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Circular Urban Systems: tracing innovation processes

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Abstract: The metabolism of cities bears important anomalies: high levels of resources flow in cities while large quantities of (hazardous) wastes flow out of cities. In order to decrease cities' environmental footprint, Girardet [1] and Rogers [2] suggested making a transition from a linear to a circular urban metabolism. Even though the concept was coined a few decades ago, it still holds prominence among academics and practitioners (see for instance [3–6]).

However, few cities have made such a transition. This shows that creating a circular urban metabolism is complex and challenging. Research so far mainly considered the creation of a circular urban metabolism as a technical endeavour. We would like to argue that organisational and institutional aspects are also of crucial importance for understanding why there is an implementation gap. However these have been understudied.

This paper tries to bridge this gap by adopting a different conceptual approach. We consider that the creation of a circular urban metabolism passes through multiple innovation processes. Such processes happen in a systemic manner wherein, not only technical but organisational and institutional solutions and changes are adopted and adapted.

In this paper we conceptualise the circular urban systems, as a robust concept to address the anomalies of the metabolism of cities. We discuss how this concept is different from existing one and why we think it can help in better grasping the challenges ahead. We also focus on the kind of insights that can be gained by adopting this new concept and how this can open a new agenda for future research.

Keywords: keyword; keyword; keyword (3-10 keywords separated by semi colons)

1. Introduction

More than half of the world's population lives in cities and this proportion is expected to keep rising. While cities are growing in size, they are also consuming increasing amounts of resources and are producing ever larger quantities of wastes. It is estimated that cities accumulate about 80% of the world's energy demand [7]. In other words, cities have large ecological footprints. To give an order of magnitude, the Global Footprint Network for instance calculated that Berlin requires 168 times its size in order to meet its citizen's needs [8]. Combining the expected growth of cities with their already heavy environmental impact leads to a straightforward conclusion: it has become increasingly urgent to work towards achieving a sustainable urban development.

The term 'urban metabolism' draws an overlapping similarity between the human body and the city. It means that both entities have flow pattern of energy and materials. Hence, energy and material flow in and out of the city [9]. As they grow, what flows in and out of cities keeps increasing which explain why modern cities have high environmental footprints. But how to address such problem?

According to Girardet [1] and Rogers [2] the solution to this problem lies in making a transition from a linear to a circular urban metabolism. Even though such a concept was coined and proposed a few decades ago, it still holds prominence among academics and practitioners (see for instance [3–6]). Moreover, it has also started inspiring practitioners and designers of districts and cities such as Masdar in Abu Dhabi [10], Caofeidian in China [11], Hammarby Sjöstad in Sweden [12], or BedZed in London [13] (see also [14]).

Tools or guiding principles have been developed that aim at making such a transition possible. Mass Flow Analysis (MFA) can for instance be used to measure inflows and outflows [15] and thereby quantify the metabolism of cities. It is claimed that by revealing inefficiencies this tool could assist in re-designs aimed at optimizing existing systems, support policy making processes or provide useful insights to develop scenarios [16–18]. The use of Energy Potential Mapping is also advocated in order to chart the energetic potential of a given area and help decision makers to take advantage of these potential [19]. Similarly, the Urban Harvest Approach has also been put forward in order to investigate possibilities to harvest local resources and limit the production of wastes [20], [21]. Finally, Lehmann [4] argues that it is necessary to embed notions such as "zero waste" in (re)design of urban area.

Moreover, models such as the Hammarby or Eco-cycle model are presented as example of how to achieve a sustainable urban development. The Swedish Trade Council even mentions seven cities that have applied or at least been inspired by the model worldwide. However, implementation proves difficult and the promises carried by these concepts are still far from the realities of today's cities. In other words, creating a circular urban metabolism is complex and challenging and requires much more than "applying" existing models.

In this paper, we would like to argue that we have a limited understanding of the barriers faced by ideas of circular urban metabolism and that this comes from three characteristics of current research: it is technocratic and relies on static perspective.

First, scholars have so far mainly considered the creation of a circular urban metabolism as a technical endeavour. As shown above multiple concepts and ideas have been developed that only address technical aspects and purely focus on material and energy flows. Even though attempts have been made to consider social aspects as well (see for instance [22]), Barles [23]argued that more research is still necessary that takes full consideration of the role and influence played by local stakeholders. Moreover, as argued by Guy and Marvin [24](p17) when one aims to change prevailing infrastructure management, developed strategies "need to be closely related to the social organisation of infrastructure, and more particularly, to highlights how opportunities for environmental innovations link to the changing contexts of urban development". In other words, it is not only technical aspects that are important but one should also consider how things are locally organised and embedded in a changing local context. Taking that argument further, we would like to argue that organisational and institutional aspects are also of crucial importance for understanding how these ideas come about.

Second, similarly to material and energy flows which change over time, organisations and institution can also change. Interests and priorities evolve as the context in which these organisations are embedded change. However, we argue that perspectives that did try to consider social elements have so far been static and hardly addressed the emergent character of solutions aiming at a circular urban metabolism. Instead we propose studying these practices not as state of affairs but as processes of change. Taking such a perspective can provide additional insights about the mechanisms and dynamics underlying these types of processes.

In this paper, we adopt a different conceptual approach which, we claim, can be used to study and understand how circular urban metabolism (does not) come about. We consider that the creation of a circular urban metabolism passes through multiple innovation processes. Such processes happen in a systemic manner wherein, not only technical but organisational and institutional solutions and changes are adopted and adapted. In this paper we conceptualise the circular urban systems, as a robust concept to address the anomalies of the metabolism of cities.

In the remaining part of this article, we discuss how this concept is different from existing ones and why we think can help better grasping the challenges ahead. We also focus on the kind of insights that can be gained by adopting this new concept and how this can open a new agenda for future research.

2. Circular Urban Systems

In this paper, instead of analysing how one may design a circular urban metabolism, we propose studying the processes underlying the creation of circular urban systems. In this section, we will explain how this concept differs from existing ones and the kind of perspectives that it calls upon.

To begin with, the term circular urban metabolism focuses on flows of resources and brings forwards an alternative way of thinking that could be used in order to optimise these flows and improve the environmental performance of urban areas. Even though this concept is powerful in triggering new ways of thinking about the resources that flow in and out of cities, it provide limited scope to conceptualise the role of social elements in concretising the ideas it embodies. However, in order to grasp how these ideas come about and how their introduction could be facilitated, it is necessary to understand how organisations and institution shape the introduction of circular urban metabolism

In this paper we put forward the concept of circular urban systems as an alternative to conceptualise ideas that involve the creation of circular urban metabolism. In the following paragraph, we will first explain how innovation studies inspired the development of this concept before summarising what the implications are of replacing the term "metabolism" by that of "system".

Innovation scholars have done a lot of work to understand how novelties are created and how they diffuse (or not) in society (see for instance [25]). Part of this literature specifically focuses on technical innovations and aims at understanding how technical change takes place and whether and how it could be steered in a desirable direction. An important contribution of scholars in this field is that they highlighted that technologies are not mere artefacts but are part of a larger whole of interrelated and heterogeneous entities that support and sustain them (see for instance [26], [27];[28], [29]). Stated differently, technologies are part of broader socio-technical systems. This implies that one cannot understand how given technological systems come about without considering the social context in which they are embedded.

Another important addition made by innovation scholars is their understanding that actors in socio-technical systems are guided by institutions (i.e. norms and rules) [30]. These rules may be hard to change and will influence how actors look for solutions (their search heuristics), what they consider (im)possible, what they expect of given technological innovations, etc.. In other words institutions prevailing in a given socio-technical system shape how actors in a system innovate.

Interestingly, the focus of innovation studies usually is on a single socio-technical system such as energy, water management, sanitation and mobility. Scholars have paid little attention to innovation that take place across different systems (see [31]; [32]). However, creating a circular urban metabolism build on integrative approaches where energy, transport, waste(water) management, construction, etc. have to be considered. Creating a circular urban metabolism requires making connections between different systems. It implies that innovations should take place across multiple systems.

In order to understand how transitions towards circular urban metabolism can take place, we therefore propose studying how circular urban systems can be developed.

Replacing the term metabolism by that of system comes with five implications. First, we understand that creating a circular urban metabolism implies connecting "systems" that were initially separated.

Second, we conceptualise a "system" as being composed of both social and technical elements. Realising a circular urban metabolism is therefore a socio-technical endeavour.

Third, building upon the previous two points, this means that creating a circular urban metabolism does not only imply connecting individual elements (technical artefacts or organisations) to one another. Instead it means connecting systems, interrelated and heterogeneous entities, to each other.

Fourth, understood in that way, this means that the challenges faced when trying to create circular urban systems come from the fact that the systems that should become connected may have characteristics (institutions) that can either constrain or enable their connection.

And fifth, we understand that the creation of circular urban systems does not happen over time. It requires that multiple technical, organisational and institutional solutions and changes to be adopted and adapted. In other words, it requires going through multiple innovation processes.

To summarize, understanding the creation of a circular urban metabolism as being about creating circular urban systems means understanding that it:

- involves more than mere technical artefacts
- requires creating connections and interactions between initially separated socio-technical systems
- is a process that involves adopting and adapting multiple organisational and institutional changes
- is a process that can be either constrained or enabled by the characteristics of initially separated systems.

2. 3. Unfolding Circular Urban system: Hammarby Sjöstad eco-cycle model

In order to illustrate our argument that the concept of circular urban systems is useful when trying to understand how circular urban metabolism comes about, we will use the Hammarby Model as an example.

Those familiar with the concept of circular urban metabolism surely have heard of the Hammarby or eco-cycle model. Hammarby Sjöstad is a district in the south of Stockholm. Its development was initiated in the mid 1990's. Initially it was planned to be the Olympic Village for the summer Olympic of 2004. However when Athens won the bid, local authorities decided to turn Hammarby in model of sustainable urban development [33]. The high environmental ambitions for the district were all summarised and operationalized in an environmental program [34]. An important part of these ambitions was that solutions should be found to close local cycles of energy and material. The City of Stockholm brought local infrastructure companies together and asked them to come up together with solutions for the district. It is through their interactions that the Hammarby Model was created (see [35]for a full description of how the model came into being).

Since it was coined, this model has been on multiple occasions presented as an example of best practice (see for instance [5]; [36]). Moreover, the consultancy firm SWECO has been building on this model when developing solutions for other eco-cities throughout the world (see [37]). As can be seen in figure 1, the model shows how solid and liquid wastes generated in the district are fed back into the district in the form of electricity, heat, cold and fuel. It shows what a circular urban metabolism can look like.

Earlier this year, the Guardian published an article entitled: "the Swedish suburb that sustains itself" [38]. The article ends with a question which is quite revealing about how the Hammarby Model is seen and the kind of hopes it brings: "*Can the UK repeat the Hammarby model and make yesterday's waste tomorrow's energy?*" This statement suggests or at least questions whether it is possible to reproduce a similar circular urban metabolism elsewhere.

However, making such a statement is disregarding that the Hammarby Model implies much more than connecting material and energy flows. It is about linking socio-technical systems which are embedded in a given local context and that have their own local specificities.

Through two examples, we will illustrate why it is important to take into account organisational and institutional elements in order to fully grasp what the Hammarby Model is about. These examples are derived from the PhD research of one of the authors. This research focuses on analysing how circular urban systems come about and uses Hammarby Sjöstad as one of its case studies (see [32]).

Firstly, the Hammarby Model shows that district cooling is produced using wastewater as an energy source and is fed back into the district. In other words, it shows that the system for wastewater treatment can be linked to that of district cooling. There is no doubt that such a connection is technically possible. Indeed, the Hammarby Thermal plant where district cooling is generated is composed of a few heat pumps. These technologies can, using electricity, extract some of the present in treated wastewater. However, what the model does not explain is how come a district cooling network could be realised in a cold Nordic area. In fact, it is in Stockholm that the largest European district cooling network can be found. Such an explanation can be found by reconstructing the process through which the systems for district cooling and that of wastewater treatment became connected (see [35]).

One would for instance find out that before the Hammarby Model was even planned, the Hammarby thermal plant, and the heat pumps that compose it, was already used for a few decades to produce district heating . Heat pumps are in fact technical artefacts that can easily be used to co-produce heat and cold. Technically speaking, generating district cooling did not require important changes.

Moreover, one would also discover that property owners in Stockholm are used to rely on centralised heat systems. Indeed, according to the local district heating company, about 70% of all property owners are connected to the district heating system [39]. It is normal for property owners. Similarly, project developers are also used to construct dwellings connected to a centralised heating system. Between operating a district heating system and constructing a district cooling system there is only one step.

To summarise, before the Hammarby Model was coined, a technical configuration existed for which district cooling would only be an add-on. Moreover, local organisations were already used to district heating which was since long institutionalised in Stockholm. Over the year, local institutions evolved as technical artefacts were adopted and developed. When the process was initiated, local socio-technical systems were aligned with the idea of district cooling. It was the next logical step.

Secondly, the Hammarby Model also shows that sewage gas produced in a local wastewater treatment plant and is fed back into the district as cooking gas. Technically speaking, this means that the sewage gas is first being upgraded (to reach the appropriate calorific value), and cleaned (to minimise the amount of impurities present in the gas) before it can be distributed to apartments in the area. What the model does not show however, is that only a few per cent of the apartment in Hammarby Sjöstad actually use this gas for cooking. Most of them still use electric stoves which is the most common alternative in Sweden. By studying the process through which the local city for city gas came to be connected to that of wastewater treatment, it is again possible to explain why this attempt was only a partially realised.

To begin with, for the wastewater treatment system, delivering cooking gas of the appropriate quality was in itself not especially challenging. Indeed, Stockholm Water, the wastewater treatment company, already had knowledge and experience with producing and upgrading biogas. There were even plans to extend the production and use sewage gas as a biofuel (see [40]).

Moreover one would understand that a small city gas grid existed in Stockholm. Gas was produced using light petroleum. This is partly related to the fact that Sweden is hardly connected to the European gas grid [41]. Moreover, another important characteristic of the system of city gas is that it did not expand since the 1970's. It suffered heavily from competition from both electricity and district heating systems [29]. Some parts of the grid were even closed down when their operation became un-economical [43]. In other words, this system was in decline at the time the Hammarby Model was coined.

Moreover, while reconstructing the process, one would find out that if Stockholm Energy, the company owning the city gas grid) suggested to use sewage gas for cooking, it is because the company was pressed by the municipality to come up with innovative solutions. However, because biogas upgrading was still rather new at the time, the company also put forward some conditions before accepting to commit to this solution: A gas storage, financed by the municipality, should be constructed to add redundancy to the system and ensure that if technical problems would arise in the system for wastewater treatment, their own system could still function properly. In order to connect the technical components of two systems, organisations first have to be convinced that the connection would not result in extra burdens.

Furthermore, the analysis would also highlight that actors from the system of construction also played an important role in limiting how many apartments are connected to the gas grid. First, project developers were not used (anymore) to construct dwelling with a gas connection and all the safety measures that it requires. Indeed, no dwelling was connected to the gas grid since the 1970's. Second, the City of Stockholm whose environmental plan was meant to stimulate environmental innovations in the district was later made voluntary. Project developers complained that the targets stipulated in the environmental program were too difficult to meet and went far beyond agreements that are recently been made in consultation with them [44]. The City gave in to their demands and the sentence "strive for compliance" was added to the program. Project developers could then freely choose whether and to which extend they wanted to meet the environmental goals. Similarly, they were also free to choose whether or not they wanted to connect to the gas network. Very few companies actually took that decision. Beyond requiring adapted construction practices, a connection to the gas grid also came with additional costs. The housing market at the time was slowing down and they were concerned that apartments would be difficult to sell.

To summarise, when the idea of supplying sewage gas for cooking for put forward, the systems for city gas and wastewater treatment were more or less already aligned with the idea. However, for the system of construction, this idea required some important adaptations. New building practices were necessary and it meant offering future property owners a new way of cooking. Project developers were reluctant to make the necessary changes. Offering to cook on sewage gas could help decreasing the dependence on fossil fuels. However, this was not a strong enough incentive to stimulate change. The system for construction that should bridge that of city gas and wastewater treatment did not fulfil that role.

The examples presented above only provide hints about the process though which the ideas came about. However, we hope this is sufficient to show that thinking only in terms of material and energy flow (or in terms of technology) is not sufficient to understand what lies behind a model such as the Hammarby Model. Contextual, organisational and institutional elements are also of crucial importance. Realising something like the Hammarby Model actually means working towards the creation of circular urban systems.

3. Circular urban system: the issue

The examples showed that making a transition from a linear to a circular urban metabolism actually implies creating circular urban systems. To be implemented, it implies using new technologies (or existing ones differently), modifying material flow, changing organisational practices and adapting institutions. The process of creating circular urban systems comes with three important issues:

a. It is not a technical but a socio-technical endeavour
b. It involves connecting multiple socio-technical systems
c. It is unique and depends on the local socio-technical context

Here of these issues is described hereafter. To begin with, creating circular urban systems is much more than a technical endeavour. The examples used as illustration show that not only technological artefacts but also organisational and institutional aspect have to be included as part of the innovation process leading to the creation of circular urban systems. This process is a socio-technical endeavour which involves interaction between private companies, municipalities, governmental institutions, and users.

Moreover, moving towards circular urban systems means that multiple socio-technical systems have to change and become connected to one another in ways that it new to the actors belonging to these systems. In a circular urban system, there are different socio-technical systems which look isolated on surface to many of the practitioners and technical experts. However, such socio-technical systems stretch over and through each other in circular urban systems. The difficulty is therefore to determine how multiple socio-technical systems can interact and evolve together, how their institutions should be adapted, and how such processes should be coordinated and if possible facilitated.

Furthermore, the process underlying the creation of circular urban systems is unique and depends on the local socio-technical characteristics. It may seem tempting to transfer something like the Hammarby Model in totally different socio-cultural context. However, implementing solutions that resulted from long term processes of change in a given location in a different location will surely face diverse issues as these may not be adapted to the local socio-technical context. It is necessary to study and understand innovation process in particular context before making concrete plans. Moreover, it is important to acknowledge that these changes may take up to decades, and that they require strong leadership. Therefore, the issue of innovation process and their benchmarking (best practices) in a particular context has high importance for creating circular urban system.

4. Conclusions and Research Agenda

This paper argues that the concept of circular urban metabolism, even though successful in inspiring to thinking differently about urban resources and waste, does not allow conceptualising the processes of change required improve the metabolism of cities. In this paper, the concept of circular urban system is put forward as an alternative to make this conceptualisation possible. We discussed that creating circular urban systems is a socio-technical endeavour, that it requires changing technologies, organisations and institutions of multiple systems and that its process is embedded in and shaped by the local context. We suggested that understanding underlying innovation processes can help in better grasping and dealing with the challenges ahead.

Finally, we would like to summarise the conclusion of this paper as follows:

a. Not copy but design for a specific city: it means the concepts should not copy as such but it should be designed by considering different socio-technical system in the focussed city.
b. Not sole focus on material and energy but focus on institutional and organisational aspects is equally important. In spite of good planning and engineering, implementation of concept become constrained and failed due to poor institutional actions and organisational conflicts.
c. Avoiding innovation process in systems interaction and integrations means inability to deal with adoption and adaption of new changes in eco-cities. Innovation processes should be main source of learning and adoption for new adopters of the concept of circular urban systems.
d. There should be more research about how these ideas emerge, the kind of challenges they face.

To conclude, building upon the concept of circular urban system can lead to a new research agenda. We would like to propose four areas that would be especially interesting to further look into.

First, studies should aim at reconstructing the processes through which circular urban systems come about. This will help understanding how the systems that are to be linked shape the processes. Moreover, it can also bring to light overarching mechanisms or challenges which are specific to the creation of circular urban systems. Such knowledge is necessary when one aims at steering these processes.

Second, research should be done to identify theories and conceptual framework that can help understand the processes through which circular urban system come about and evolve. Innovation studies have not yet looked into innovation processes as those involved in the creation of circular urban systems and there is no ready-made conceptual model that can be relied upon.

Third, research should also focus on understanding how transitions from linear to a circular urban system can take place, the kind of policy tools and instruments that could be used to steer such a process. To do so, it will be necessary to merge body of knowledge from ecology, innovation, socio-technical transitions and management areas to develop further new approaches for policies and implementation in cities.

And finally, research should also look into the governance of circular urban systems and reflect on the role that public authorities, local inhabitants and private enterprises will have to play in governing these systems.

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