Cyclifiers: an investigation into actors that enable intra-urban metabolism

Jan Jongert,[1]* Nels Nelson,[2] Gijsbert Korevaar[3]

January, 2015

Keywords: Cyclifier, Industrial Ecology, Built Environment, Urban Metabolism, Urban planning, Waste Management

Abstract

The term "cyclifier" is introduced to identify a type of actor that improves the metabolic efficiency of an urban system. The research investigated practical case studies of industrial ecology within architecture, infrastructure, and planning. The definition of cyclifiers is derived from patterns of starting conditions, roles, and material flows found in analyzed case studies. Cyclifiers are defined as metabolic processors that decrease system-level inputs and outputs by operating in ecological niches, creating symbiotic connections, and increasing resource efficiency. The potential utility of the term in the discourse of industrial ecology is to describe actors that improve intra-urban metabolism.

Material flow accounting theory and ecological systems theory were used to investigate potential cyclifier cases. The research found that cyclifiers operate in ecological niches with material and policy dimensions, perform supply-demand matching and transformational processing activities, inputs may be from point or nonpoint sources, and outputs either directly substitute existing demand or create novel flows that replace existing demand pathways with resource-efficient activities.

Introduction

The lack of connectivity between supplying demand and existing resource streams within cities is a barrier to a diverse and resilient intra-urban ecosystem. This disconnection contributes to negative environmental impacts through excess ex- and inter-urban imports and exports. Intra-urban material and energy exchanges can create a more efficient overall urban metabolism, as stated by Newcombe et. al. (1978): "Reduced dependency on external supplies of resources would increase the stability, diversity and resilience of the urban ecosystem." Within this context, the research analyzed cases of architectural, infrastructural, and planning projects that enabled novel metabolic exchanges within the built environment.

Industrial ecology has demonstrated relevance in contemporary architectural practice. Design and engineering firms are using the flow of materials as a structural element of their practice (Doepel Strijkers Architects 2009; van Bergen Kolpa Architecten 2009; De Urbanisten 2010; EXCEPT 2011). The presence of and demand for connecting and preserving processors, buildings, and urban functions led the authors to define "cyclifiers" as a pattern of metabolic activities.

---

[1] Director of Superuse Studios in Rotterdam and lector at the Royal Academy of Art in The Hague, the Netherlands.
[2] Urban planner and designer, Boston, USA
[3] Assistant Professor Industrial Symbiosis at Delft University of Technology

* Corresponding author e-mail: jan@superuse-studios.com, cyclifiers website: http://cyclifiers.org

The term cyclifier seeks to extend the industrial ecology discourse by identifying a specific type of actor contributing to sustainable urban systems such that the defined classification could be methodologically analyzed, discussed, and designed. The cyclifier concept is an elaboration of 2012Architects' previous publication, *Superuse* (2007), which focused on repurposing waste material flows.

Definition

The cyclifier definition stems from patterns found in case studies and literature review of actors performing metabolic processes within the built environment that create ecological connections, decrease system-level inputs and outputs, and intensify the use of space. Research and analysis led to the following definition: "Cyclifiers are urban actors that create, guide, or improve urban metabolism in such a way that a system becomes more interconnected and reduces its environmental impact."

Characteristics

Cyclifiers are identified by three characteristics:

1. Cyclifiers operate in ecological niches
2. Cyclifiers create symbiotic connectivity
3. Cyclifiers increase resource efficiency

An ecological niche is a functional space describing an actor's role and relational position in its ecosystem. A niche can be either a potential opportunity or a realized role (Hutchinson 1957). Ecological niches in cities can be within a variety of timescales and opportunities, such as spatial conditions, local economies, policies, legislation, regulation, consumer choice, and presence of underutilized flows. Cyclifiers use existing resources within a context as inputs for an existing demand or to create novel services.

Locality is a dimension of symbiotic connectivity. Systems adapt to local circumstances and limitations (Korhonen 2005). In a natural ecosystem, locally available resources are used via interconnected metabolic pathways (with zero waste), whereas global-industrial systems replace local circumstances with imports and exports. A requirement of a cyclifier is to substitute industrial systems' linearity with circular symbiotic connections.

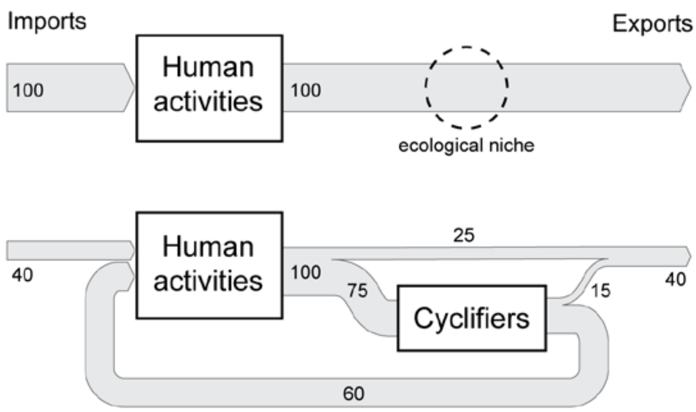

Figure 1 Comparison between urban metabolism flows originating from non-renewable sources shown as theoretical percentages in the anthroposphere without and with cyclifiers.

The improved efficiency of material and energy flow through the system boundary is a quantifiable outcome for cyclifiers. Cyclifiers use flows of material and energy that would otherwise dissipate into lower quality inputs for processes that generate outputs with utility for another actor. Urban metabolism's essential function is to support human activities, allowing people to nourish, clean, reside, work, transport, and communicate. The main goal of a sustainable economy is to best satisfy these needs at the least cost (Brunner and Rechberger 2004). As shown in figure 1, a cyclifier contributes to supporting human activities while decreasing environmental imports and exports.

Categorization

While the physical layer of cities is readily tangible, there are additional layers of flows in urban systems that can be cyclified, such as energy and value. Dijkema (2009) recognized that flows within complex urban systems are not only materials and energy, theorizing that cities are layers of technical networks and social networks, within which information, knowledge, and policy flows are analogous to water and energy. The authors use the three layers defined by INSIDEflows for categorizing and analyzing flows affected by cyclifiers. INSIDEflows is a systemic understanding of the working of flows that aims to positively contribute to design on several scales. In this definition, flows are subdivided into three layers: physical, energy and value (Jongert 2013).

- The physical layer is tangible or observable matter, in solid, liquid or gas shape, including users, organic material, traffic, water, and gas.
- The energy layer is available power in a physical system, including electricity, heat, light, and sound.
- The value layer is the appreciation and quality of the physical and energetic flows passing through a system, including data, information, knowledge, money, culture, and identity.

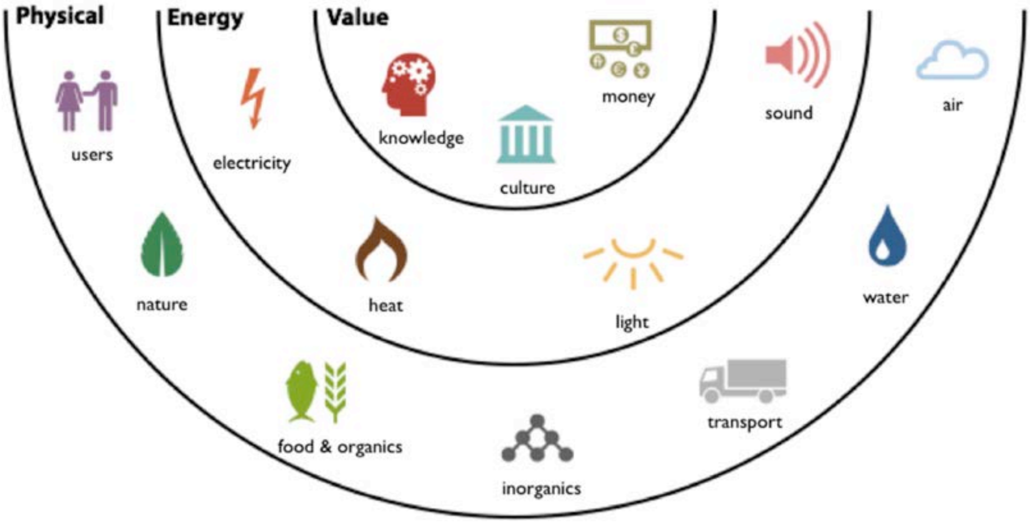

Figure 2 INSIDEflows categorization of physical, energy, and value flow layers in cities.

Methods

Case studies are analyzed using process analysis, ecological analysis, and graphical analysis methods, which are described in detail in the following section. Quantitative and qualitative data were collected by site visit and interviews with case study operations managers.

Process analysis

Process analysis is a quantitative review of an actor's input-output. This analysis considers actors in the built environment as rational and quantifiable strings of reactions. While process analysis of urban metabolism is only possible with idealization, it is an important method for measuring the flows of goods, materials, and energy through urban systems (Newcombe 1978). The analysis of a process requires knowledge of its context, such as the ambient temperature during a reaction. In the cyclifier analysis, the context includes the processes' location, climate, source of inputs, and destination of outputs.

Process analysis of a cyclifier is design-oriented, as it presumes reality to be controllable and determinable by the laws of physics. The primary methodology is material flow accounting (MFA) (Brunner and Rechberger 2004). MFA generates an overview of inflows, outflows, and accumulations of materials in the system. The system boundary for MFA is the cyclifier plus the actors in its essential network it interacts with, as shown in figure 2. Each process is a block box that can be divided into sub-processes following similar logic. The system is modeled by accounting for flow quantity and quality. With this technique, otherwise unknown or difficult to measure flows can be identified and quantified by accounting for a mass balance of inputs and exports.

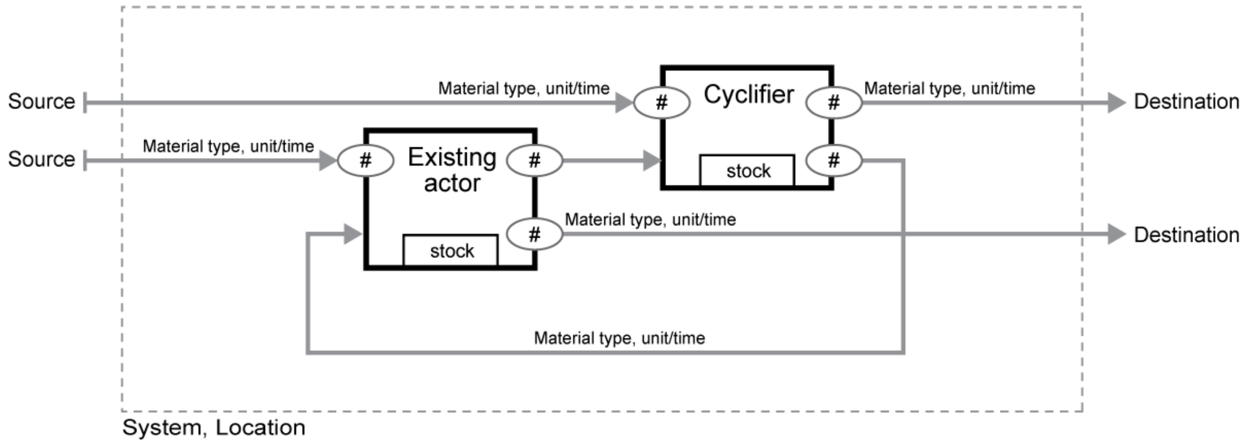

Figure 3 Idealized MFA diagram with a system boundary, generic actor, a cyclifier, and system inputs and outputs.

Ecological analysis

In this analysis, the city is metaphorically biological. Solutions organically grow into particular conditions. Ecological analysis examines the web of metabolic connections between actors and opportunities within. In contrast to process analysis, which conceives of cyclifiers as rationally designed, ecological analysis conceives of cyclifiers as grown into ecological niches. An ecological niche is an opportunity created by certain set of conditions that allows the evolution of a species to fill a role.

The methodology of ecological analysis is qualitative. It is investigated through the ecological conditions surrounding a project's growth and development. Ecological conditions researched in the literature review and interviews are:

- Description of the ecologic niche that the cyclifier inhabits
- Situation before the cyclifier was initiated (may include MFA of pre-existing flows)
- History of the development of the cyclifier
- Qualitative results of the cyclifier
- Policy and legal context affecting the cyclifier

- Contributing factors towards the success of the cyclifier
- Challenges confronted during the start-up of the cyclifier
- Approaches and methodologies that facilitated implementation
- Risk factors that threaten the cyclifier’s operation
- Roles of stakeholders during realization and operation
- Ease-of-use compared to a conventional processor

Each question illuminates specific attributes in case studies. The authors found it important to physically visit case study locations to gauge the differences between the ambitions found in literature and marketing versus reality on the ground.

Graphical Analysis

MFA diagrams and Sankey diagrams are ways to delineate a system in standardized and uniform terms, thereby reducing the complexity of system representation for presenting the results of research (Brunner and Rechberger 2004). In addition to the conventional MFA and Sankey diagrams, a diagrammatic representation method was developed to represent ecological connections and spatial characteristics of cyclifiers. The resulting hybrid graphical representation method conveys the role a cyclifier plays in its context and can be seen in the case study section.

Results

Case studies were gathered in a diverse set of disciplines, including industrial design, architecture, urbanism, agriculture, and manufacturing. Actively operating case studies were preferred, though concepts and planned projects were also considered. Data were collected with a standard form through literature review, interviews, site visits, and telecommunication. The data collection form contains fields for categorical data (start date, flow types, location, and operating scale), economic investment and return, quantitative MFA, chain partner analysis, and qualitative ecological analysis. The research team evaluated each case as either: plausibly a cyclifier nominated for further investigation, plausibly a cyclifier not prioritized for investigation, or not a cyclifier.

Of 108 reviewed cases, 11 were rejected non-cyclifiers, 81 were potential but uninvestigated cyclifiers, 1 was an investigated non-cyclifier, and 15 were approved investigated cyclifiers. 7 cases were in the physical layer, 5 cases were in the energy layer, and 3 cases were in the value layer.

Table 1 Investigated cyclifier case studies.

Layer	Main flow	Name	Scale	Phase
Physical	Water	Water Squares (*Waterpleinen*)	Block	Active
	Organics	Hallum Algae Production Plant	Building	Active
	Food	Food Bank (*Voedeslbank*)	Region	Active
	Food	Gro-Holland	Region	Active
	Inorganic	WarmCO_2	City	Active
	Water	Kolding Pyramid	Block	Active
	Water	Minnaert building	Building	Decommissioned
Energy	Heat	Eindhoven Bio-energy centrals	Neighborhood	Active
	Heat	Floating Urban Hotspring	Building	Concept
	Heat	Mine Water Project	City	Active
	Heat	Plato Wood Heat Treatment	Building	Active
	Sound	Moving Noisebarrier	Building	Concept
Value	Money	Flintenbreite neighborhood	Neighborhood	Active
	Knowledge	Geneva Symbiosis	Region	Active
	Knowledge	PowerMatching city	Neighborhood	Active

Emergent cyclifier themes

The authors recognized patterns and themes in the collected data. The following three emergent themes are discussed: ecological niche dimensions, ecosystem roles, input and output types, and risks faced. Each of the themes are discussed below with illustrative narratives from relevant cases.

Ecological niche dimensions

A combination of two ecological niche dimensions, material and policy, were observed in cyclifier crystallization. Investigated cases exhibited a combination of both a material niche, in which material is available for metabolic processes that otherwise would be lost, and a policy niche, in which a subsidy, tax break, or regulation facilitates the cyclifier's role. The degree to which a cyclifier is stimulated by either a material or policy niche varies.

The Food Bank (*Voedselbank)* in the Netherlands exists because food producers must pay to destroy their mislabeled or overstocked products, while they are tax-incentivized to donate to the Food Bank, who then distributes the food to low income households. Without the policies, the food producers would more likely take the easier route of destroying their food. The cyclification occurs because the entire system is more efficient as the Food Bank creates a material and economic shortcut between the food producers and low income families.

An algae production plant in Hallum, the Netherlands, exists because a farmer wanted to sell electricity onto the grid from biogas combustion with a renewable energy price subsidy, but in order to do so the farmer was obligated to utilize the residual heat from combustion. The farmer decided to work with partners to develop an algae facility on site, which now sells dried algae as a nutrient supplement for livestock. Again, without the supportive policies, the ecological niche would not have been strong enough for a cyclifier to develop.

The WarmCO_2 case study, on the other hand, has a strong material niche in which the CO_2 and residual heat from artificial fertilizer production is transported to industrial greenhouses through pipelines in Terneuzen, the Netherlands. Nevertheless, one of the reasons actors are attracted to using the cyclifier is for the prospect of green-labeling their products and subsidies.

Ecosystem role types

Two types of ecosystem roles for cyclifiers were found. One role is the supply-demand matching cyclifier, which connects the supply of a process's by-products to input demand of another process by creating a new metabolic pathway. The WarmCO_2 case matches the supply and demand of two local processors. The Geneva Regional Symbiosis project matches input-output data from 19 industries in the region leading towards ecological connections. Even though the data flows were previously unformulated, the primary role of the project was a new pathway connecting the companies. PowerMatching city uses information technology to connect the data of supply and demand curves of local energy consumers and producers, thus increasing the efficiency of the entire system by one quarter.

The second ecosystem role found in cyclifiers is "transformational," wherein novel products and services with additional value are synthesized from by-products within the ecosystem. For example, the Floating Urban Hotspring uses residual heat to create a new recreational platform, thus transforming the by-product heat into an ecosystem service that did not exist beforehand. Another case, Flintenbreite, transforms the neighborhood's blackwater into an energy source for the neighborhood and redirects the inhabitants' wastewater bills into ownership of the neighborhood infrastructure through a local integrated infrastructure company (Otterpohl 2010).

Input and output types

Two input types (pre-existing versus uncollected potentiality) and two output types (substitution versus novel) were found in the investigated cyclifiers. Interestingly, all four of the possible input-output combinations were found.

A cyclifier's input can either be a pre-existing flow or an uncollected potential flow. Pre-existing flows are already collected and separated; only the destination of the flow is changed to a process that maintains its quality. Pre-existing flows used as inputs in the investigated cyclifiers include separated waste, sewage, and waste heat. Conversely, uncollected potential inputs need to be coordinated and cohered from surroundings and transformed into a useful flow. Uncollected potential inputs in the investigated cyclifiers include data, biomass, and distributed heat sources. This distinction was interesting because it spoke to the different roles that cyclifiers play in their ecosystems.

A cyclifier's output can either substitute existing consumption demand or provide novel flows. Flow substitutions replace conventional inputs with inputs from the cyclifier's processes, including electricity, heating, cooling, food, and water. In the case of substitution, the quantity nor quality of consumption are necessarily changed, only the source of the flow. An example of a substituting cyclifier is the Eindhoven bio-energy centrals, in which several neighborhood-scale combined-heat-power units have been installed to use local biomass from green spaces and abattoir by-products to fulfill energy demands. Novel flows, on the other hand, create new services in their context, providing a supply that was not present beforehand. In the investigated cyclifiers, novel services are data (PowerMatching city and Geneva Symbiosis), recreation (Floating Urban Hotspring), and awareness (Water Squares). Novel flows increase the resource efficiency of a system by replacing an activity with a more efficient activity rather than substituting a flow for an existing activity.

Risks faced

Although most investigated cyclifiers are thriving, cyclifiers do face risks to their operations from internal and external pressures and design flaws. The Minnaert building in Utrecht, the Netherlands is the only investigated cyclifier to have been decommissioned. The Minnaert building was designed to transform rainfall into cooling potential by harvesting the rainwater from the roof into a large open pond inside the building foyer. The pond was to be used as a thermal buffer and in the air conditioning system of the large building. However, soon after starting operation, the open pond began leaking and the thermal buffer was found to be too small to cool the entire building. The technical failure was so large that the cyclifying operation was abandoned.

A cyclifier in limbo is the Mine Water Project in Heerlen, the Netherlands. In 2008, the project started pumping warm (28° C) and cool (17° C) water from abandoned mine galleries to the city of Heerlen for pre-heating and pre-cooling climate control systems in new office and residential buildings. A seven kilometer distribution network with hot, cold, and return pipes connect the various users in the city. The Municipality of Heerlen, which initiated and owns the project, accumulated a debt of 4 million euros in the realization of the 15.7 million euro project. According to the project manager (Weijers 2011), the cost-effectiveness was questioned from the outset, but the project was carried out for social and environmental reasons. The pay-back-time gambles that energy prices will continue to rise, though there is a risk that new forms of energy could stabilize the price. Prospective adopters of the Mine Water infrastructure must balance the additional expenses incurred for investing in the building technology that allows them to utilize the mine water with the risk that the mine water may be more expensive than other fuels in the future.

Another cyclifier in limbo is the Bio-works pyramid in Kolding, Denmark. As part of an urban renewal project in 1995, the city of Kolding constructed an innovative decentralized wastewater cleansing operation in a glass pyramid within a city block to serve 120 homes. Blackwater and greywater are collected together inside the block via a sewer pipe. The sludge is removed and treated in the municipal treatment plant. The remaining liquid fraction of the wastewater passes through a series of reactors for aeration, clarifying, and purification with ozone and ultraviolet light. After this last step, the cleaned wastewater was intended for irrigation and supporting tilapia fish. Four levels in the pyramid were planned as greenhouse space for the inhabitants to grow their own food. However, 16 years after completion, two of the major functionalities, water reuse and food production, have ceased. According to the site manager (Anderson 2010), there three major issues with the social adoption of the cyclifier. First, the community has changed from owners to renters, and the renters have no long-term invested interest in utilizing the space provided. Second, the small scale discourages professional cultivators. Third, the pyramid is a repetition of service, as the neighborhood’s apartments are equipped with glass-enclosed patios in which plants can be grown with more convenience for the users.

Gro-Holland case study

Gro-Holland was selected to demonstrate the cyclifier case analysis methodology because it closely approaches the ideal cyclifier definition. In short, Gro-Holland uses coffee residue from La Place, a café franchise, as a growth substrate for oyster mushrooms, which it then sells back to the cafés that provide the coffee residue, thus inhabiting a unique niche in the distribution network. It is an elegant case of chain-thinking, as the delivery trucks dropping off the coffee residue also pick-up the mushrooms in the same trip. In the following demonstration, the methodological steps are walked through, including process analysis, ecological analysis, and graphical analysis.

Process analysis

The following is a narrative of the cyclifier's process followed by a MFA diagram. Coffee grounds (2500 kilograms per week) are transported to the facility, where they are mixed with oyster mushroom spores (240 kilograms per week imported from Belgium) and a natural agent that prevents compaction of the mixture. The mixture falls into tubular, finely-perforated plastic bags. The bags are hung in the incubation room during which time mycelia grow through the mixture and a large amount of heat from composting aerobic bacteria is generated (in this pilot facility the heat is not captured). After four weeks, the bags are temperature-shocked for one day at lower temperature to activate the mushroom growth. The bags are then sliced open and hung in the fruition room. The fruition room is precisely climate controlled to maintain warmth and humidity without disturbing the air, which must remain as still as possible. The odor from mushroom growing is strong, so an air filter is used on the exhaust from the fruition room to reduce emissions. When the mushrooms are ready, they are hand-harvested. The coffee-mycelia mixture is given to nearby tulip farmers as a soil conditioner. The mushrooms are delivered to La Place cafés across the Netherlands, where they substitute the flow of mushrooms from conventional sources.

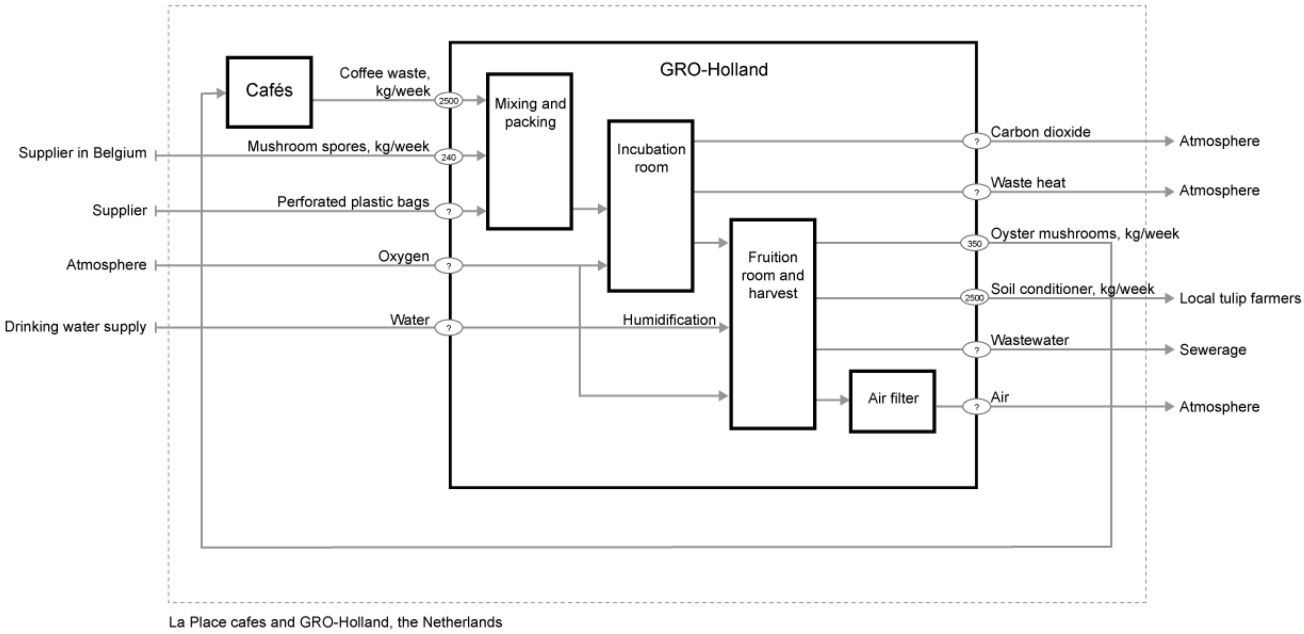

Figure 4 MFA of the Gro-Holland case study.

The mushroom growing process had minor start-up complications. Time was needed to optimally set up the production facility, adapt growing techniques, and regulate temperature and humidity. Regarding investment, it was thought that 50,000 euros would be enough for the entire project, but that amount more than doubled. The income of the project is set to the market value of oyster mushrooms. Their business is slightly affected by fluctuation of the demand for mushrooms, which changes seasonally, especially when asparagus and strawberries are in season.

Ecological analysis

Gro-Holland is a supply-demand matching cyclifier type. Its inputs come from a pre-existing stream of coffee residue, which previously would be treated as green waste. Its outputs are substitutive; replacing the import of mushrooms typically cultivated using straw as a substrate. It exists in a material ecological niche, using the opportunity to close cycles of material and transportation. In the policy dimension, Gro-Holland benefits from green innovation financial awards and from the café chain’s eagerness to improve their sustainability image.

The project’s chain thinking exhibits strong symbiotic relationships. Gro-Holland implanted itself within the café chain’s existing distribution network, in which coffee residue was already being separated. Previously, mushroom-delivery trucks would be empty returning from the distribution center and La Place supply trucks would be empty on their way to the distribution center. Now, the pathway between the consumer and producer is bi-directionally efficient as distribution trucks are full in both directions, dropping off coffee grounds and picking up mushrooms. The growing medium is connected to tulip farmers within the locality, who use the material as soil conditioner, though there is no economic value generated by the flow.

Gro-Holland was the initiator of the project. When approached, La Place accepted the project idea. La Place’s sustainability goals, including natural and organic ingredients, regional ingredients where possible, and a large vegetarian menu, fit within the concept of recycling coffee waste into mushrooms.

Permits are not required for the relatively small size of the growing operation in the Netherlands. In order for the growing medium (coffee grounds plus mycelia) to be used as a soil conditioner, a lab analyzed the substance for heavy metals and eutrophic nutrients, and approved the quality. Gro-Holland would consider becoming certified organic in order to add economic value to its product, though all of the coffee would need to be certified as well.

The non-optimal aspect of the Gro-Holland facility is its use of space. The growing facility is located in a rural village north of Amsterdam, whereas it could have been in an urban interior space, for example in the Netherlands' plentiful empty office space, or in a basement, as no natural light is required. Spatial optimization in an urban interior would have the double benefit of improving land use as well as decreasing transportation costs.

Gro-Holland's success shows that on a relatively small scale, organic waste streams can be utilized in mushroom cultivation. For a future implementation, further improvements could be found in the energy efficiency in operations, such as reusing heat from incubation in fructification and heat exchange from outgoing air from the fructification and optimization of geographic location.

Graphical Analysis

The ambition of the cyclifier’s hybrid diagram, figure 4, is to convey MFA along with spatial and contextual information. An axonometric projection was chosen to architecturally represent the processes and actors with labeled platforms and sub-processes shown as stacked platforms. The system boundary is shown as an extruded block. Starting from the edges of the cyclifier, intervals are marked to indicate distances traveled by inputs and outputs. Flows are scaled by mass (as in Sankey diagrams) and are color-coded by flow type. Flows to and from the atmosphere are represented as traveling vertically. Most flows are represented as travelling left-to-right, while cyclified flows travel right-to-left.

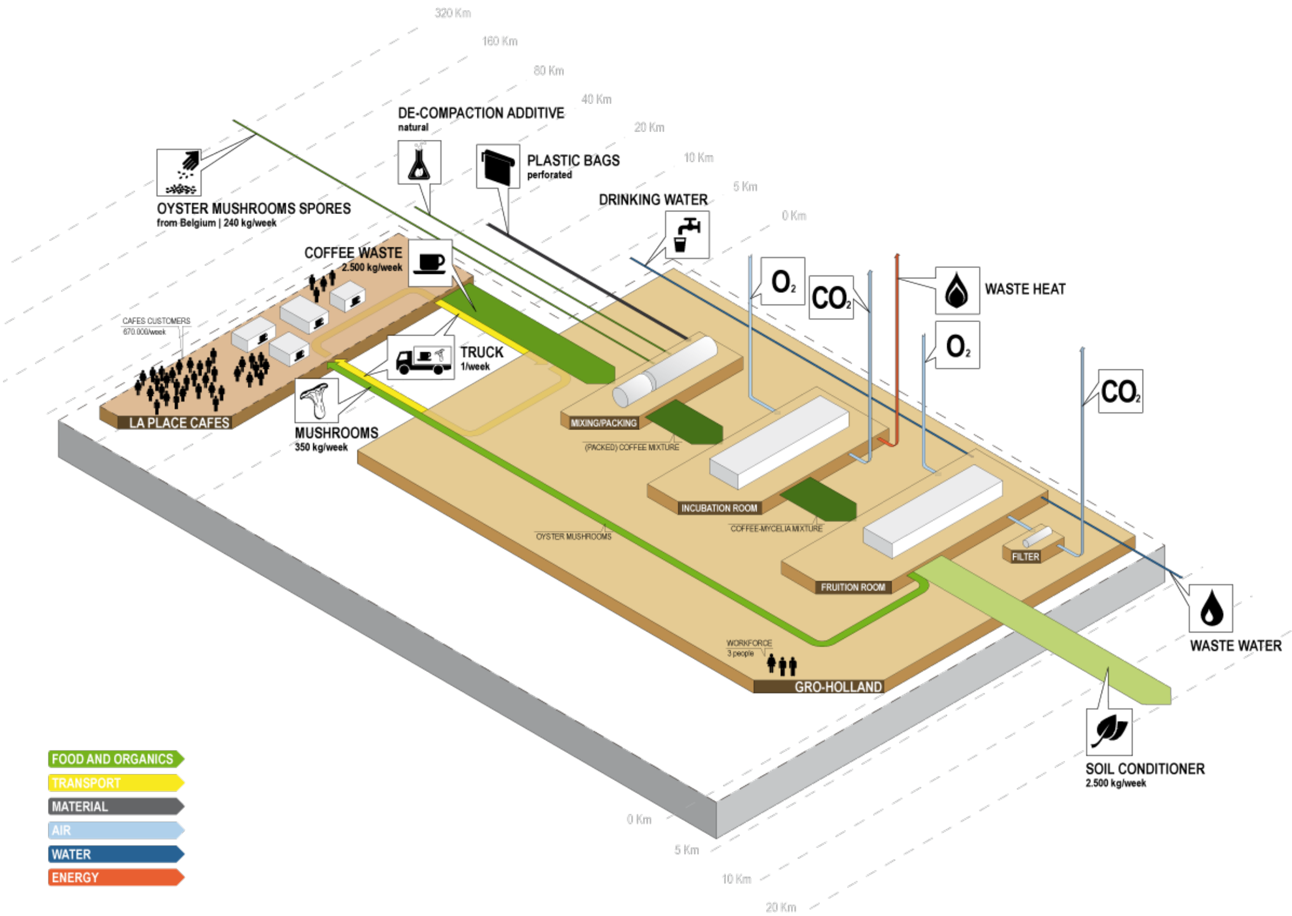

Figure 5 MFA and context hybrid cyclifier diagram for the Gro-Holland case.

Cyclifier criteria assessment

The authors checked to confirm that Gro-Holland meets the cyclifier definition's three criteria:

1. <u>Cyclifiers operate in ecological niches:</u> Gro-Holland exploits a material niche containing a pre-separated coffee residue stream and a policy niche of awards for innovative in green business.

2. <u>Cyclifiers create symbiotic connectivity:</u> Gro-Holland creates two flows with additional utility: oyster mushrooms and soil conditioner. It creates a feed-back loop with La Place cafés substituting the input of oyster mushrooms and an alternative materials supply for local tulip farmers. Gro-Holland has also creates local employment opportunities.

3. <u>Cyclifiers increase resource efficiency:</u> Resource efficiency is gained by creating a material loop between La Place and Gro-Holland that reduces material import and waste output and improving transportation efficiency. Gro-Holland does not create any additional inputs or outputs beyond the cultivation of mushrooms it substitutes.

Concluding remarks

Achieving sustainability requires recognition of connectivity within urban metabolic systems. The cyclifier concept recognizes a classification of actors that operate in ecological niches, create synergic connections, and decrease system-level inputs and outputs. The intention of the new term is to be able to intensify the urban metabolism discourse regarding flows by labelling actors involved in similar patterns of activity. The research team investigated relevant cases revealing patterns and themes within the physical, energy, and value layers of the city.

Acknowledgements

The authors are grateful to those who granted the research team access to their projects for site visits and interviews, and for the guidance and support of Frans de Jong, Fabienne Goosens, Coen de Koning, and Anna Brambilla. The authors also acknowledge funding from Stimuleringsfonds voor Architectuur and Fonds BKVB.

References

Anderson, T. 2010. Personal communication with Tove Anderson, manager of the Bio-works, Kolding, Denmark, May 1010.

Brunner, P. H. and Rechberger H. 2004. *Practical handbook of material flow analysis*. Lewis Publishers.

De Urbanisten 2010. *De Urbanisten and the Wondrous Water Square*. Rotterdam, the Netherlands: 010 Publishers.

Doepel Strijkers Architects 2009. Generic scenarios. In *REAP: Rotterdam Energy Approach and Planning*, edited by A. v. d. Dobbelsteen et al. Rotterdam, the Netherlands: Rotterdam Climate Initiative.

EXCEPT 2011. *Mooi & Duurzaam Schiebroek-Zuid* [Beautiful & Sustainable Schiebroek-Zuid.] Utrecht, the Netherlands: InnovatieNetwerk.

Hutchinson, G.E. 1957. *Concluding remarks*. Cold Spring Harbor Symposium on Quantitative Biology 22:415-427.

Korhonen, J. 2005. Industrial Ecology for Sustainable Development: Six controversies in Theory Building. *Environmental Values* 14: 83–112.

Jansen, J. W. B. 2011. Personal communication with Jan Willem Bosman Jansen, GRO-Holland, Egmond Binnen, the Netherlands, 9 May 2011.

Jongert, J., Dirkx, L. 2013. INSIDEflows: Reinventing the performance of space. *INSIDE*. Royal Academy of Art, The Hague, the Netherlands.

Newcombe, K., Kalma, I.D., and Aston, A.R. 1978. The metabolism of a city: the case of Hong Kong. *Ambio* 7: 3-15

Otterpohl, R. 2010. Personal communication with Ralf Otterpolf, Institute of Wastewater Management and Water Protection, Hamburg, Germany.

van Bergen Kolpa Architecten 2009. Park Supermarket. In *Architecture of Consequence,* edited by O. Bouman et al. Rotterdam, the Netherlands: NAi Publishers.

Van Hinte, E., Peeren, C., Jongert, J. 2007. *Superuse: constructing new architecture by shortcutting material flows*. Rotterdam, the Netherlands: 010 Publishers.

Weijers, J. 2011. Personal communication with Jean Weijers, Mijnwater NV, Heerlen, the Netherlands.