The socio-spatial effects of Circular Urban Systems

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Abstract. This article shows what kind of urban spaces are produced by circular systems. The focus is on the socio-spatial dimension of closed material loops in two neighbourhoods (e.g., reuse of grey water, recycling of waste, provision of renewable energy). Although the Circular Economy (CE) narrative is increasingly part of urban transformation policies, there are considerable implementation gaps in how regenerative or self-sufficient systems are operationalised in practice. I argue that the application of circularity principles in the urban context requires conceptual clarification to be useful for urban theory and praxis. Therefore, I provide a political ecology perspective of circular urban systems by analysing two cases: Block 6 in Berlin and Schoonschip in Amsterdam. I explain how such systems were established, who benefits from them, and what kind of socio-spatial conditions they produce. Methodologically, I use several qualitative research methods in the framework of a case study analysis. The results show that the incremental and publicly financed low-tech development of circular systems is socially compatible while privately funded high-tech developments result in stronger levels of sustainability but are reserved to a small exclusive group of people and provoke gentrification processes.

Keywords. Sustainable Neighbourhoods, Circular Economy, Climate Change, Infrastructure, Urban Political Ecology

1. Introduction and overview

Can cities be designed to regulate climate, cycle nutrients, and produce their own energy and water? Scrutinising circularity as a concept and its application to urban planning and design is central to this paper. I take a socio-ecological perspective and shift the focus on resources and how they are governed. I am particularly interested in circular urban systems, where the organisation of material flows (energy, water, food, materials, and waste) is partly or fully regenerative – made possible by interconnected infrastructural arrangements. Therefore, the research question of this article is how do circular systems transform urban spaces and what socio-spatial effects do they produce? The starting point of my analysis is not a technology-oriented viewpoint but rather the social and functional construction of circular urban systems. This allows to focus on socio-spatial practices, such as planning processes, actor-networks, and the type of spaces that are emerging including the power relationships that underpin these practices.

The new climate paradigm is framed as a multidimensional problem for cities and the potential starting point for self-sufficient models of city planning. Although there is an increasing (policy) trend of applying principles of the Circular Economy (CE) in cities, I argue that this endeavour requires a re-conceptualisation for urban planning and design including a look into historical approaches of combining ecological thinking with urban development. Thus, the literature review gives an overview
about historical planning perspectives connected to circularity, frames the current debate, and identifies two research gaps. The theoretical part of the paper presents two intertwined concepts (Urban Metabolism and Urban Political Ecology) that are useful for analysing the socio-spatial effects of circular urban systems. The case studies offer a detailed account of two distinctive circular urban systems that have different foci and boundaries as well as diverging development logics.

The main emphasis is to develop a political ecology perspective of circular urban systems to identify how the application of circularity in urban planning and design influences local socio-spatial practices. Therefore, the implicit first question is where and how circularity is established in an urban system. By exploring the dynamics of two urban transitions that are based on circularity principles, I identified whether a CE informed city planning is the starting point of a socio-ecological transformation or leads to social inequalities and gentrification. Besides that, I will draw conclusions for spatial planning. The next chapter starts with the background of the paper and the problem definition.

2. Cities and the new climate paradigm

50 years ago, the infamous ‘Limits to Growth’ was published that put the exponential economic and population growth in relationship with the finite resources of our planet. Supported by computer simulations, it was the first time that global resource use was scientifically discussed in relation with societal progress. The tone of the book, however, was not alarming but rather hopeful. The authors suggested that there was enough time to embark on a pathway that limits growth while creating a global equilibrium to keep the planet’s ecological system intact [1]. But quite the opposite happened: cars were not substituted by sustainable public transport, average apartment sizes grew, and product cycles became significantly shorter. The period from the mid-20th century until today was named ‘The Great Acceleration’, which summarises the increased human impacts on the Earth. This includes several socioeconomic and Earth system parameters that all accelerated at unprecedented rates. Examples are total global population, total real GDP, damming of rivers, water usage, food production, motor vehicles, and surface temperature. Another example is the number of motorised vehicles, which skyrocketed from about 40 million in 1945 to nearly 700 million by 1996 [2].

At the same time, there are new record highs of Greenhouse Gas (GHG) concentrations in the atmosphere and there has been a 41% increase in the radiative forcing of the long-lived GHG from 1990 to 2017. Of the five most important GHG, CO₂ (Carbon Dioxide) is by far the largest contributor to direct warming. Alongside with CH₄ (Methane), it is the only one that continues to increase at regular rates over decades [3]. Thus, the Earth’s energy budget is significantly out of balance. The escalation of human’s effects on the global environment has led to the proposition of the Anthropocene as a new geological epoch [4]. This now widely accepted suggestion indicates that since the mid 20th century, substantial and globally synchronous changes to the Earth System were observed that have been significant enough for the global climate to depart from natural behaviour [5].

The world is not seeing a climate crisis, which supposedly can be reversed, but an altered condition of the environment that was caused by a pathway based on the exploitation of natural resources and mechanisms of capital accumulation. This new condition is characterised by steadily rising temperatures and different forms of climate change that reveal the vulnerable infrastructures of cities. This is a problem that affects cities in two major ways: they have been heavily contributing to and at the same time are being affected by climate change. On the one hand, they account for more than three quarters of the world’s CO₂ emissions and urbanisation has been transforming large parts of arable land into urban spaces. On the other hand, the effects of climate change become ever more visible in our everyday lives and surface through severe floods, extreme weather events, human migration, and large costs. Place-specific climate phenomena such as heat islands, resource depletion or water scarcity are strongly related to the human-built environment and can possibly contribute to destabilising the organisation of it [6]. In other words, urban agglomerations became parasites of landscapes that drain resources and

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1 The Gross Domestic Product (GDP) measures the market value of all the goods and services produced by countries in a specific timeframe.
2 Radiative forcing is a direct measure of the energy balance of the Earth and includes all forces that are cooling or warming the planet.
energy from the planet’s ecosystems while releasing pollution into the air. Therefore, how cities are designed and how they operate significantly affects the warming of the planet and impacts the health of communities and ecosystems.

City governments urgently need to start transformation processes that reduce emissions and prepare the urban infrastructure for the consequences of climate change. Thus, cities cannot anymore operate according to the linear ‘take-make-waste’ logic but instead their socio-technical systems (urban communities and infrastructure) need to adopt an ecological and regenerative use of resources to provide healthy and sustainable livelihoods in the future.

3. Self-sufficiency and regeneration in urban planning

One promising approach for increased sustainability and resilience is to identify and (re-)organise the material flows of a city towards closed loops. Against the background that fully circular systems only appear in biological systems, the principle of circularity has found application in different fields. For example, in the context of industrial symbiosis, one manufacturing company reuses the waste of another or in cradle-to-cradle production processes, goods are designed in such a way that they can be made into new ones. Another example is the CE with its primary goal to close material loops by using the notions of reducing, reusing, and recycling [7]. In the recent past, this idea has been heavily associated with cities and the narrative of the CE is increasingly part of urban transformation policies. Here, I concentrate on the potentially problematic landscape of inequalities situated in the transition from policy rhetoric to action. CE is seen as a way to help solve cities’ complex sustainability challenges by transforming their metabolisms and by applying looping actions to material flows. Urban planning is considered as the key tool for moving towards circular systems because space is interlinked with the main arguments for the CE including environmental, economic, social, and geostrategic improvements [8]. Although there are strong arguments for the CE to enter urban development, conceptually it needs to be aligned with urban planning and design. Therefore, the following sections show firstly the historical connection between urban planning and self-contained systems, then I propose circular urban systems as the conceptual bracket between CE and urban development, and finally discuss the research gaps.

3.1. Historical perspective: the search for sustainable urban form

Circularity thinking can be identified as central element in some urban planning approaches of the 20th century. Sparked by the industrialisation where cities suffered from overpopulation and pollution or as a countermovement to globalisation and centralisation, several theories for cities were developed that are based on ecological principles and decentralised systems. Common features were the idea of self-sufficiency, the integration of water management and sanitation, and generating energy at scales nearer to users or residents [9]. At the beginning, these approaches were focused on relatively small settlements and mostly had to do with food security. Then, from the 1970s onwards, they were characterised by technological advancement, and since the 1990s, the synthesis of urban and natural systems was systematised on behalf of future generations and planetary ecology [10]. The search for sustainable urban form started at the beginning of the 1900s with Howard’s ‘Garden City’ that sought to integrate the urban and the rural in small communities (30,000 inhabitants) that are surrounded by green belts in permanent agriculture. Another similar example is the self-contained housing typology that was initiated by the settler’s movement in Vienna at the end of the 1st World War in 1918. As a result of an economic crisis and due to homelessness, citizens started to occupy the fringes of the city and – later in cooperation with the city – built homes with allotment gardens. Organised in cooperatives, they managed to articulate common interests and based on self-help, they implemented their ambitions [11]. A similar concept is ‘Fruchtlandschaften’, put forward by Migge in 1933. It suggests installing productive agricultural zones in the direct hinterland of cities, most prominently in Berlin, to provide self-supply of produce in order to lower the city’s dependency on imports. For that, he proposed the relocation of 1 million inhabitants who would become part-time farmers in settlements that connect the urban with the landscape [12]. Another example is McHarg’s ‘City Designed with Nature’ (1969), a method that analyses natural
conditions (water catchment boundaries, wildlife corridors, agricultural soils, etc.) to find the best places to build cities. Lastly, Girardet’s ‘Circular Metabolism’ (1992) focuses on compactness and closing the natural resource cycles upon which an urban settlement depends on [10]. These few examples show that the idea of integrating nature and regenerative material flows into urban systems was present in urban planning for more than one century.

3.2. Current debate: from the Circular Economy to circular urban systems

The current debate about self-containing systems in cities is dominated by the CE but since this concept has its origins in waste management, its application to the urban context requires some translation. The focus of the CE is on economic systems, typically on sectors (e.g., food, construction) or business models. When trying to bring together the CE and urban systems, scholars identified at least two discrepancies: firstly, the CE tends not to focus on a spatially bounded area since economies usually operate beyond local scales (e.g., nationally, or internationally). But cities are physical entities with diverse land-uses and a variety of functions, which together determine the possibilities of introducing circular actions. Secondly, the CE’s focus is on systems of production whereas resource and material flows in cities are governed by infrastructure and services (systems of provision) that focus on delivering a range of societal benefits [13]. Thus, to conceptualise the CE for cities, it is necessary to consider the spatial complexity of the city and its resources as well as the logic of provision. Based on this, the focus should shift to the specifics of urban material systems and their internal context including material flows, infrastructure, and social actors as opposed to only an economical production perspective that necessarily needs to consider the broader national and international context. Therefore, I argue that it is more appropriate to conceptualise the CE in cities as circular urban systems.

3.3. Research gaps

In the context of circularity in cities, I have identified two research gaps in the current literature. Firstly, some authors point to a bias towards technology-driven industrial transformation, while the socio-spatial dimension of urban transformations is overlooked. There is agreement in the literature about the missing emphasis on the social dimension while links between environmental and economic issues are pointed out explicitly [14]. There are arguments to analyse the dynamics beyond urban CE policies and practices to identify how and by whom the agenda is driven and to ultimately address the question of who benefits or loses from such transitions [15]. Secondly, other authors remark that there is a limited understanding about the political implications of the CE on urban development including whether existing circular urban systems and circular practices contribute to a socio-ecological transformation or are continuing an exploitative development logic [16]. Besides that, critical scholarship has pointed to considerable implementation gaps in how circular ideas for city systems are operationalised in practice [17] indicating that ‘circular urban developments’ tend to remain largely on a rhetoric strategy level and are disengaged from urban theory and praxis [18]. The next chapter provides the theoretical lens for analysing the cases.

4. Sustainable and just resource use in cities

I will make use of Urban Metabolism and Urban Political Ecology, two connected concepts, to frame and analyse the socio-spatial effects of circular urban systems. Therefore, this paper contributes to the ‘re-materialisation’ of urban studies that is focusing on the relation between urban processes, urban resource flows, and their environmental impact [17].

Under the umbrella of urban metabolism (UM), various studies and methods have emerged that quantify resource flows to better understand where, how, and when material flows occur. UM is a perspective that conceptualises the city as an ecosystem or an organism. It evaluates the ‘metabolising’ of resources as they come into, are transformed by, and are moved out of an urban region [19]. This concept assumes that the transformation of natural resources in goods, services, and waste is necessary to maintain life, but this only contributes to sustainable development if the increase in throughput of materials and energy does not exceed the biosphere’s capacity for regeneration and waste assimilation [20]. A sustainable UM that respects its ecological boundaries is “based only on renewable resources,
does not reduce biological diversity, [and] does not lead to systems that reduce the freedom of future generations” [19].

Urban political ecology (UPE) is a tradition of studying the ecology of urban space and how economic, political, and cultural processes in cities shape, and are shaped by ecological conditions [21]. The assumption is that urbanisation processes are sustained by non-human actors such as pipes, cables, sewers, and canals. These networked infrastructures create the metabolic vehicles responsible for moving different types of nature (energy, water, waste, fat, chemicals, viruses, etc.) into, through and out of the city [22]. Latour conceptualises these phenomena as hybrids, which he defines as “mixtures (…) of nature and culture” [23]. Understanding the power over the process of hybridisation and analysing the resulting effects for specific social groups is key to the concept of UPE.

UM provides an analytical concept for measuring the in- and outputs of a defined system to understand the possible circulation of materials and the production of waste or emissions. UPE has a descriptive focus on the socio-political effects of resource use in cities. I will use them in combination to analyse the increasingly urban focus of the CE that suggests transforming resource flows towards closed loop systems. Thus, the way how nature (resource flows) and culture (actors, infrastructure) are entangled in the context of circular urban development and what externalities this produces is the focus of the subsequent analysis.

5. Case study: Block 6 and Schoonschip

The aim of the case study is to assess social practices and micro-politics in relation to complex networked infrastructure to better understand the socio-spatial effects of circular urban systems. The two selected urban developments are: (1) Block 6, a pilot project based on half a housing block in Berlin that deals with water recycling in connection with food production and blue-green infrastructure, and (2) Schoonschip, a floating neighbourhood with 46 households that is a living lab for circular and bio-based urban development in a post-industrial district in Amsterdam. I explain how these circular urban systems were established, how they function (UM), who benefits from them and what kind of socio-spatial conditions they produce (UPE). Based on the literature review and the theoretical foundation, I chose the following categories for the analysis of the cases: actors, infrastructure, and space. Methodically, I combined the following qualitative research methods: the analysis of documents, interviews with experts and residents, and on-site observations.

5.1. Block 6

Located in Berlin-Kreuzberg, this project includes a large backyard and six residential buildings with 106 apartments that were built as part of the International Building Exhibition in 1987 (IBA 87). At the same time, an integrated water concept for the local reuse of grey water was implemented. It included a 900 m² grey water plant purification system in the inner courtyard of the residential complex in combination with a multi-stage planting concept. There, the nutrient-poor grey water from bathtubs, showers, and kitchens was decentrally treated and reused for open space irrigation and domestic needs. In 2006, the water management system was technically re-designed and further developed. An industrial recycling station was added as infrastructure to process the grey water of about 250 people mechanically and biologically into service water quality and reuse it for flushing the toilets and watering the tenant gardens. Additionally, the rainwater from the 2,350 m² roof area and 650 m² sealed area is discharged into the original water system. In 2013, the technical infrastructure was improved and a greenhouse with hydro- and aquaponic systems for food production was installed that uses the recycled greywater. For a limited time, it was even possible to produce liquid fertilizer out of the blackwater of around 50 tenants. In 2022, the water recycling system inside the recycling station was completely renewed to filter a bigger amount of water and to also recover the heat from the process.

5.1.1. Actors. Today, the central actors are the ones who are operating the recycling station (Nolde & Partner), an educational initiative (Roof Water Farm) who runs the greenhouse including a small-scale food production (limited to tomatoes, chilis, and herbs), and an owner’s association who owns and
manages the building stock. The tenants of Block 6 who typically have a low- to middle-class income apparently play a minor role since they partly don’t know about the water recycling processes and are not actively using the green backyard of their buildings. During the regular events of the greenhouse initiative, which are taking place on-site, usually no to very few local tenants are attending. This is surprising because they are positively affected by the water management system and the project has a city-wide legacy. For example, the residents of Block 6 pay less for the water used to flush their toilets (approx. 3€/m³ instead of 5€/m³) because it is recycled service water instead of fresh water.

5.1.2. Infrastructure. The central innovation that makes the local water treatment possible in the first place is the separation of black and grey water using different pipes and installations inside the buildings. This was part of the experimental and ecological building design of the IBA 87. The inner courtyard is the place, where all the infrastructure and functions for recycling the water are located, (rainwater pond, greywater sedimentation tank, constructed wetland with reed, technical recycling in the recycling station). For legal reasons, it is only possible to use the serviced water for toilet flushing. Thus, the water that is fed back to the toilets of Block 6 is where the loop is closed. This means that although the recycling capacity is technically much larger, only a small amount of the entire grey water is recycled and indeed goes back to the buildings. This is also the amount that can be economically utilised and sold to the tenants. Attempts to realise a larger network and find new consumers for the service water in the adjacent buildings have failed so far, although there is a business case. Finally, a heat recovery system integrated with the recycling station was installed to further optimise its energy efficiency.

5.1.3. Space. The courtyard is an accessible semi-public space, but all the facilities are fenced because the land-use is defined as premises (Betriebsgelände) and additionally, the city declared it a technical heritage site. The swimming pond is not active anymore and according to an expert, it is filling up only temporarily during heavy rain events. Also, both tenants and experts recognised an increased amount of litter that sometimes is intentionally dumped at one entrance point because this is a place that is usually unattended. This makes the backyard not necessarily a lively place but with its lush greens it was compared to an urban oasis by a frequent user who attributes it with positive psychological effects during the warmer months. Over the last decade, there was no significant rise of rents in the area although the water recycling system was optimised step-by-step. There are no signs of gentrification in the neighbourhood that might be connected to the circular urban system.

5.2. Schoonschip
Schoonschip is a part of Buikslootersham, an area located in the north of Amsterdam that used to contain mostly industrial activities but is being transformed into a sustainable residential area. The first idea of realising a floating neighbourhood on water based on circularity principles dates to 2008. Schoonschip, which is based on collective private commissioning gradually developed and only in 2021, the last housing unit was added. Today, 144 residents live in the area.

Figure 1. Backyard of Block6 including recycling station, greenhouse, and fenced wetland.
5.2.1. **Actors.** Key to this development have been its inhabitants who shared the dream of building a sustainable, close-knit community on the water. During its realisation, they were challenging legal, economic, and ecological standards to realise a high degree of circularity – both in terms of construction materials and operational aspects. For this reason, they have been collaborating with a range of partners including research institutions, legal firms, utility companies, and the municipality.

5.2.2. **Infrastructure.** In Schoonschip, a broad vision of circularity was implemented that includes construction materials, energy, water, biodiversity, food, mobility, governance, and community aspects. When planning the buildings, as many construction materials as possible that either were reused or can be reused later (e.g., second-hand timber facades) were utilised. Therefore, a material list with colour codes was developed to determine the level of sustainability. A total number of 516 solar panels were distributed across the homes and a smart grid was installed to flexibly exchange each other’s renewable energy as well as to deliver excess energy to the main grid. 30 heat pumps that extract heat from the water in the channel were installed to keep the houses warm. All this infrastructure is well integrated into the buildings or hidden under the jetties that connect infrastructure underground and the houses above ground. Vacuum toilets, which only require one litre of water per flush were implemented that will soon be connected to a water treatment station to win nutrients and biogas from black water and recycle the grey water. Many homes have an upfall shower that filters and reuses its grey water. There are ecology islands just for birds and fish. There is a culture of sharing food among the residents, and they share tools, electric bikes, and cars.

5.2.3. **Space.** The neighbourhood is accessible but at the entrances there are signs saying ‘This is private property. Feel free to have a look but respect the following rules: dogs allowed, no cycling, no shouting, no swimming’. The walkways through the neighbourhood are semi-public including a lot of plants and opportunities to sit but as a visitor, it feels as if you enter a private residential zone that is reserved to Schoonschip’s residents. From the jetties, it is possible to watch the tenants in everyday activities such as working, cooking, playing with kids, etc. One of the residents explained that there was resistance to the project by people who lived in the area before the project started because it used to be cheap and empty and now it gets full and more expensive. The group was not able to realise housing for low-income classes, the costs ended up far beyond the reach of social housing. Additionally, the access to the buildings in Schoonschip is exclusive, in the sense that if a house becomes available, it is first advertised to friends from the community before it goes on the market, one of the residents explained.

**Figure 2.** Schoonschip includes 46 floating households built with strong sustainability criteria.
6. Discussion and conclusion

At the historically grown pilot project Block 6, the focus is on the reuse of grey and rainwater and their integration with other infrastructures (e.g., production of food and energy) while the new-built Schoonschip has taken a holistic approach of circularity with an emphasis on the use of materials as well as on renewable energy production and sharing. In both cases, residents are directly profiting from the circular urban systems. In the former case, they pay less for the water used to flush the toilets and have a green backyard that contributes to the micro-climate via evapotranspiration. In the latter case, the residents have created one of Europe’s most sustainable urban neighbourhoods with low per capita CO₂ emissions. However, the development logic is contrastive. At Block 6, the infrastructure and the current systems were mostly publicly funded or implemented through research projects whereas the Schoonschip project including its infrastructure was predominantly privately financed. There are also opposing tendencies regarding the community involvement. At Block 6, there is currently a lack of involvement although research projects such as Roof Water Farm have achieved this in the past. In this case, the decisions for the design of the circular system were only to a limited extent co-created with the residents. In Schoonschip, the entire project was developed through co-design strategies and essentially driven by the residents. Another key difference lies in the low-tech solutions on the one hand (separate pipes for grey and black water, constructed wetlands, retention ponds, biological recycling) and the high-tech solutions on the other hand (micro smart grid, upfall showers, vacuum toilets, heat pumps). But it is remarkable that the comprehensive set of technologies implemented in Schoonschip was intentionally chosen by its developers with the ambition to be as sustainable as possible. Yet, this aspect makes the community in Schoonschip very exclusive with no possibilities for low-income groups or housing associations to join. There is another major difference: in and around Block 6 there are no signs of gentrification or displacement processes while Schoonschip has contributed to the upgrading (“look and feel”) of the area. Nobody was directly pushed out of their homes since it is a new development on the water but in the broader context of the Buikslootserham district, Schoonschip is a lighthouse project that contributed to rising land values.

This paper had a focus on the socio-spatial effects of circular urban systems asking how circular systems transform urban spaces. The new climate paradigm was identified as a threat to both a city’s sustainability and resilience. Circular urban systems, a conceptual translation of the CE to urban planning, were identified as a promising solution and then analysed in a case study. The two cases have in common that both are operating at a neighbourhood scale, which seems to be well-suited for the implementation of decentralised self-sufficient material systems. What can be learned from the case study is that if largely based on public funding, the incremental development of circular systems over a long period of time is socially compatible, provides open spaces and does not provoke gentrification processes. In contrast to that, innovative high-tech developments result in stronger levels of sustainability and resilience but limit the number of beneficiaries to a small exclusive group and produce semi-closed spaces with no possibility for low-income groups to join.

The two analysed cases represent two different social, spatial, and economic contexts, thus having a limited transferability to other urban systems. However, there are some aspects that seem to be relevant for implementing circular urban systems: (1) during the planning phase, it is important to integrate the technical infrastructure necessary for creating closed loop processes at the earliest stage possible; (2) co-design, especially with inhabitants or future users, plays a critical role for them to take ownership of the solutions (and actually use and develop them further); (3) low-tech solutions can possibly lead to effective results; (4) recycling processes in cities are only efficient when there is a certain mass of materials to be recycled or reused; (5) closed loops or recycling at urban scale ideally provides a business case to enable widespread implementation, which might make it necessary to connect different domains (e.g., energy-water-nexus). One way forward to overcome the implementation gap regarding circular urban systems could be the publicly organised provision of circular infrastructure and subsidies for low-income groups to enable a just socio-ecological development.
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