Are cities resilient?

Les villes sont-elles résilientes ?

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ABSTRACT. This paper first argues that the driving force behind the aggregation of human settlement, throughout the centuries, has been the ever-increasing need for collective problem solving. Villages and cities have emerged in 'dissipative flow structures' in which organization (information processing capacity) spread out from cities into their hinterland, enabing energy and other resources to increasingly flow into cities to meet the needs of the population. Information processing is thus the driver of urbanization, and energy is the constraint. With the Industrial Revolution, the growth of such dissipative flow structures accelerated very rapidly due to the fact that fossil energy became available and lifted the constraint. Hence the urban explosion of the last couple of centuries.

In the second part of the paper, some of the potential consequences of this explosion are discussed. First, whether the ever accelerating increase of global urbanization will continue or not, and then what might be the consequences of that acceleration for urban planning and architecture, emphasizing that cities need to become pro-active rather than re-active. They need to start designing for change rather than responding to it. In a final section we discuss some of the risks to urbanization that are posed by the Information and Communication Technology (ICT) Revolution, and conclude with a suggestion how, in developed countries, information technology might reverse the trend to increasing concentration of the population in cities, whereas for the moment, this is not likely to be the case in developing countries.

KEYWORDS. cities, information processing, dissipative flow structures, complex adaptive systems, energy, innovation, long-term evolution.

What cities are all about

If we want to talk about the future of cities the first thing to do, of course, is to come to understand what cities are all about. Not to understand that in terms of what "a city" is all about, or what other proximate explanations there might be for the phenomenon of organization, but to find a way to explain the urban phenomenon based on the most general characteristics of humans. In my opinion, those characteristics are the fact that (1) they live by processing matter and energy in order to eat and do what they want to do, and that (2) they organize themselves and their environment by processing information in order to avail themselves of the matter and energy they need.

What differentiates these three basic commodities is the fact that matter and energy are subject to the law of conservation, and therefore cannot be shared, while information is not, and thus can be shared. So societies accumulate matter and energy from the environment – both the social and the natural environment – and they sustain their people with those resources, but what brings people together in groups, towns or even societies is the processing of information because that can actually be shared. We cannot both eat the same piece of food simultaneously, but we can share the knowledge about how to avail oneself of a certain piece of food.

So I see societies, towns and cities as 'dissipative flow structures' in the sense of Ilya Prigogine (1978, 1980), dynamic structures that sustain the life of their members by generating inward flows of energy and matter, in exchange for an outward flow of information that organizes a society, a city and their environment and thereby dissipates chaos (Greek: χάος, a state of complete non-organization). Organizing the society's or the city's environment is necessary in order to gather in that environment the flows of energy and matter that are needed for the society's members. It must be emphasized that these flows follow very different patterns. The energy flows are essentially dendritic: they gather energy from all over the environment, bundle it together and then distribute it among individuals. The information flows are based on sharing and occur in complex communication networks.

Note that this approach focuses on cities as living organisms, rather than on their 'exoskeletons', the buildings in which their dynamics take place. It also abolishes the distinction between structure and process by considering what happens in terms of dynamic structures, transforming our emphasis from the study of 'being' (stable states and structures) to that of 'becoming' (generative processes). In other words, we move from an Aristotelian perspective to a Heraclitan one. Rather than assuming stability and explaining change, we assume change and therefore have to explain (apparent) stability. The dynamics involved are considered to be 'complex' in the strict scientific sense of investigating how relationships between parts give rise to the collective behaviors of a system and how the system interacts and forms relationships with its environment.

Looking at the long term of human societal evolution

How may this model help us understand the long-term evolution of human societies? I see that evolution as driven by another feedback loop, even more fundamnetal than the one above. It is responsible for human (individual and collective) learning. On the individual level, I would argue that problem solving structures knowledge and thereby increases a person's information processing capacity. The enlarged information processing capacity then enables the cognition of new data and the solving of more problems, yet further enhancing information processing capacity. Over time, this leads to the acquisition by the individual of an increasingly complex set of 'tools for thought and action'.

But because there are natural limits to individuals' information processing capacity (Read & van der Leeuw 2015), as the flow of information grows beyond a certain threshold, processing it involves the interaction between more and more people. That in turn demands more organization, and therefore, more information processing. This collective feedback loop results in more knowledge, and in making more resources available, but also in strengthening the multual dependencies between the people involved, and thereby enhancing their belonging to the community. In that process the groups of interactive people — villages, towns, cities, societies — get bigger and bigger, knowledge and social structures become more encompassing, and the unknown is reduced.

In order to maintain that dynamic, of course, one has to keep enhancing the information processing capacity, and that requires permanent innovation of new 'tools for thought and action', including new institutions, new customs and beliefs but also new artefacts. Were the increase in information processing capacity to stagnate, being part of the group would no longer be attractive to people, and they would start looking somewhere else, so that the society would eventially disintegrate. There always has to be something to be gained by being part of the society, and that is generated by the innovation process.

Sedentism and settlements

It is this process, and the need for people to interact more and more frequently as part of it, which actually creates, over long-term time, settlements. When people are roaming around in small groups, as they did for most of human history, their collective information processing capacity is limited by the fact that people will spend a lot of time searching for other people they need to communicate with. When people are sedentary, one generally knows more closely where they might be found and that cuts down on the search time, and makes communication a lot more efficient. One aspect of the Neolithic transition to viillage life is therefore that people banded together and shared information more and more intensely. That was in turn enabled by new inventions: cultivation and herding. These transformed a subsistence economy based on mobile harvesting of wild foodstuffs into one based on investing in locally growing food, transforming the environment and creating relatively easily accessible resources in sufficient quantities to sustain the people settled together.

In the process, collective information processing also changed. In villages, after a while, everybody knows everything about everybody, which basically means that the information pool that the inhabitants have in their village is very, very homogeneous. That creates stability as long as the village is isolated from other villages with other values. Hence life changes only very slowly in isolated village societies, as we can see today.

But that stability may be challenged by internal as well as external perturbations, so that size of the village population is no longer sufficient to assemble the information processing capacity that is needed to deal with these challenges. In that case, village communities will respond by increasingly communicating and exchanging ideas with people in other villages, linking the village concerned into a network of villages. Within each village, that causes values and opinions to differentiate, and the information pool of each village to grow. That in turn creates societies – groups of people in space and time – that share more and more values between them and differentiate themselves from other groups in behavior, thought, material culture, customs and institutions. That then, in turn, leads to exchange and trade when people try and obtain those things they desire but do not have at their own local disposal.

From villages to towns

The next stage is the transition from villages to towns (van der Leeuw, 2007, 2012). Towns, cities, and urban agglomerations always emerge in groups, never singly, because their emergence and growth are part of emerging networks of trade and exchange. Without exchange and trade, there would be no towns. So what we need to look for concerning cities from the earlies times to the present, is their connectivity, their functional differentiation, and the phenomena that derive from them.

What does this tell us about the dynamics of urban systems as they co-evolve with their environment through time? On the one hand, that the need to solve problems drives the aggregation of the population, but on the other that limits in resource availability constrain the growth of cities. Why? Well, the more people live together, the further they have to go to get their food and other resources, and so the more energy they actually expend in gathering the resources that they need in the city. Hence, growing large agglomerations is not an economic thing to do. And once growing numbers of people reside together they have to try and find ways to reduce the amount of matter and energy they require for the functioning of the city. Information processing is the driver of urbanization, energy and matter availability are constraints.

I have already outlined the feedback loop in which organization spreads out from the center of the system, from the cities, and resources are brought in from the periphery. That is a long-term, permanent feedback loop, in which innovation is essential because it attracts people, uses their cognitive dimensions, involves them in the problems that need to be solved. Innovation drives urbanization and urbanization drives innovation. But within the cities some people get to deal with more information than others. Hence, little by little the power to do things, which is initially delegated by the population to their leaders, is transformed into power of the leaders over the wider population, in a process that leads to the creation of wealth differentials and power hierarchies. Because the larger the group of people the more frequent differences of opinion are, that lead to problems, conflicts, misunderstandings etc. And that pushes populations to develop things such as measuring, counting, writing, administration, institutions, ways to adjudicate in conflict situations, laws and so forth. Archaeologists find the material remains of these developments in the form of monumental buildings such as palaces and temples that reflect power hierarchies,. But they also find the material remains of the development of the counting and writing systems that are needed to develop trade, as well as traces of a professional class of administrators and codified laws to solve disputes between members of society.

Over the time between the 5th millennium BC and the beginnings of the current era, such urban systems spread all over Eurasia, emerge in the Americas, and create true metropoli such as Thebes, Rome, Alexandria, Teotihuacan, Xi'An and many others. In some cases the populations in such centers are so large that their footprint largely exceeds that of the society that initiated them, and whole "empires" are geared to catering to them. But the fundamental dynamics do not change: information (organization) out, energy and resources in; information processing as the driver; energy and resource availability as the constraint.

The current situation

That dynamic is fundamentally transformed by the beginnings of the industrial revolution. From about AD 1800 the discovery and harnessing of fossil energy lift the energy constraint to the growth of cities, and that paves the way for the urban explosion that we are seeing to this day. This is represented in figure 1. Virtually all of the extra energy beyond the bare minumum needed for individuals to live on goes towards maintaining the physical and social infrastructure and material culture of our society! At the same time it paves the way for increased innovation because one of the main (energy) costs of innovation is actually implementing inventions in society.

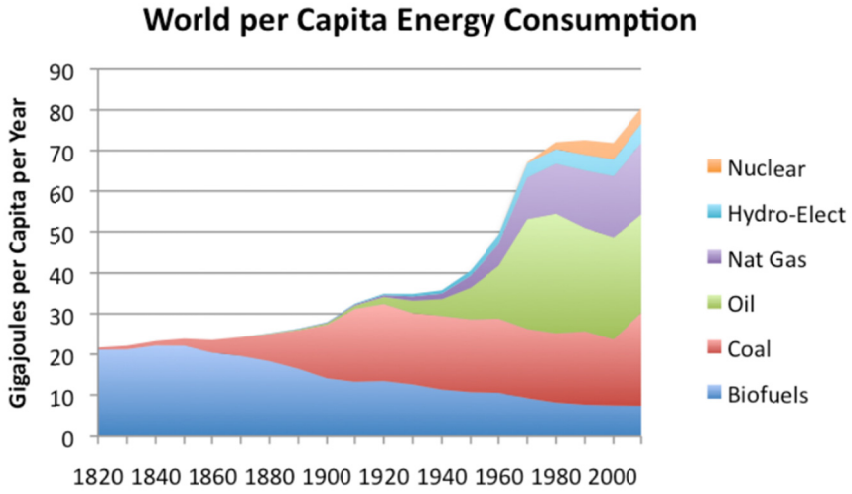

Figure 1. *The evolution of per capita energy use since the Industrial Revolution. Note that the global figure obscures huge differences, for example between the USA (c. 300GJ/a) and India (c. 26 GJ/a). [Source: Tverberg "Our Finite World", reproduced under CC licence]*

While energy was costly, inventions were only implemented when there was a pressing demand for them in everyday life. But with plentiful cheap energy, the innovation dynamic changed. As it became cheaper in energy terms to introduce innovations in society, needs started being met that were not fundamental to everyday life, and sometimes this included needs that people were totally unaware of before introduction, such as the cellphone.

But equally important is that because we have to keep innovating to keep our societies together, the availability of cheap energy pushes us to innovate faster and faster and faster. The end result is not unlike a Ponzi scheme in which the people managing the scheme have to find new funds faster and faster because they need to reimburse participants for non-performing loans. Or to put this in terms more frequently used in biology, this is a case of the "red queen" phenomenon encountered in "Alice in Wonderland". Each society accelerates its innovation within a particular conceptual and value framework (culture) which creates for that process an increase in path dependency. As a result, in New York nowadays, people can buy or sell more than a million different artefacts, whereas about twenty centuries ago, we sold maybe a few hundred, maybe a thousand, no more!

Urbanization so far has been the most persistent social evolutionary dynamic known to mankind. Individual cities have disappeared, but urbanization as a phenomenon did not disappear. The fundamental drivers – aggregation and innovation – remained intact. In order to determine whether cities will be resilient, we need to determine in how far those fundamental drivers will continue to favor urbanization as they have until now. In fact, recently the energy-information balance has changed again. Energy is becoming more expensive than it was for the last couple of centuries and information is becoming much less expensive than it has ever been. Hence the question is whether the dynamic that drives urbanization – getting more people closer together so that information processing becomes easier at the cost of increasing the need for energy – is actually going to continue?

This development has several implications. For the moment, cities are growing faster and faster, and so do innovation and wealth differentials. But members of our communities and societies increasingly have difficulty keeping up with technological change. Societal effects of the rapid rise of urban systems include such "societal planetary boundaries" as important increases in wealth disparities, with negative implications for social stability, individual and collective health, drugs, crime, traffic, pollution and other aspects of urban life. In general, social risks have increased. Hence I would argue that cities are in the current context very vulnerable systems. They have a very costly infrastructure (which in many countries is degrading rapidly and cannot be repaired or upgraded because the funds are lacking), they are dependent on a very large footprint that currently, collectively far exceeds what the Earth can durably produce with current techniques), and in view of the changing balance in cost between energy and information that I just mentioned, they are no longer necessarily the most persistent social dynamic that we have known on Earth.

How about the future of cities?

Most of the predictions about urbanization, and in particular that we will have about 80% of the people living in urban situations by 2100, are based on a linear extrapolation of the current dynamics. But we are increasingly becoming aware that we are actually dealing with a complex system with lots of unintended consequences, so that such linear scenarios are not necessarily applicable. The ICT revolution, which is only beginning and will change the world much more dramatically than anything we have seen before, undermines the need for spatial concentration in innovation and therefore undermines the need to actually build cities. Climate change will exert pressure to increase transport costs and to reduce the use of bulk transportation, so that we may have to develop economies that are more regional, more local. The food/water/energy nexus, I would argue, will hit us long before the heaviest impact of climate change. This is important because the mechanization and upscaling of agriculture have greatly facilitated urbanization by reducing the number of people involved in producing food for the cities. As the area of earth that is suitable foir agriculture is virtually all under exploitation, one of the potential alternatives to grow more food will be a return to more labor intensive, differentiated agriculture that exploits the local differences in agricultural potential better. And another important factor is the current drive towards automatization of industrial production, which in the next generation will make very large numbers of people unemployed, particularly in cities. To avoid mass social instability, one could see a drive towards a "return to the countryside" as is currently, on a voluntary basis, observed in South Africa, where many inhabitants of shantytowns are spreading out into the countryside in the hope of having a better life, for example by practicing (unmechanized) agriculture on small plots.

Together these dynamics may very well impact on the business-as-usual scenario for urban development that predicts nearly full urbanization by the end of this century. ICT may shift the dynamic towards dispersed settlement when information exchange no longer requires proximity. That saves energy and improves resilience because it keeps de-localized social groups together through online interaction and makes such groups more resilient. Mega-cities, as a result, might lose some of their predominance, and this will lead to an adjustment of national rank-size curves under

globalization, as very heavily "primate" rank-size distributions are replaced by less biased ones, strengthening networks of smaller cities. Individual cities may also gain in autonomy because one might well see an erosion of the dominance of very large national and supra-national units of governance due to the fact that their control over information processing is undermined by the capacity of people, through the web, to communicate at will with anyone in the world. That will make it more and more difficult to manage large socio-political entities, and might lead to a breakdown of such entities and a re-organization of societies based on smaller ones, such a cities. These cities must then find effective ways to manage focused change and stability, forcing them to invent novel ways to solve social challenges.

Innovation, as it is currently practiced, is destructive of our societies because of the acceleration that it has been undergoing for some 250 years. When politicians and other people talk about "innovating our way" out of the sustainability conundrum, I respond that the last two-and-a-half centuries of undirected innovation have actually caused our present predicament! If we want to deal with it, we need to rethink innovation and the mechanisms that suppress it together and begin to understand them in different ways, so that we can begin to focus invention and innovation on contributing to a sensible reorganization of our current societies. And that in turn requires us to change our perspective on the phenomenon. For the moment, generally, in science we consider creativity as occurring in a black box and study the conditions under which this black box works best, and the result of what happens inside it, without looking at the process of invention itself in a scientific manner. Understanding, and therefore steering, innovation requires replacing our current reductionist approach to science with a complex systems approach that can deal with emergence of novel ideas.

Novel approaches in architecture, development and urban planning

Because of the "great acceleration" that our information processing is undergoing, and the consequences thereof, (mega-)cities, rather than design change when they think it is necessary, will need to start designing for permanent change. They will have to start integrating top-down and bottom-up co-design. To illustrate what means for architecture, I will take the example of the construction of a science park (Park 20/20) in the town of Haarlemmermeer, in the Netherlands, based on the "Cradle to Cradle" approach of Bill McDonough (see McDonough & Braungart 2002). Haarlemmermeer is a little town just south of Amsterdam and it is in full expansion because the Amsterdam airport, Schiphol, is on its territory. There the Delta Development Group has been implementing the circular economy in buildings (http://www.deltadevelopment.eu/en/sustainability). Buildings are designed for disassembly and reassembly whenever that may be needed, and not necessarily in the same form. The occupier of the building rents many of the building materials from their producers, and when these are no longer needed at the end of the use-life of the building, he gives them back to their owners. By that point, these materials have become scarcer and pricier so that the owners of the materials make a profit, and the rental price during their lifetime can be reasonable. Everything else is either composted or recycled back into industry.

This approach requires a complete rethink of the economic and legal context in which such a circular approach to building materials can emerge. It implies a new business model for architects and developers, a new legal framework, new approaches to governance, etc. Although that imposes, for those initiatinge this development, a number of serious challenges, I think this is nevertheless one of the ways forward that we need to start exploring much more effectively. It is in tune with major social trends towards the sharing economy, and would contribute in important ways to reducing excessive resource use.

What about urban planning? In general, action to instantiate change is taken too late due to slow, multi-level bureaucratic decision making. Moreover, existing and well known political systems with relatively fixed ideas derived from a linear perspective on the future are the standard and determine

how we plan. People inside the system often become immune to signals from the outside, so that these systems tend to reproduce themselves and become more robust when confronted with external threats or new ideas. As a result, urban planning takes longer than the dynamics that are inspiring it, and the results are often not adapted to the needs. And realizing the actual results of the planning last even longer. From planning to realizing a highway may take 30 years! To adapt to the great acceleration and the newly emerging challenges it poses, we will have to look further forward in planning, on the one hand, so that we actually plan let's say with a horizon of 30, 40 or 50 years, and we have to find faster ways to adapt plans and cities.

SwarmPlanning, developed by a Dutch urban planner, Rob Roggema, might offer a tool to achieve this (http://swarmplanning.com/Articles/04%20Ravage09%20roggema-klein%20kopie.pdf). In his approach a region is seen as an adaptive complex system, which can be planned according the rules of complexity. It is deemed more effective to intervene spatially at strategic locations and at crucial times ('tipping points') and then let the urbanization process evolve from that moment on, instead of blueprinting a future, which will most probably not be implemented according to plan, or might end up constraining the process of urbanization.

Roggema argues that two things are essential for urban planning: the full spatial characteristics of the region under consideration, understood as a complex network, and the availability of extraordinary ideas. When there is a large group of individual elements – people, buildings, connections, high quality relations in a network – and enough diversity, one may be able in advance to develop several co-existing patterns and co-existing ideas for further development, in which small groups of people will engender creative jumps, and new structures and information will evolve. But rather than focus on one future, multiple scenarios are prepared and multiple pathways are put in place, so that when the city is faced with the need for change, one actually can implement such change much more quickly around some of the fixed points that are at the basis of the different plans made, much as a swarm of birds can very suddenly change direction based on almost invisible signals. Roggema illustrates this approach with a case study that took place in the Northern Netherlands, around the city of Delfzijl. But since then, he has also been working in Australia and in Italy on futher developing the approach.

What are some of the risks and opportunities?

There is of course no clearly delineated future for cities in general. To begin with, they need to adapt themselves to local environmental, societal and poltical circumstances, and these differ importantly across the Earth. Whereas it may be possible to some extent to 'steer' the evolution of cities in the developed world, it is for the moment almost inconceivable that one could do the same in many parts of the developing world because the dynamics driving urban development in, for example, Africa, are very different indeed.

A major potential development that may affect cities in many places, but in particular in the developed world, is the possibility that our current political institutions will seriously be threatened by the Information and Communication Technology (ICT) Revolution. As I have argued elsewhere (van der Leeuw, in press a,b), the rapid evolution of our information processing and communication technology is accelerating several major tendencies in our societies that, taken together, are currently undermining our current societal institutions. This concerns the *international diplomatic system* that is undermined by cyber-warfare (Haass 2017), the *democratic approach to national policy-making* that is being undermined by foreign meddling in elections, and the *coherence of our communities* by the realignment of our social networks from a local to a global level. At a more fundamental level it undermines our use of place (Augé 1992) the management of time, our relationship with reality (Debord 1967) and the values on which our societies are based. Viewed against the wider background of growing inequality among peoples and nations, major migrations due to political, environmental and economic discrepancies, and the impact of climate change worldwide, the conjunction of a number of

these trends might well push our societies to exceed the societal 'safe operating space' that we are currently trying to define for the Earth's natural environment. That would create a period of relative chaos in the world that may be as profound as the dark period of about a century following the Industrial Revolution, in which society had to adapt to a completely different use of energy.

How this might affect cities is an interesting question. In considering it, we have – again – to distinguish between the developed and the developing world. In the former, if cities succumb to, or are overtaken by, the chaos I just mentioned, the urban way of life may in many ways dissolve itself. Archaeologists have studied this process at the end of many major phases of demographic accretion that constituted the basis for major empires. In the 7th to 10th centuries AD, for example, after the end of the Roman Empire, people in Western Europe left cities, spread out over the landscape and led rural lives. Cities shrank to such an extent that, in Arles for example, the whole of the urban population fit into the *Arènes*. After that period, very slowly, a new dynamic emerged bottom-up that is characterised by growth of the population, growth of the urban centres that had survived the 'dark ages', growth of long-distance commerce and the (re-) introduction of many technologies.

On the other hand, it is not inevitable that cities to succumb to this dynamic. Instead they could, at least for a certain time, become the political, economic and social entities that took the place of increasingly disfunctional higher levels of organization. Stirrings of this kind can currently be observed in a number of phenomena, including the Transition Towns movement, the various regional or global associations of cities and city mayors that have filled the role of national governments in moving towards a more sustainable way of life, etc. Cities have a major advantage in the fact that their populations are directly, and daily interactive, so that their populations are not totally dependent on information technology to create a sense of 'shared circumstances' and a shared fate.

But of course that posits the question of how these cities are going to interact between themselves. Will they, within a relatively short time, be able to develop alternative ways to constructively do so, or will they not? The ICT revolution has created one unique difference between earlier phases of societal disintegration and the present: the possibility to maintain low-cost long-distance communication networks. What could be their role?

And what would be the future of the mega-cities that we have created? They could not possibly shift their dependency from their current global footprint to more local procurement of energy, food and other resources without major loss of population. It seems to me that the ICT revolution will therefore shift the balance towards smaller urban centres that are more or less independent, or at least able to confine their material dependencies to a hinterland over which they have some degree of control.

In the developing world, it is for the moment less certain that the ICT revolution will enable the population to spread. The inordinate growth of cities in Sub-Saharan Africa, for example, is driven by forces that do not follow the known trends experienced in Europe, the USA and China over the past few decades (Martine 2012). Unlike in the other continents, where the rural-urban migration was, and is, mainly driven by the industrial revolution and the development of manufacturing in urban centers, factors like climate change, population pressure, environmental degradation play a big role. Not only is population pressure affecting the availability of arable farmland and grazing areas, thereby forcing people to move to cities, it also impacts negatively on other social sectors like education and health. With respect to climate change, abnormal weather patterns (i.e. severe floods and droughts) experienced in the past few decades have had negative impacts on agricultural production systems (both crop and livestock), forcing more, particularly young, people to migrate to urban areas. The strenght of these drivers is such that in these parts we may well, for the moment, see further aggregation.

Conclusion

This contribution has tried to argue for several things. *First* of all, the need to look at societies through the lens of complex adaptive systems, and to focus *ex ante* on the emergence, at all periods, of novelty rather than try, *ex post*, try and analyze how the present came about. *Second*, it has presented a general model of the dynamics of socio-environmental interaction, in which an outward flow of processed information, in the form of knowledge and organization, generates an inward flow of matter, energy and resources. I argue that this is valid for all socio-environmental interactions, and that among others it drives the emergence and co-evolution of urbanism. The core of this model is anchored in the feedback loop between data, information processing and knowledge. *Third*, the paper has pointed at the fundamental changes occurring with the Industrial Revolution, when energy becomes less of a constraint on innovation and agglomeration because fossil energy is plentiful and can be harnessed. This leads to the "Great Acceleration" and, ultimately, to the current sustainability predicament. *Fourth*, the ICT revolution and the energy transition, together, have now resulted in a situation in which information is no longer a constraint, and energy may become one. This has major consequences for the resilience of urban systems, and sheds some doubt on the assumption that by the end of the 21st century, 80% or more of the human population will live in cities. It forces us to begin systematically designing for change in infrastructure and urban planning. The paper ends with presenting one example of novel thinking in each of these two domains.

References

Augé, M., 1992 "Non-lieux: Introduction à une anthropologie de la surmodernité"., Paris: Seuil (Engl. Transl.: *Non-Places: An Introduction to Supermodernity*, 1995, New York: Verso)

Debord, Guy, 1967, La société du spectacle, Paris: Buchet Chastel (English 1970/1977 The Society of the Spectacle, Detroit MI: Black & Red)

Haass, Richard, 2017, A World in Disarray : American Foreign Policy and the Crisis of the Old Order. Retrieved June 12, 2018 (https://www.amazon.com/World-Disarray-American-Foreign-Policy-ebook/dp/B01ESI3PPG).

Martine, George, Gordon McGranahan, Mark Montgomery, Rogelio Fernandez-Castilla (eds.), 2008, The New Global Frontier: Urbanization, Poverty and Environment in the 21st century, London: Earthscan

McDonough, William & Michael Braungart, 2002, Cradle to Cradle: Remaking the Way We Make Things, Northpoint Press

Prigogine, Ilya, 1978, Time, structure and fluctuations. Science, 201, 777–785. doi: 10.1126/science.201.4358.777.

Prigogine, Ilya, 1980, From being to becoming. San Francisco: Freeman.

Read, Dwight & Sander van der Leeuw, 2015, "The Extension of Social Relations in Time and Space during the Palaeolithic" In: Settlement, Society and Cognition in Human Evolution (F. Coward, R. Hosfield, M. Pope & F. Wenban-Smith, eds.), pp. 31-53, Cambridge: Cambridge University Press

van der Leeuw, Sander, 2007, "Information Processing and Its Role in the Rise of the European World System". In: Sustainability or Collapse? (R. Costanza, L.J. Graumlich, W. Steffen, eds.), pp. 213-241. Cambridge, Mass: MIT Press (Dahlem Workshop Reports).

van der Leeuw, Sander, 2012, "Global Systems Dynamics and Policy: Lessons from the distant past" Complexity Economics (2012): 33–60

van der Leeuw, Sander, in press a, "Not an ordinary tipping point" to appear in Anthropocene (Special issue on A safe operating space for humanity – A past-present-future perspective on Sustainability)

van der Leeuw, Sander, in press b, Drilling Down into Sustainability, New York: Cambridge University Press (to be published 2019)

