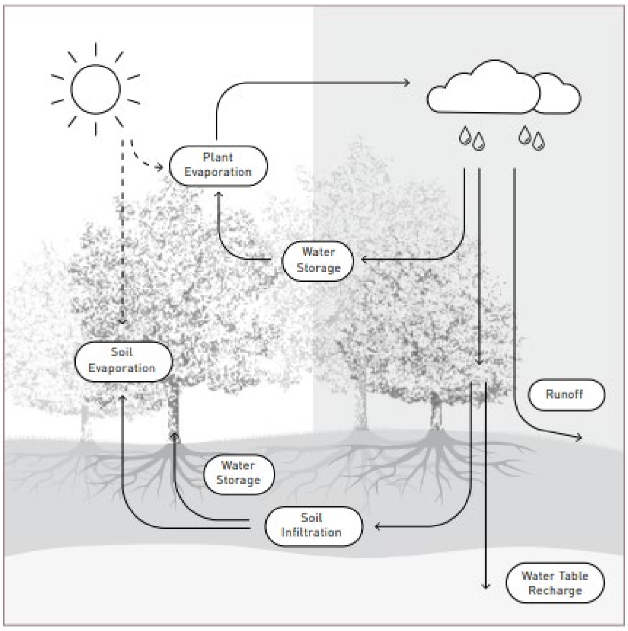


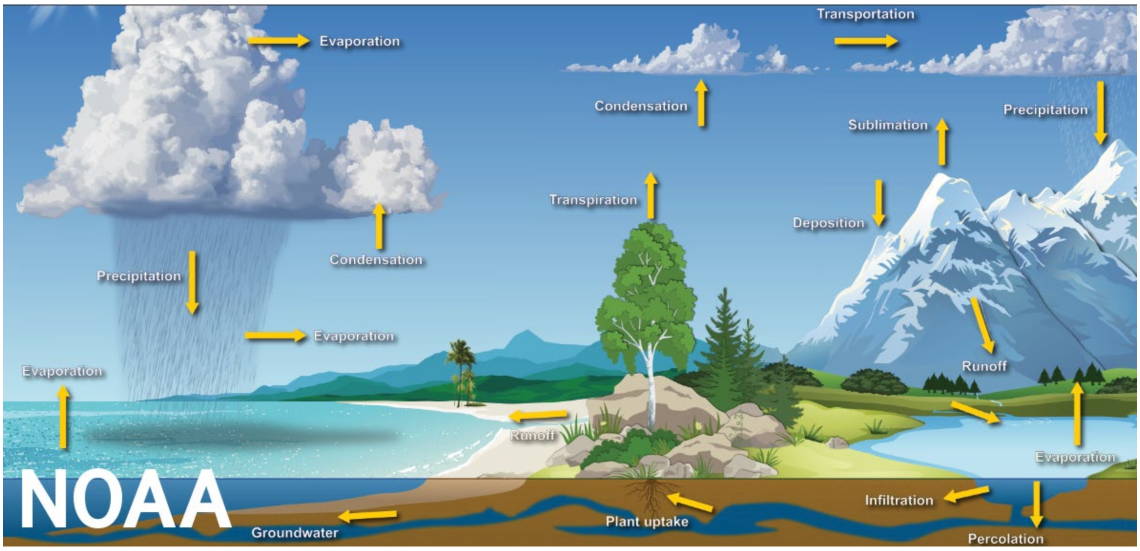
Fig. 2.15

Linear and circular metabolism (Girardet 1990. Used with permission)

Appendix 2



Water cycle



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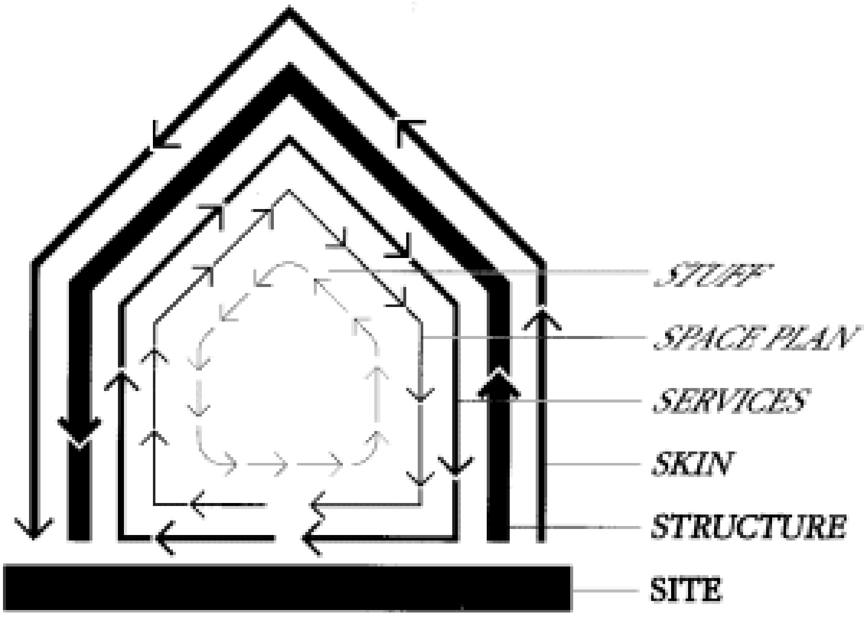
Appendix 3



Source: Brand S. (1994) How Buildings Learn: What Happens After They're Built New York City: Viking Press

Appendix 4

The water cycle is calculated per person per day

Water input

Shower use	20	minutes/day	140 liter/day
Eco-shower head	Yes		
Shower heat recovery	No		
Kitchen sink use	10	minutes/day	60 liter/day
Bathroom sink use	2	minutes/day	12 liter/day
Bath	1	times per week	14 liter/day
Other DHW demands	50	liter/day	50 liter/day
Total hot water use per day			276 liter/day

276 litre/per day with around 2 liters for drinking is about 278 liters/day

Water Output

- The grey water = **226 liter/ day**
- The black water = **50 liter/day**
- Pee 0.8 liter - **2 liters/day**

Based on:
https://medlineplus.gov/ency/article/003425.htm#:~:text=The%20normal%20range%20for%2024,about%202%20liters%20per%20day

Nutrient Input

- An average person eats **2.5 kgs** (approx.) of cooked food

Source: https://idswater.com/2021/04/21/how-many-kilograms-of-food-does-an-average-person-eat-in-a-year/

Nutrient Output

- **Human feaces:** average 70 kilogram person, that works out to about a half a kilogram **0,5 kg -** 75% water and 15% indigestible fibres, toxic substances dead and living gut bacteria
- **Kitchen waste:** MSW "The generation rate was 4.9 pounds per person per day in 2018" which **0.2 kg** (0.42 pounds) person/day for composting

Source: https://www.cbc.ca/natureofthings/features/is-my-poop-normal-heres-the-scoop

Source: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials

Appendix 5

Table 7: The relative tolerance of common plants to salinity. Brady and Weil, 1999

Tolerant	Moderately tolerant	Moderately sensitive	Sensitive
Barley (grain)	Ash (white)	Alfalfa	Almond
Bermuda grass	Aspen	Broad bean	Apple
Black cherry	Barley (forage)	Cauliflower	Apricot
Cotton	Beet (garden)	Cabbage	Bean
Date	Broccoli	Celery	Blackberry
Olive	Cow pea	Clover	Boysenberry
Rosemary	Fescue (tall)	Corn	Carrot
	Fig	Cucumber	Celery
	Harding grass	Grape	Grapefruit
	Kale	Lettuce	Lemon
	Orchard grass	Pea	Onion
	Oats	Peanut	Orange
	Pomegranate	Radish	Peach
	Rye (hay)	Rice (paddy)	Pear
	Ryegrass (perennial)	Squash	Pineapple
	Safflower	Sugar cane	Potato
	Sorghum	Sweet clover	Raspberry
	Soybean	Sweet potato	Strawberry
	Squash (zucchini)	Turnip	Tomato
	Wheat		

Richert, A., Gensch, R., Jonsson, H. Stenstrom T. Dagerskog, L.(2009) *Practical Guidance on the Use of Urine in Crop Production* Stockholm: Stockholm Environment Institute, EcoSanRes Series 2009-1