Interconnection of clustered decentralised networks: a precondition for real sustainable development

Arjan van Timmeren¹, Jón Kristinsson² and Wiek Röling³

¹ ³ Faculty of Architecture, Delft University of Technology (D.U.T.), Delft, the Netherlands
² Architecten en Ingenieursbureau Kristinsson, Deventer, the Netherlands

ABSTRACT: The technical infrastructure (networks) of the three essential flows (energy, water, waste) is determinative to what degree a project, varying in scale from a (part of a) building to a city or conurbation, will or can be sustainable or even self-sustaining. This is due to its ‘path-dependency’, long term- and endogenous character and the existence of a limited number of dominant actors per network or flow, which have interest in little change of the ‘ruling’ paradigms. The physical and formal distance to users and the complexity for them to understand the processes and possible (sustainable) alternatives result in an increasing dependence and a declining overall involvement. To be able to change the built environment in accordance with the principles of sustainable development there is a need to turn around the inter-relationship between the infrastructure and the suprastructure [1]. Decisive aspects in a continuing urbanizing, and connected world with crucial dependency on integrated computer networks, will be the flexibility of the concept of generation, treatment and transport of the critical flows; the adaptability to passive- and natural technologies; the seize of space; and the overall resiliency to failure, inaccurate use and sabotage. The paper focuses on rethinking the urban planning as a whole, with emphasis on a changing attitude towards the relationship between the technical infrastructures of especially the energy flow related networks and the ‘suprastructure’. Basis forms the application of the power-law concept, also known as Pareto or Zipf to the technical infrastructures concerning the essential flows in the built environment. Not only the (known) dependency of decentralized concepts on central networks, but also the reverse will be argued: the needed aggregation of decentralized micro-networks, or clusters and systems to the complex and continuously growing centralized networks. Main objective is to cope with the risks of rising complexity and continuing unity, apart from the rising need of resilience of the overall network in case of loss of parts. This, for our economy is increasingly reliant upon interdependent and cyber-supported technical infrastructures and information systems.

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INTRODUCTION

Most of the existing urban infrastructures can be typified as ‘end-of-pipe’ planning strategies. We transport waste, wastewater and even relatively clean rainwater outside urban districts to centralised treatment plants. We attempt to generate electricity or gas in centralised gas plants. The upshot of this is much more than the transport requirement and the use of extra material and energy. The inevitable mixing of different elements is detrimental to the quality. The majority of the transported flows undergo losses during transport, which also has serious impacts on the immediate environment. The way to permanent urban development appears to be elusive. In modern town planning new inventions and the introduction of intelligent light infrastructure are required. In this paper the presented research has an exploratory character, for it tries to take the well-known metaphoric factor 20 improvement [2] as a starting point: this means to preserve the essential flows and try to sustain the process to bend them towards closed cycles. The idea is to make urban development, mainly resulting in buildings and technical infrastructures, following to the (social) needs and goals, which form the basis of physical networks of the logistical chains, and not the other way around, like it can often be qualified today. In this way it will be possible to uncouple sustainable solutions from the existing ‘centralisation-paradigm’, without the release of other relevant criteria for today’s society. Therefore research can be placed at the penultimate step of the ‘ladder of Brezet, Cramer and Stevels [3] (Fig.1). In this scheme the first and lowest step concerns the improvement of existing aspects and operating procedures. In the second step, the (re)development of the existing concepts, has a more ambitious goal. In this case research tries to optimise within the limitations that physics, chemistry, nature and technology put forward with
regard to the existing structures and operating procedures. This phase mostly comes down to the making of compromises between the various environmental aspects. It is a rather costly phase, while the results in the end by no means are beyond all dispute [3].

Figure 1: Ladder of Brezet, Cramer and Stevels [3]

Apart from this step, Girardet [4] and Rogers [5] recognize a trajectory next to the ultimate step, which involves “creativity and darning” [5]. The consequences of research in between the second step (existing concepts) and the third step (alternatives) are huge for all actors in question: industry, consumers and government. It implies changes in the societal structures, e.g. the infrastructure, the facilities, the policies, the tax systems, etcetera. Most of the times it also implies (sometimes even radical-) changes in the lifestyles of consumers. Apart from that these changes concern such 'time-constants' that the revoking of these processes is almost impossible. Moreover this step impossibly can be taken by only one driving force. It will only be feasible through common (re)development, -realisation and –support, of ideas and plans. This essential step is a precondition for the final step: towards a sustainable society, according to so-called 'ecological position' of the Brundtland definition [6].

The ‘Ecopolis strategy’ [7] is a new form of urban planning which may assist in lowering the environmental pressure. This strategy differs from traditional planning in the Netherlands where urban planning is normally one-dimensional. Instead of only assigning functions to locations, the Ecopolis strategy attempts to incorporate the different flows (water, energy, waste) and transport as key factors in ecologically sound planning. Another aspect of this strategy is that both the participants and the spatial quality of areas play an important role in the process of sustainable urban planning. Therefore, the Ecopolis strategy focuses on these three basic elements for urban planning: flows, areas and participants.

The city is seen as material support for an integrated multiplex patterning of social, economic and cultural activity, and the interest extends from the scale of the (eu)region to the local scale of the neighbourhood and building. It tries to focus on the way these different scales interact to generate the dynamics of urban activity, produce and sustain and vitalise urban life.

2. INFRASTRUCTURE & SUPRASTRUCTURE

2.1 Social needs

During the contemplation of the different flows and the several belonging energy- or water- concepts and belonging forms of technical infrastructure one needs to pose the question: what is the real exigency of this specific infrastructure and which is the best physical form of appearance? Additionally one should think about the relation between (technical) infrastructure and the social goals that are aimed at, doing this as much as possible independently from the existing ways of thinking and existing arrangements.

In case of the stated question, one has to reflect newly upon which social needs exist, and which (technical) infrastructures belong to these needs. Within this approach one should also try to integrate the different sorts of infrastructures and the different aspects of sustainability in the reflection. Unlike the more to traditional infrastructure restricted definitions this research supposes especially out of the post-industrial and often called 'invisible' infrastructure. Infrastructures concerns in this vision not only the (physical) line-infrastructure, but "all goods and services that social activities facilitate as far as these bring along direct or indirect spatial effects" [1].

2.2 Infrastructures

The urban infrastructures can be split in two main categories: technical and social infrastructure [8]. The holistic approach of different forms of infrastructure can be realised by analysing how individuals and society think to realise their needs and goals using infrastructure. In this case first of all one could look at the infrastructure related to the essential processes in life, the technical infrastructure. Within this framework one speaks of technical infrastructure in case of the different, mostly technical networks that are associated with the flows (waste)water, energy, waste(material), other nutrients and materials. This also involves buildings necessary for the processing of the associated flows, like wastewater treatment plants and power plants. But also ‘green infrastructure’ like reed beds and other natural ecosystems used for treatment or generation of the former mentioned flows. The green, urban infrastructure is an important element, and offers starting-points for the integration of technical- and biological systems that are based on natural technologies [9]. The social (urban) infrastructure contains buildings and systems for different private and public services [8]. Both social- and technical infrastructure can include also organisations that create or manage the networks and belonging physical structures.

Within the (technical) infrastructure per sector one speaks of (logistical) chains. These logistical chains can be defined as the concatenation (subsequently or together) of all conveyance, transport and distribution processes of (raw) materials (spring), via scaling steps towards consumption as well as the return-treatment and the bringing-back into natural ecosystems (dump) of the used (or not) flows. These kind of physical flows are connected to networks (infrastructures, trade, finance) and other flows (data,
information). The several logistical chains together form logistical networks which most of the times have an own dynamism and structure which is being influenced by the fields of technology, consumers (miss)behaviour, social- and societal constellation, liveability and sustainability. All elements that form part of these logistical chains have their own so-called life-cycle [8].

2.3 Suprastructure

The different standards of societal needs and goals, which form the basis of all physical networks of logistical chains, including the (technical) infrastructures, are defined as the 'suprastructure' [1]. On a more abstract level this suprastructure can be indicated in terms of human interaction, health and prosperity. Formulating the suprastructure cannot just be defined by a certain political disposition. Also out of science through empirical research, stocktaking of the suprastructures of today and 'back-casting' of long-term developments, contributions can be made to the optimisation of the suprastructure according to sustainability aspects. The 'Development Alternatives Centre’ (CEPAUR) together with the 'Dag Hammarskjöld Foundation' were the first in formulating the suprastructure of a society. The developed theory is based on two suppositions: First of all, fundamental human needs are not unlimited but restricted in number, moreover can be classified. Secondly, fundamental needs of different cultures and historical periods are the same [1]. Fundamental needs are: Maintenance (vital needs), Protection, Affection, Understanding, Participation, Relaxation, Creation, Identity and Freedom [10]. There is no matter of mutual hierarchy. However, Maintenance (staying alive) is from a more essential order, and is less life-style or culture bound.

In the decision processes concerning changes or extensions of the (technical) infrastructure the decision-making will be optimal if the suprastructure (planning) and the infrastructure (maintenance) are tuned in well to each other. This is easier said than done since there is a matter of a ‘centralisation paradigm’ in case of technical systems (concepts) and belonging infrastructures. This goes especially for the essential energy- and waste- and (waste)water flows considering the different chain units. This centralisation paradigm comes down to a striving for (on)going increase of scales of application and utilisation, according to the principles of the 'scale-economy', as opposed to 'the economies of scale'.

2.5 Interdependence

Technical infrastructure, i.e. the moving of substances, goods and persons or the disposal and process of waste, most of the times should be derived from the suprastructure. The suprastructure should always be named before one can say something about the most appropriate infrastructural facilities to realise the societal goals, like for instance health and sustainable development. Apart from that, to be able to formulate the suprastructure it will be necessary to have a certain perception or outlook towards the future, for most of the infrastructure will be constructed for several decades of use.

One should try to explicit the suprastructure to find instruments that link the new infrastructures better to the increasingly faster changing societal goals. Some new directing concepts in this field are ‘dematerialisation’, ‘ecologisation’, ‘multi-functionality’ and interconnection. In the realisation process of technical infrastructures several dilemmas come up. Three important ones are 'rate versus quality', 'security versus legitimacy' and 'efficiency versus participation'. The first two dilemmas concern both flows- and areas-related aspects, while the third dilemma relates to the actors [7]. The main three technical infrastructures (water, waste, energy) are controlled by a limited number of 'dominant actors', which have an interest in little change in the 'ruling' paradigms. The physical and formal distance to users and the complexity for them to understand the processes and possible (sustainable) alternatives result in an increasing dependence of these institutions and a declining overall involvement due to the decreased understanding and growing feelings of powerlessness. However, newly planned and constructed infrastructures to a certain extent will be determined by the suprastructure, which results from the existing balance of power or customs (paradigms) of certain institutions (Ruis [1]). One could state that the (technical) infrastructure of the essential (or critical) flows, due to its 'path-dependent', long term character and the existence of a limited number of dominant actors per network or flow, is determinative to what degree a project -varying in scale from a (part of a) building to a city- will or can be sustainable. In case of the energy flows for instance, conventional sources of energy are being extracted, isolated and in high concentrations brought together in central installations in which they are converted into large amounts of energy which via large distribution networks can supply large areas with energy. The loss during conversion and distribution is overshadowed by the abundance of energy that can be generated inside these over dimensioned power plants. Most of the sustainable energy sources however are present everywhere but in relative small concentrations and most of the times less continuous available. For most of these sources it is illogical and not profitable to generate high-energy revenues and distribute it to larger areas.

Considering the former mentioned key-question concerning the necessary forms of (technical) infrastructures and the nowadays chosen appearance (paragraph 2.1), stands out that especially the (waste)water infrastructure and the energy infrastructure can be characterised by transported flows which are not drawn up out of ongoing 'ecologisation' and dematerialisation but out of efficiency in central management and other economical factors. From the point of view of sustainability the technical infrastructure therefore seems to be insufficiently efficient. Another problem is the fact that infrastructures still are being described in traditional parameters: tons, watts, bites, litres or square kilometres. Apart from other, more relevant economical criteria, like employment, supplementary environmental criteria and –parameters, based on 'ecologisation' and ‘dematerialisation’ –and not
3. INTERCONNECTION VERSUS AUTONOMY

3.1 Complex structures

Indiscriminate structures with complex topologies are usual in nature, but also in man-made networks. The complexity of many social, biological, communicational and transportation systems is rooted in a relative interwoven network, which can be defined by the systems components and their mutual interactions. Due to the rising importance of sustainability, flexibility and security of the so-called essential (or critical-) systems and infrastructures, the call for a more holistic approach based on source oriented and preventive policies already has resulted in several concepts of 'integrated approaches'. However, most of these cases refer to administrative organizational integration, arising from either horizontal or vertical integration. 'Integrality' in urban development is being used one-sidedly too often, and therefore threatens to become an empty paradigm itself. The dynamics of irregular simultaneous transformation is necessary to gear complex structures within society to the essential flows and natural processes. Therefore it is within integral developments like urban planning inaccurate to keep on thinking in separate systems. Especially in case of technical infrastructures there is a rising mutual interconnection and interdependence [11]. This does not solely concern local interconnections. The whole, worldwide human system depends on the question to what extent increasing speed and complexity of change is being treated [12].

3.2 Influence of the network-architecture

For complex systems the coherence and method by what means adaptively dynamic processes are being treated is normative for the translation of physical 'integrality'. The stability, or resilience of networks is directly linked to its complexity [13]. Mathematical research proved that not the vertices within structures are essential, but the way these are mutually organised [14]. The recognition of the network architecture, or geometry therefore is essential for an inclusion in structures of increasing speed of change, without loosing the necessary ambitions concerning sustainability and user security. Alexander [15] was one of the first to recognize the importance of underlying structures for the conception of spatial disposition of urban development and belonging physical and social networks. He distinguishes two scale-independent opponent structures: the tree axiom and the semi-grid axiom. Recent research [14] showed that any minor addition of arbitrarily connections within an ordered physical network results in advantages, also known from social networks, or the small-world principle [16]. It also showed that the degree of clustering of these ordered networks was large. However, in contrast to social networks the so-called degree of separation (the typical number of steps between points in an ordered network) also is relatively large. After scattering random links, no results were noticed on the network's clustering, nevertheless a devastating influence was noticed on the degrees of separation. Main conclusion was that the lightest dusting of random links was always enough to produce a small world [14]. And since the number of degrees of separation reflects the typical time, distance and belonging losses, needed to transport data and/or material from place to place, the small-world architecture can be considered as basic principle to improve structures and the belonging environmental load. Research on the U.S. electrical power grid, that can be typified as merely random, due to thousands of historical 'accidents as new technologies were invented to meet the needs of industry and a growing population [13], showed that the degree of clustering is ten times higher than it would be if the network were built at random. At the same time the number of transmission lines is relatively small too. Again the, in this case nearly random, geometry of the network is the key towards network quality and indirectly, however partially, to related aspects like the security, flexibility and the sustainability of the whole.

Like Alexander, two regimes concerning the geometry of complex networks can be distinguished: an exponentially regime, leading to homogeneous egalitarian networks, and a 'scale-free', aristocratic network, characterised by a clear inequality with concern to the amount of connections a junction [14][17][18][19]. The aristocratic network structure approaches the semi-grid axiom of Alexander and has a potentially more complex and subtle structure, which makes it easier to adapt to changing complex physical and social structures.

3.3 Clustering within networks

Within aristocratic networks the structure of most of the investigated large networks which topology is known shows similar features: a scale-free character and a distribution of (transportation) connections according to the principle of power-law (also known as pareto or zipf) [19]. This principle is also indicated as 'self-organising'. It can be considered as the most important generic effect of growing networks or complex structures. It is important to state that, besides self-repair, self-organisation is considered the most important feature within green technologies, also known as 'natural technologies' [20].

Most of the designed, or 'ordered' structures and networks of today however can be defined as similar to the tree axiom of Alexander, with an egalitarian character [15][17][18]. In case of continuing growth (e.g. by axiom of Alexander and interdepenecy these structures cannot be considered as optimal with regard to security and sustainability. With regard to these aspects and guarantees for users on smaller scales it is important to look upon the effects of change (growth, disturbance, loss) on larger scales.

Research to the resilience or security of different simplified distribution networks showed clear differences between aristocratic and egalitarian networks. In case of un-coordinated loss, due to e.g. wrong use or aging, egalitarian structures fail apart
quite fast. However, in case of an aristocratic structure even if more than half of the nodes were moved, the ‘typical diameter’ of the network was unchanged: those that remained were still sewn together into one integrated whole [19]. Key feature for this robustness, or resilience are the so-called ‘weak connections’ [21].

The importance of clustering within interconnected complex networks is related to especially its error- and attack tolerance: the loss of one (or more) element(s) will not lead to a dramatic fragmentation of the network into uncoupled subsystems. This goes especially when the network is aristocratic, with clusters and highly connected so-called ‘hubs’ [17][18][19]. In case of coordinated attack, e.g. due to sabotage, these aristocratic structures are far more sensitive. However, at the same time it is considered much easier to protect these networks by securing the ‘critical’ nodes within networks (in advance) or isolating failures (afterwards) [13][19].

One can conclude that in case of sustainable urban development on the basis of the ‘scale economy’, being the chosen development of most of today’s critical infrastructures, a complex, adaptive and aristocratic structure for each of these networks, or the acting in conjunction of them, is the best goal. In that case the (generic) conditions are: the network should grow continuously by adding new vertices (connections), and: new vertices should be added in accordance with the principle of ‘preferential attachment’ [17]. To understand the necessary process of clustering, it is important to know the underlying forces of this principle of preferential attachment, also known as ‘the rich-get-richer’ principle [13]. The feature ‘fitness’ comes in place, especially in case of competitive networks. Therefore this is also called ‘the fitter-get-richer’ principle [22].

The aspect ‘competitive’ doesn’t point to competition between networks (e.g. gas versus electricity), but to competition within networks (a new development e.g. in the -in Europe- liberating energy market). The ‘fitness’ feature differs for each of the essential networks (energy, waste/water, waste). It comes down to a combination of the formerly mentioned extent of: flexibility, uniformity, consistence and optimisation of generation, collection, storage and transportation.

3.4 Decentralised, connected autonomous clusters

Using the small-world principles, there is however a possibility to improve the possibilities of resilience, and ultimately sustainability of critical infrastructures. The strategy combines principles of development in accordance with both the ‘scale economy’ and the ‘economies of scale’.

Starting point is the strengthening between weak nodes in the existing infrastructures with simultaneous introduction of new ‘weak connections’ between essential nodes in the interconnected, (inter)national infrastructures. Within the mentioned conditions it introduces a direct importance for large-scale, centralised networks to include subsystems, being decentralised clusters, within the complex network structures. It offers possibilities to include local decisions and therefore the principle of self-organisation within the increasingly complex and impalpable networks, without loosing the assurance of loosing-control at smaller scales. Local interventions, e.g. with regard to sustainability, can be made without leaving the existing scaling-up principles and without the disposal of belonging, already made investments. In some technological sectors this principle is also known as the ‘Vision Lean’, within concepts of ‘empowerment’ and Business Process Re-engineering [23]. Vision Lean takes on the one hand a more market oriented, and on the other hand a more localised organisation as a starting point. Background is the worldwide started transformation from ‘mass production’ towards ‘custom-made for the mass’ [23]. Especially dictated by the many processes of change due to the liberalisation within the essential flows and belonging infrastructures at present almost all attention concentrates on the former. The latter however constitutes a more structural change, and offers conditions for innovation and far-reaching concepts on sustainability at different levels of implementation.

Procedural this means that governments and mains-administrators can abandon present policies that aim for fixed goals. It eliminates the growing problem of policies that run after reality and result consequently in gliding decision-making. Within this strategy, systems that come under decentralised planning concepts can end in compound networks with more decentralised substructures, which network subparts can work relatively autonomous. In this way the infrastructure is able to become following to flexible concepts of urban planning. It helps to resolve the problems concerning a desired more exact attribution of (use of network) costs to certain customers or transactions, an aspect of rising concern in liberalised markets. Apart from that making the networks more flexible makes it easier to anticipate to changed market circumstances. In case of liberalised markets this results in smaller investments, with less risks.

The main technical advantage of (incorporating) decentralised systems within larger networks is the more straightforward solutions concerning the separation of different flow qualities near the source (in case of wastewater and waste) and easier cascading and use of energy based principles (energy). Apart from that, the transportation, treatment, generation and use of each sub flow can be more efficient. Especially the better tuning to the user/customer is needed to be able to achieve a real paradigm-shift concerning sustainability.

Main disadvantage is the difficult organisation and execution of maintenance, exploitation and inspections. Therefore especially (juridical) conditions concerning responsibilities and maintenance/periodical inspections will be essential, and determine the successful penetration of (incorporation of) these decentralised technologies.

CONCLUSION

Differentiation and urban flexibility (i.e. buildings and infrastructures) are pre-conditions for anticipating
long-term uncertainties, due to actual liberalisation processes, rising complexities and even sabotage. Sustainable starting-points are suppressed more and more by these changes. However, at the same time especially the urban scale can start up the necessary process of transformation towards real sustainable development, for it takes the best of two worlds. At present however, technical infrastructures still are leading to urban development, often even to the suprastructure of society. The historical development of the sanitation and energy infrastructure can be qualified for being 'quasi-evolutionary' and endogenous. There is rising concern for the infrastructures and even several places of congestion. The development can be qualified for being 'path-dependent': as for the essential flows this means a 'centralisation paradigm', resulting most of the times dependent' as for the essential flows this means a combination of conventional (centralised) systems and additive decentralised systems might avert the danger of a possible 'deadlock' of the existing centralised systems, with belonging health risks.

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