A ZÖLD INFRASTRUKTÚRA FEJLŐDÉSE A VÁROSI METABOLIZMUS SZEMSZÖGÉBŐL

Nyugat-európai megújítási projektek összehasonlítása

EVOLUTION OF GREEN INFRASTRUCTURE FROM AN URBAN METABOLIC PERSPECTIVE

A comparative study within Western Europe

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ABSZTRAKT
A tanulmány a zöld infrastruktúra adaptív újrahasznosításának fejlődését vizsgálja városi metabolikus szemléletmódból, nyomon követve a zöld infrastruktúra transzformatív gyakorlatait a közelmúlt jelentős adaptív újrahasznosítási projektjeiben. A 20. század végétől napjainkig terjedő projektek során elemzésével a kutatás feltárja a zöld infrastruktúra elemek – mint például a biota, az energia- és a vízáramlások – integrációjában bekövetkező változásokat. Rámutat a korai fenntartható gyakorlatoktól a körforgásos gazdasági modellek felé történő elmozdulásra, amelyek a városi metabolizmus keretrendszeréhez kötődnek, ahogyan azt a közelmúltbeli projektek, például a De Ceuvel és a Schoonschip is példázzák. A projektek elemzésével a tanulmány értékeli ezeknek az elemeknek a városi metabolikus áramlásokra gyakorolt számszerűsíthető hatását, olyan indikátorok bemutatásával, mint a biodiverzitás, az energia- és vízhatékonyság. Az eredmények kiemelik az adaptív újrahasznosítás általános fenntarthatósági céloktól a komplex városi metabolikus stratégiák felé történő felgyorsult elmozdulását, hangsúlyozva a körforgásosság, az erőforrás-hatékonyság és a közösségi részvétel szerepét a közelmúlt projektjeiben. Ez a fejlődés a városi reziliencia kifinomultabb megközelítését jelzi, bemutatva, hogy a robusztus városi metabolizmus modellek milyen mértékben növelhetik az adaptív újrahasznosítás-projektek alkalmazkodóképességét és ökológiai értékét.

Kulcsszavak: zöld infrastruktúra, városi metabolizmus, adaptív újrahasznosítás, körforgásos gazdaság, fenntartható városfejlesztés, összehasonlító elemzés ⦿

4D 74, 24–31. (2024)
DOI: HTTPS://DOI.ORG/10.36249/4D.74.5594

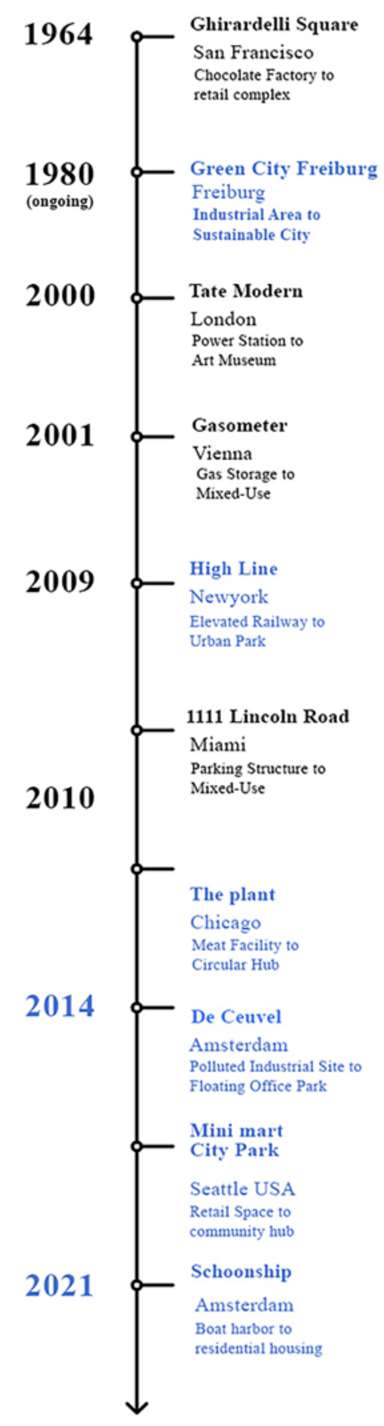


Figure 1: Adaptive reuse timeline and its relationship with urban metabolism (Appendix A) as a trend
SOURCE: AUTHOR

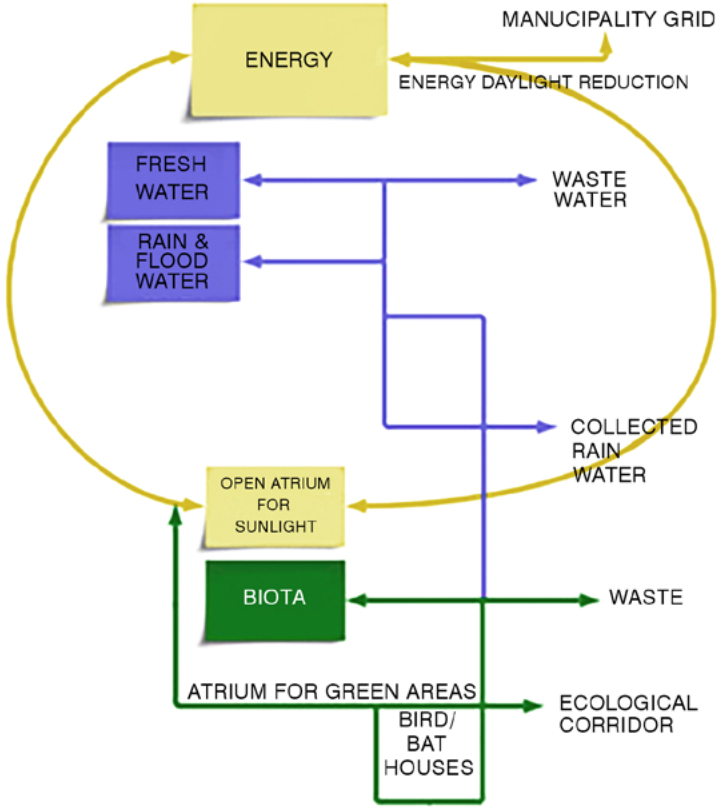
ABSTRACT
Exploring the Evolution of Green Infrastructure from an Urban Metabolic Perspective: Af Comparative Study within Western Europe. With the Gasometer in Vienna and De Ceuvel in Amsterdam as case studies, this research investigates the transformative potential of green infrastructure in adaptive reuse urban projects separated by 15 to 20 years. Employing a flow analysis methodology, this study examines the utilization and impact of green infrastructure elements, such as green roofs, farming, aquaponics, and phytoremediation techniques, on urban metabolic flows. The findings reveal a significant evolution in sustainable practices, characterized by a shift towards utilizing existing resources to enhance soil quality and minimize waste generation. Through strategic integration of green infrastructure, these projects demonstrate a holistic approach to urban development, emphasizing circularity and resource efficiency. The comparative analysis underscores the importance of learning from past endeavors to inform future sustainable urban initiatives, highlighting the role of green infrastructure in fostering resilient and regenerative urban ecosystems.

Keywords: green infrastructure, urban metabolism, adaptive reuse, circular economy, sustainable urban development, Comparative analysis.

INTRODUCTION

Urbanization has led to the emergence of cities as complex systems with dynamic processes governing their functioning. One key concept that has gained prominence in understanding these processes is that of urban metabolism. Urban metabolism refers to the [1] continuous flow of resources, energy, and waste within urban areas, encompassing various activities such as transportation, consumption, and production. Just as metabolism is vital for the sustenance of living organisms, understanding urban metabolism is crucial for comprehending the functioning and sustainability of cities.

At the heart of urban metabolism lies the intricate relationship between the built environment and natural ecosystems. Green infrastructure plays a pivotal role in this relationship, serving as a multifunctional network of natural and semi-natural areas that provides ecosystem services essential for urban well-being [2]. Green infrastructure encompasses a range of elements, including



parks, wetlands, green roofs, and urban forests, which contribute to enhancing air quality, mitigating urban heat island effects, managing stormwater, and promoting biodiversity. These green spaces not only enhance the aesthetic appeal of cities but also play a crucial role in regulating metabolic flows and fostering resilience to environmental challenges.

This study embarks on a comprehensive investigation into the evolution of green infrastructure within the context of urban metabolic dynamics, with a specific focus on adaptive reuse projects in Western Europe. By juxtaposing the Gasometer in Vienna and De Ceuvel in Amsterdam as case studies, separated by a significant temporal gap, the main hypothesis being that a Comparative analysis the projects reveals an evolution in green infrastructure strategies, characterized by a shift towards greater integration of existing resources, circularity, and resilience in urban development practices that can be seen in the green infrastructure and its development. By keeping in mind, the similar region (west Europe), similar intent (following urban metabolic concepts) and finally compatible functions (residential and some office areas).

2. LITERATURE REVIEW

The intersection between urban metabolism and green infrastructure offers valuable insights into the functioning and sustainability of cities.

Urban metabolism, as expounded by Kennedy et al. (2007), encompasses the dynamic flow of resources, energy, and waste within urban environments [1]. This evolving concept underscores the necessity of comprehensively understanding urban systems to address contemporary challenges. Green infrastructure, as defined by Benedict and McMahon (2006), constitutes a network of natural and semi-natural spaces crucial for supporting urban well-being and ecosystem services [2]. This includes parks, green roofs, urban forests, and wetlands, essential for managing stormwater, improving air quality, and fostering biodiversity.

The synergy between urban metabolism and green infrastructure is evident in studies such as those by Andersson and Barthel (2016), which underscore the role of green spaces in enhancing sustainable urban metabolism and resilience [3] where green infrastructure acts as a buffer against urban pressures, regulating metabolic flows and mitigating environmental impacts. In their intersecting uses, both urban metabolism and green infrastructure have common interests which could be analyzed and reached out through different urban development concepts.

3. METHODS OF STUDY AND ANALYSIS IN LITERATURE

One key theoretical framework used in studying urban metabolism is the Industrial Ecology approach. This approach treats cities as ecosystems and applies principles of ecology to understand the flow of materials and energy within urban systems [4]. By viewing cities as

◂◂**Figure 2:** The Geometer's overall design and distribution from an interior point of view
SOURCE: WIKIMEDIA COMMONS. GASOMETER INTERIOR. LICENSE: CREATIVE COMMONS ATTRIBUTION-SHAREALIKE 3.0
◂◂**Figure 3:** Gasometer's system and flows network
SOURCE: AUTHOR
Figure 4: Showcasing the original concept of moving unused boats as residences and workshops by space and matter
SOURCE: SUPERBASS. (2019). DE CEUVEL [PHOTOGRAPH]. CC BY-SA 4.0. RETRIEVED FROM HTTPS://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:2019-06-09-DE_CEUVEL-5737.JPG
Figure 5: Close up image of De Ceuvel
SOURCE: SPACE & MATTER, SUPERBASS. (2019). DE CEUVEL [PHOTOGRAPH]. CC-BY-SA-4.0. RETRIEVED FROM HTTPS://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:2019-06-09-DE_CEUVEL-1.JPG

metabolic systems, researchers can analyze the inputs, outputs, and transformations of resources, facilitating a holistic understanding of urban dynamics.

Systems theory is another valuable concept utilized in studying urban metabolism. Systems theory emphasizes the interconnectedness and feedback loops within complex systems, such as cities [5]. Applying systems thinking to urban metabolism allows researchers to explore the relationships between different components of the urban system and their influence on metabolic processes.

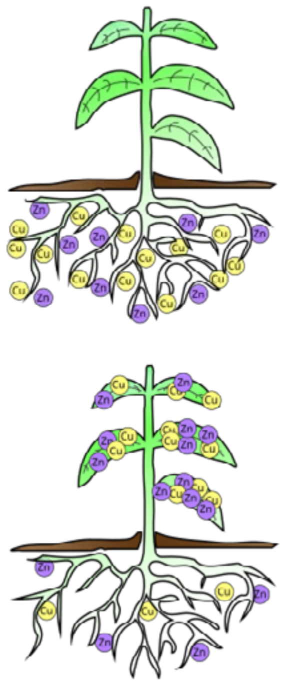
In the realm of green infrastructure, the ecosystem services framework provides a comprehensive approach to understanding the benefits provided by natural and semi-natural spaces [6]. This framework categorizes ecosystem services into provisioning, regulating, supporting, and cultural services, highlighting the multifunctional role of green infrastructure in urban environments.

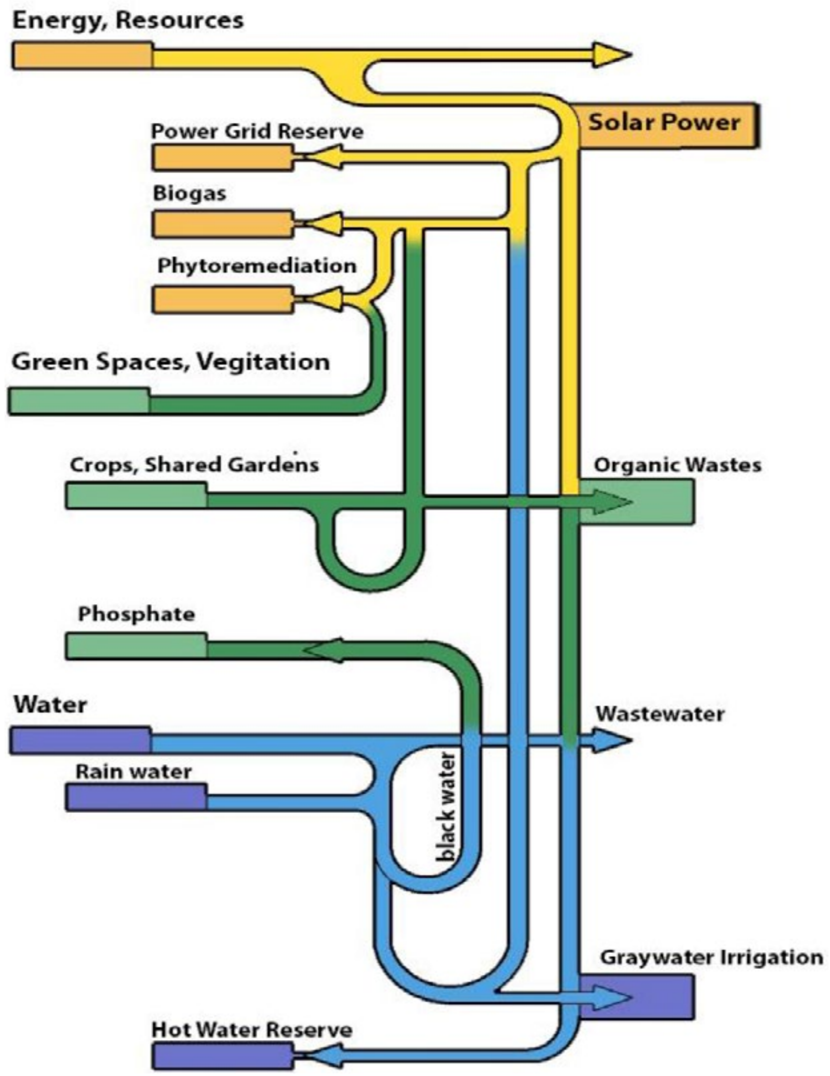
Methodologies for studying urban metabolism and green infrastructure range from quantitative analysis of material and energy flows to qualitative assessments of ecosystem services and social values. Material flow analysis (MFA) and energy flow analysis (EFA) are commonly used quantitative methods for assessing the metabolism of cities [1]. These methods involve tracking the flow of resources and energy through urban systems to quantify inputs, outputs, and stocks. Qualitative methods, such as participatory mapping and social surveys, are employed to assess the socio-cultural dimensions of green infrastructure [7]. These methods involve engaging with local communities to understand their perceptions, preferences, and use of green spaces, providing valuable insights for planning. Integrating these theories and methodologies enhances the sophistication of research on urban metabolism and green infrastructure by combining interdisciplinary approaches to develop an understanding of the complex interactions shaping urban sustainability [8].

4. CHOSEN METHOD

In comparing the De Ceuvel and Gasometer projects, a comprehensive methodological approach will be employed to gather and analyze data from various sources, including architectural records, publications, studies, and user feedback. This data will be meticulously organized and synthesized using a flow analysis method to assess the efficiency and effectiveness of green infrastructure interventions within each project. By quantifying the inputs, outputs, and transformations of resources, focusing on the generation and mitigation of waste, this approach aims to illuminate the dynamic interplay between urban development and environmental sustainability, this informs us of the life cycle of each project in one graph, which helps understand how green infrastructure stands out, and how much waste is generated or mitigated.

This methodological framework aligns with the principles of Industrial Ecology, which views cities as interconnected ecosystems and emphasizes the analysis of material and energy flows within urban systems. By adopting





a material flow analysis (MFA) perspective, the study will track the flow of resources through the De Ceuvel and Gasometer, providing insights into their metabolic processes and environmental impact. Through this lens, the study seeks to elucidate how GI contributes to the optimization of resource utilization and waste management practices, thereby advancing our understanding of sustainable urban development strategies.

4. ANALYSIS:

Project 1: De Ceuvel

Introduction

De Ceuvel, situated in Amsterdam, emerged from a polluted plot transformed into an urban oasis through community-driven development. Spearheaded by a diverse group of architects, sustainability experts, and community members in 2012 hosting around 50 residents, De Ceuvel's regenerative concept aimed to repurpose the former shipyard into an Eco hub for creative and social enterprises. The project's innovative approach prioritized mobility, reuse, and the transformation of wasteland and waste materials into valuable resources. Uniquely designed houseboats, retrofitted and placed on land without foundations, form the centerpiece of the site, surrounded by a landscape of soil-cleaning plants and connected via a wooden walkway [9].

Optimization of Urban Metabolism

A. Synergistic Community engagement: At the heart of the project lies the profound strength of community engagement, fostering a sense of inclusivity and empowerment among its residents. Through initiatives such as real-time data monitoring of energy consumption, individuals are equipped with the tools needed to make informed

Figure 6: Showcasing the phytoremediation technique used in the project, with plants like Typha Latifolioa, Salix Nigra & Agrostis Capillaries
SOURCE: RONA.FAWZY19. (N.D.). PHYTOEXTRACTION DIAGRAM [DIAGRAM]. CC BY-SA 4.0, HTTPS://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:PHYTOEXTRACTION_DIAGRAM.SVG

Figure 7: De Ceuvel's system and flows network
SOURCE: AUTHOR

decisions about their energy usage. Moreover, communal facilities such as shared kitchens and gardens, to cultivate their own crops, process food, and collectively manage laundry facilities.

b. Technology based Optimization: The project leverages technology to optimize resource management, empowering residents to make informed decisions aligned with waste reduction. In the beginning, Flow analysis cards offer insights into resource utilization to understand what each element like wind turbines or greenhouses could add to incomes/outcomes, while then a technology selection tool suggests efficient up to date information about each element [10]. A sharing system facilitates energy exchange, reducing reliance on external sources. Finally, the financial estimation tool projects costs and savings, aiding environmentally conscious decisions.

C. Adaptive Reuse of industrial area: with adaptive reuse in an industrial context, revitalizing previously polluted land and promoting ecological health. Through creative landscaping, the project enhances air quality and biodiversity, fostering a thriving urban ecosystem. Key to its identity are repurposed houseboats, embodying sustainability and waste reduction principles. By salvaging and refurbishing materials, reducing costs, transportation emissions, and waste [11].

Integration between Green infrastructure and Urban metabolism:

1. Utilizing Green Infrastructure for Remediation: Employing soil-cleaning plants and phytoremediation techniques to purify polluted soil and enhance ecosystem health, this also includes air purification, stormwater management, and habitat creation, enhancing the overall environmental quality and resilience of the site while creating a barrier from the decontaminated industrial site's soil [12]. (Purifying polluted soil using phytoremediation techniques, stabilizing, breaking down, and absorbing pollutants while producing low-impact biomass.)

2. Maximizing Resource Efficiency: Implementing compost toilets, biofilters, and renewable energy technologies to conserve resources, reduce waste, and mitigate environmental impact like using the black water to harness phosphate using filtering and a collector to be used later for the different landscape elements. Looping the existing elements in a less wasteful approach [11].

3. Circular Economy concepts: The project is Prioritizing mobility, reuse, and waste reduction, with a focus on repurposing materials and transforming wasteland into valuable resources. In a way turning the surrounding port to marches with existing sediment, turning the existing soil into a thriving landscape, and using existing resources from arriving imports like food rafts into future elements in the landscape [10].

4. Water Management as a Green infrastructure Method: Rainwater harvesting systems collect and store rainwater for irrigation and non-potable uses, reducing reliance on freshwater sources and mitigating stormwater runoff. [12] The Use of Green infrastructure is also done in a smart way to minimize any flooding and erosion while enhancing biodiversity and urban aesthetics using stormwater management techniques.

5. Project Flow Analysis: When looking into the relation between blue/green infrastructure and the metabolic flow of the space to understand the development of the urban space [13], the storyline is cut into energy as a source that can be stored for future use or for a shared PowerGrid, while green spaces themselves like crops are used to induce biogas which can be sent to restaurants and others for future use. Meanwhile water plays an important role, with rainwater being collected and used in basins and flushing toilets while then filtered for irrigation or black water sent for refineries to investigate production of phosphate mineral or resent to the solar power reserves which will heat them automatically, Finally the green spaces are used as a phytoremediation method to remediate contaminated soil.

Project 2: Gasometer

Introduction

Gasometer City in Vienna stands as a testament to transformative urban renewal and sustainable development. Originally built as gas storage facilities in the late

19th century, the Gasometers faced abandonment before undergoing a remarkable revitalization effort in the 20th century. Through adaptive reuse, it emerged as a vibrant mixed-use development, blending heritage preservation with contemporary functionality [14]. This innovative project has not only revitalized historic structures but also reduced environmental impact within the urban landscape.

Optimization of Urban Metabolism

Water Management: The adaptation involved innovative water management strategies such as rainwater harvesting and sustainable drainage systems (SuDS) [8]. These systems help mitigate urban flooding, enhance groundwater recharge, and overall water efficiency.

Energy and Waste: The redevelopment emphasizes energy efficiency through the integration of renewable energy sources, energy-efficient building designs, and waste-to-energy technologies. With the adaptive reuse of the existing industrial space to save building and construction materials and opening the atrium for daylight and reducing the need for electricity daily.

Integration between Green infrastructure and Urban metabolism:

1. **Biodiversity and Biota emphasis:** Gasometer City incorporates green roofs, vertical gardens, and landscaped courtyards, providing habitats for various plant and animal species in a linear open space that can resemble an ecological corridor. (In-between Nature: Berlin's human and natural constructed spaces, Elena Ferrari) like bird and bat houses. This enhances biodiversity, promotes ecological connectivity, and fosters a healthier urban eco-system.

2. **Community Gardens:** To promote sustainable food production and community engagement, including community gardens and urban farming initiatives within its green spaces. These empower residents to cultivate their own produce, foster a sense of ownership and stewardship.

3. **Green Roofs:** The rooftops feature greenery installations, transforming previously underutilized spaces into ecosystems. Green roofs not only provide insulation and reduce energy consumption but also support biodiversity, mitigate urban heat island effects, and enhance stormwater management by absorbing rainwater. [14] With each roof being slightly more unique, gasometer C for example has an inner courtyard, planned with top lighting and gaps allowing green areas to be surrounded by green roofs and residential areas with green terraces.

4. **Landscaped Courtyards:** Within the units, courtyards provide residents with tranquil retreats and communal gathering spaces amidst the urban environment, this can be evidently seen in all gasometers A, B, C and especially in D, The new structure achieves natural lighting through the organization of units on the upper floors, the central focus of three intersecting axes, and the creation of inner courtyards that face the outer shell, maximizing surface area. Additionally, the courtyard is considered as green space, serving recreational purposes and aiming to visually convey the outer shell (16). The creation of green areas signifies an attempt to implement a "Green House".

5. **Project Flow Analysis:** in the beginning, the Energy used within the project is connected with the municipality grid, as outcomes are reduced with the open atrium to save electricity, while there are rainwater collection systems in addition to a green roof absorbing water, later, which is used for green area irrigation, the space has a open corridor for the existing ecosystem along with small local spaces for local species.

Apartments are either supplied by a large courtyard on the sides, or central large gardens with communal gardens and small green terraces.

5. RESULTS AND IMPLICATIONS

1. De Ceuvel prioritizes community-driven development, actively involving residents and stakeholders in decision-making processes, fostering a strong sense of ownership and stewardship. Gasometer City, while featuring communal spaces, places less emphasis on direct community engagement during planning and execution, with that the ability for down to top involvement in design allowed the community to also later feel more responsible towards their environment, allowing continues efforts in different initiatives. This aligns with the responsibilities of users to develop their green infrastructure, Moreover, engagement with nature can also inspire a sense of stewardship and responsibility towards environmental conservation and sustainability. People who feel connected to a natural resource like the river Thames are more likely to advocate for its protection and preservation, leading to positive outcomes for both the environment and the community [17].

2. With both projects similar reuse of an industrial site, De Ceuvel implements green infrastructure solutions,

including phytoremediation techniques, to remediate polluted industrial areas and enhance environmental quality. Gasometer City, although repurposing industrial structures, may prioritize transforming these spaces into mixed-use developments over implementing specific green infrastructure solutions for industrial remediation, while creating a small green corridor, the implementation of green infrastructure as a mediator for existing industrial sites showcases the ability of integration and synergistic planning using GI.

3. The newer technology allows a more active flow analysis and sensor technologies, as a solution for urban metabolism like advanced waste management systems, optimizing resource usage found actively in De Ceuvel. Gasometer City integrates technology to a lesser extent, with a focus more on adaptive reuse and repurposing existing structures.

Considering De Ceuvel's newer technology, smaller scale, and more modern approach 20 years later, it appears to have a more advantageous position concerning green infrastructure. Its emphasis on community engagement, advanced technology integration, and innovative use of existing sites and shared technologies contribute to a more comprehensive and efficient utilization of green infrastructure. This aligns well with the evolving trends and development of adaptive reuse structures, which tend to have a better circularity rate, and resilience in urban development practices within the context of urban metabolic dynamic. ⦿

1 Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology,* 11(2), 43-59.
2 Benedict, M. A., & McMahon, E. T. (2006). Green infrastructure: Smart conservation for the 21st century. *Renewable Resources Journal,* 24(4), 12-17.
3 Andersson, E., & Barthel, S. (2016). Assessing the potential of urban green infrastructure to support urban metabolism in Stockholm, Sweden. *Journal of Environmental Planning and Management,* 59(12), 2205-2223.
4 Graedel, T. E., & Allenby, B. R. (2010). Industrial Ecology and Sustainable Engineering. *Industrial Ecology and Sustainable Engineering,* 1(1), 1-17.
5 Meadows, D. H. (2008). *Thinking in Systems: A Primer.* Chelsea Green Publishing.
6 Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis.* Island Press.
7 Barthel, S., & Isendahl, C. (2013). Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities. *Ecological Economics,* 86, 224-234.
8 Bai, X., Wu, J., & Yan, H. (2010). Urban metabolism and sustainability in the context of China: A review. Journal of Industrial Ecology, 14(5), 691-714.
9 Barba Lata, I., & Duineveld, M. (2019). A harbor on land: De Ceuvel's topologies of creative reuse. *Environment and Planning An Economy and Space,* 51(20).
10 Metabolic Lab (2013): CLEANTECH PLAYGROUND [online]. Amsterdam North: Metabolic Lab. Available at https://www.metabolic.nl/publications/cleantech-playground
11 Pistoni, R., & Bonin, S. (2017). Urban metabolism planning and designing approaches between quantitative analysis and urban landscape. *City Territory and Architecture,* 4(1).
12 Space and Matter. (n.d.). De Ceuvel: A playground for innovation [online]. Retrieved from https://www.spaceandmatter.nl/work/de-ceuvel.
13 Blue Green Solutions. (2017). Blue Green Solutions: A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development.
14 Plicanic, M. (September 2012). A Society of Spectacle and Architecture: Gasometer City Vienna. In "Architecture & Ideology" Conference Proceedings. Faculty of Educational Sciences.
15 Špirić, A., et al. (2012). Spatial criteria in urban renewal of industrial brownfield sites. DOI 10.14256/JCE.1011.2014
16 Dejaco, M. C. (2015/2016). Adaptive reuse of the industrial heritage: Best practices definition by case studies analysis. [Department of Architecture, Urban Planning, and Building Engineering, master's degree Program in Management of Built Environment].
17 Heynen, N. C., Kaika, M., & Swyngedouw, E. (Eds.). (2006). In the Nature of Cities: Urban Political Ecology and The Politics of Urban Metabolism. Taylor & Francis. ISBN: 0415368286.