



TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

Jenni Partanen

'Don't Fix It if It Ain't Broke'

Encounters with Planning for Complex Self-Organizing Cities



Julkaisu 1514 • Publication 1514

Tampere 2018

Tampereen teknillinen yliopisto. Julkaisu 1514
Tampere University of Technology. Publication 1514

Jenni Partanen

‘Don’t Fix It if It Ain’t Broke’

Encounters with Planning for Complex Self-Organizing Cities

Thesis for the degree of Doctor of Science in Technology to be presented with due permission for public examination and criticism in Rakennustalo Building, Auditorium RG202, at Tampere University of Technology, on the 12th of January 2018, at 12 noon.

Tampereen teknillinen yliopisto - Tampere University of Technology
Tampere 2018

Doctoral candidate: Jenni Partanen
Laboratory of Architecture/ Urban Planning and Design
Faculty of Business and Built Environment
Tampere University of Technology
Finland

Supervisor: Anssi Joutsiniemi, Professor
Group X
Department of Architecture
Aalto University
Finland

Instructor: Yuval Portugali, Professor
The Department of Geography and the Human
Environment
Faculty of Humanities
Tel Aviv University (TAU)
Israel

Pre-examiners: Michael Batty, Professor
Centre for Advanced Spatial Analyses (CASA)
University College London (UCL)
United Kingdom

Raine Mäntysalo, Professor
Department of Built Environment
Aalto University
Finland

Opponent: Gert de Roo, Professor
Department of Spatial Planning & Environment
University of Groningen
The Netherlands

ISBN 978-952-15-4050-9 (printed)
ISBN 978-952-15-4073-8 (PDF)
ISSN 1459-2045

CONTENTS

CONTENTS	3
SYNOPSIS: CITIES IN A CONSTANT STATE OF FLUX - A CHALLENGE TO PLANNING.....	7
1. THE FORMATION OF CITIES AS TWOFOLD INTERPLAY BETWEEN AUTONOMOUS PROGRESS AND PLANNING.....	10
HOW CITIES EMERGE AUTONOMOUSLY	11
Individual decisions as drivers in urbanity	11
Circular processes	12
Technological revolutions and the city evolution	13
Irreversibility and uncertainty.....	14
Metapolis as a major urban type throughout scales	15
City remains physical	15
PLANNING EVOLUTION.....	16
Metropolis planning - control through physicalism	18
Planning the city with systems theories and science.....	19
Non-spatial city – the planning of processes	20
Planning of city fragments.....	21
<i>The move forward: a call for new theoretical ground</i>	23
2. ‘THEORIES OF COMPLEX SYSTEMS’ AND ‘RESILIENCE THEORY’- AN INTELLECTUAL AND METHODOLOGICAL FRAMEWORK FOR COMPLEXITY PLANNING	24
BACKGROUND: THE EVOLUTION OF SYSTEMS THINKING.....	24
Emerging systems	24
General Systems Theory.....	26
Cybernetics	26
FRAME ONE: THEORIES OF COMPLEX SYSTEMS	28

FRAME TWO: RESILIENCE – ANOTHER READING OF COMPLEX ADAPTIVE SYSTEMS (CAS)	35
Adaptive cycle – self-organizing criticality revisited.....	38
HOW TO KEEP THE SYSTEM COMPLEX: THE DO'S AND THE DON'T'S	42
How to build resilience.....	42
How to reduce resilience: the maneuvers to avoid.....	46
3. EPISTEMOLOGY OF COMPLEXITY.....	49
EMERGENCE: SOLVING THE MYSTERY	51
BALANCING BETWEEN OBJECTIVITY AND RELATIONALITY: SUBSTANTIALLY REAL	52
SINGULARITIES AND GENERALIZATION THROUGH PATTERN ISOMORPHISM.....	53
COMPUTERS AND THE PRODUCTION OF KNOWLEDGE.....	54
SIMULATION AND KNOWLEDGE.....	55
EPISTEMOLOGICAL CONCLUSIONS	57
4. RESULTS INTERPRETED: PLANNING FOR COMPLEXITY, A TWO-FOLD APPROACH.....	59
PHASE ONE: SPECIFYING THE SCOPE OF PLANNING – <i>THE SLOW CYCLE</i>	62
PHASE TWO: ADAPTIVE PLANNING - THE FAST CYCLE OF IMPLEMENTATION AND EVALUATION (IMPEVA).....	64
COMPLEXITY PLANNING TOOLS.....	66
Methods related to plan implementation	67
Methods related to evaluation:	75
Monitoring the level of complexity or self-organization.....	75
5. DISCUSSION.....	81
6. EPILOGUE - COMPLEXITY PLANNING:	84
A PARADIGM SHIFT.....	84
REFERENCES	88
APPENDICES	99

List of original publications:

Partanen, J. (2015), “Indicators for Self-Organization Potential in Urban Context”, *Environment and Planning B: Planning and Design*, volume 42, pages 951–971.

Partanen J, Joutsiniemi A (2015): “Complex patterns of self-organized neighbourhoods” in Boelens, L & G. de Roo (eds.): *Spatial Planning in a Complex Unpredictable World of Change: Towards a proactive co-evolutionary type of planning*, InPlanning, Groningen.

Partanen J, (2016A): “An Urban Cellular Automata Model for Simulating Dynamic States on a Local Scale.” *Entropy* 19(1), 12. doi:10.3390/e19010012. Published online with supplementary material (<http://www.mdpi.com/1099-4300/19/1/12/htm>).

Partanen J (2016B): “Liquid Planning, Wiki-Design - Learning from the Case Pispala”, in *Environment and Planning B: Planning and Design*, 0265813516647965. Published online (<http://journals.sagepub.com/doi/abs/10.1177/0265813516647965>).

Author's contribution in the appended article Partanen J, Joutsiniemi A (2015): "Complex patterns of self-organized neighbourhoods",

The author is responsible for the initiation of the study, along with the theory section, data collection and research operations of the paper. Dr. Joutsiniemi participated in writing and editing the paper

Dr. Joutsiniemi is also responsible for the coding of the model used for simulations in the article Partanen (2016A): An Urban Cellular Automata Model for Simulating Dynamic States on a Local Scale, in Entropy.

SYNOPSIS: CITIES IN A CONSTANT STATE OF FLUX - A CHALLENGE TO PLANNING

In recent decades, we have increasingly faced challenges as to how to plan our towns and cities. In traditional planning thinking, autonomous urban progress has been considered flawed and colliding with successful planning presumably producing and controlling the city. However, cities seem to repeatedly avoid such control, and the resulting multifaceted urbanity manifests as edge cities, sprawl and multi-nodality, self-organizing patterns and processes, clusters and networks. Overall, it seems that the city has gradually become too complex to be controlled in respect of both physical form and spatio-functional configurations, and socio-economic processes. Most importantly, we forget that many of these autonomous processes are necessary for the viability and renewal of cities – for innovation and creativity in economic, social, and cultural life. Until recently, the response to such uncontrolled urban progress has been either to impose stricter controls (Pakarinen 2004), or to seek for adaptation through incremental implementations (Kuusela and Partanen 2016). Both methods evade the major issues of emergent bottom-up progress, either by ignoring the very processes, or their assessment and considering guidance. Questions about appropriate planning methods and tools emerge for both guiding and enabling urban systems dynamics, along with the essential question of fundamental nature of city planning, design and urbanity.

In Chapter 1 of this thesis I suggest that this chimeric urbanity has not emerged for one single reason - such as flawed planning or autonomous processes alone, but from complex co-evolutionary interactions between the two, resulting in the extreme complexity of the urban systems we are witnessing today. In light of this, I claim that such complexity requires, first, completely new theoretical views to understand the very nature of the late modern urbanity, and secondly, a novel set of planning tools and methods to guide it in an appropriate manner.

In Chapter 2 I build a theoretical understanding of such fluctuating dynamic city systems, following, for example, Michael Batty and Stephen Marshall (2009, 2016) in proposing that the so-called *complexity sciences* – and particularly the theory of self-organization as a key

mechanism of how complex systems organize – and related *resilience theory* provide a robust frame for future planning discourse. Complexity refers here to a set of theories originally from the natural sciences contemplating complicated open systems and applied within variety of fields including urban research. Resilience theory originates in ecosystem studies, and basically contemplates the capacity of complex systems to adapt and recover from crises autonomously. These approaches are able to consider the neglected characteristic of complex urban systems, such as unpredictability and nonlinear dynamics, thereby enhancing our understanding of possible planning premises, but also providing actual methods and measurements – such as scaling, entropy or dynamic states used in the related articles – for complexity planning.

However, adopting such theories from natural sciences to human systems is naturally not straightforward, and hence in Chapter 3 I build an epistemological basis which enables adopting the complexity view while maintaining the relationality of human systems. In the framework of the proposed "substantial structural realism", in Chapter 4 I answer the research question, and provide a robust frame for following complexity methodology. Furthermore, along with introducing "complexity planning methods", all the articles which form the substance of this thesis elaborate empirically and in detail the question by scrutinizing thoroughly (yet not exhaustively) some of the most central 'complexity planning' methods.

In the first article (Partanen 2015) I aim at recognizing and measuring self-organization in the case area Nekala old industrial area using typical measurements of self-organization such as entropy and scaling. Such methods would assist planning to reveal areas with a high capacity for renewal presumably facilitating regionally economic, social or cultural life. In the second article (Partanen and Joutsiniemi 2015) the same case area is scrutinized more carefully to reveal other self-organizing, unplanned patterns resulting from actors' interaction, with results proving that self-organization of activities is a much more diverse and unrecognized phenomenon than previously assumed, requiring more freedom and delicacy in planning operations. The third article (Partanen 2016A) introduces a simulation model with which the planning rules and their impact on the continuity of the systems dynamics is studied, assuming that complex states, that is, partly predictable, partly chaotic behavior of the model, represent the system's ability for renewal. The model is run in two case areas, the previous Nekala area and Vaasa old garrison area. The planning would benefit from such simulations by pinpointing what must be controlled by plan for preferable continuous and adaptive dynamics, leaving the rest intact to operate autonomously. Finally, a self-organizing planning experiment is introduced in the fourth article (Partanen 2016B), proposing a structured method for a genuinely bottom-up (beyond participation) way of co-creation of space, based on self-

organization of information, and considering actual (invisible) processes within the city for more considerate planning.

Although the methods and analyses applied and presented in this work are fairly well established in academia, in planning praxis their use is still limited, and hence they provide relatively novel viewpoints and methodology. In this thesis I present an overview of a potential methodology for planning, and illustrate in an exploratory manner how complexity could be applied in urban planning, bridging theory, philosophy and operational analysis. The implications and limitations of these approaches are elaborated in Chapter 5., Discussion.

In the Epilogue I then discuss what the role of the proposed complexity planning would be in the context of the planning evolution presented, suggesting that such continuous and contemplative mode implying methods for plan assessment or evaluation and implication could form a new paradigm for planning, not completely replacing the existing ones but complementing the spectrum of planning methods, and probably also enabling the emergence of lighter, more flexible planning overall.

The title of the thesis refers to a common saying suggesting that something that is operating well should left intact, or to “leave something alone; avoid attempting to correct, or improve what is already sufficient (often with an implication that the attempted improvement is risky and might backfire)” (Wikipedia). In the context of this work, and as regards self-organizing processes overall, this is even more true: due to their inherent non-linearity, changes in the well operating system - actor networks, clusters or other processes - or in its environment might kill them. Rather, we should adopt a new attitude in planning – to understand that urban processes emerge intrinsically from city life, and learn to nourish the preferable ones while restricting those considered unfavorable.

1. THE FORMATION OF CITIES AS TWOFOLD INTERPLAY BETWEEN AUTONOMOUS PROGRESS AND PLANNING

The dilemma exists between the apparently ineffective control mechanisms of planning and the surprising outcomes of urban processes resulting in unpredictable impacts in the form and functions of the city. This issue was noted decades ago for example by Thomas Sieverts, François Ascher, and Franz Oswald and Peter Baccini among others. These views emphasize seemingly random changes that occur in many fields of urban life: turbulence in the (city) economics, or rapid shifts in basic principles concerning work, retail, recovery and other routines of daily life often appear unpredictably (Ascher 2007, Baumann 2000, Oswald et al. 2003, Graham and Marvin 2001). For example, surprising location preferences of activities or the resulting spatial and movement patterns are related to regions' competitiveness and typically resist top-down ideals of city and city planning. The variety of social and other networks, digitalized organizations and institutions and enterprises emerging bottom up render even more complex the ways we use the city, probably producing completely new spatial configurations (Batty and Hudson-Smith 2013, Batty 2016). These systems are nested and closely interlinked: they imply increasingly complex, nonlinear feedback mechanisms between human systems, and with systems in Nature. Economic, social, cultural, and natural networks are inseparable. In response to such dynamics, planning has continuously evolved to better control the emerging issues in cities, ignoring the autonomous nature of urban processes and in many cases only caused new ones. In many cases urban areas in the West have become overly complex through a twofold process involving both autonomous progress and planning attempting to tackle it.

Consequently, in the context of these challenges, in this thesis I am asking a twofold research question: *what kind of a mental, processual model¹ would allow the city planning to respect the urban processes while still guiding the urban systems in a preferable manner? And particularly, what could be the actual planning tools and methods for implementation of plans and evaluation the desirability of these in the context of complex urbanity?*

¹ A model refers here to a simplification of a phenomenon instead of an idealization. This is typical of quantitative (spatial) research.

HOW CITIES EMERGE AUTONOMOUSLY

By the 1990s many urban theorists had recognized the autonomous² nature of urban progress, for example Sieverts 2003, Oswald et al. 2003, Ascher 2004 and Castells 2011. In these theories of the late modern city, characteristics appear rather alien to the traditional (static) understanding of urbanity. These theories describe cities as dynamic and ever changing, spatially and functionally fragmented and in many ways incoherent systems, following certain logical principles and rules whose overall outcome was still hard to predict. In the mid-1990s the French sociologist François Ascher introduced a term aptly describing the urban characteristics, namely *Metapolis*, stating that cities can metaphorically be considered as systems with metabolia³ - constant, life supporting fluctuation of matter, information and energy through the system - similar to natural organisms⁴. Conceptually, the view embracing cities as systems with metabolia is particularly challenging as regards planning, first, due to its dynamic, constantly changing nature; secondly, for the self-organization of actors and emergent patterns they produce; and thirdly, to their inherent uncertainty – the unpredictability of these processes avoiding permanent equilibrium.

Individual decisions as drivers in urbanity

At the core of the concept of Metapolis is urban dynamics. Metapolis is sustained by continuous dynamic processes which support the system, manifest as flows of goods, information, and people along the highways and communication networks, and built structures as physical concentrations of these, channeling the flows, constantly changing and moving, following the logic of the circulation of the flows (Ascher 2004, 2007, Oswald et al. 2003). The physical city is in a state of constant flux and constantly transforms as a result of collective impacts of individual activities such as firms, individuals, institutions, and organizations seeking their best interests and choosing the best environments for their operation, hence planning locally - in the framework of larger scale planning and regulation with certain (often

² *Autonomous* refers here to independent dynamics within the urban system, which is not subject to control from outside rather than to the self-governance of a community. In the first sense, autonomous complex entities or systems are often self-organizing, implying that the (autonomous) order emerges unintentionally from the agents' interaction. Conversely, the resulting organizations in self-governing autonomy are intentional; self-organization may emerge, but it is not planned. See more in e.g. Partanen&Wallin (2017). Hence, in this thesis, autonomous progress implies no overall governance/control of the whole, nor of the emerging results.

³ The metabolia discourse is, however, older; the first spatial reference is probably from Burkes in urban economics in 1925.

⁴ Note that the reference to organisms is functional, not formal as in planning discourse stressing physical form in the early 20th century.

diversified and transitive) interests and aims (Portugali 2012). It is noteworthy that the plan is not a driver of change as such, and that the same technological innovations and progress which allegedly played a role in the dispersion of city structure also formed certain planning ideals encouraging this (Batty 2007, Shane 2011). Furthermore, seemingly random preferences of actors on the global level also guide the planning decisions in a straightforward manner, resulting in less strict overall steering, and making a plan in many cases appear just as a license to build (Kuusela and Partanen 2016).

Apparently, the intrinsic dynamic drivers for change in late modern cities can be considered to be related to randomness and utilizing available advantages. Furthermore, in such dissipated mechanisms actors' location decisions always embrace a certain extent of stochasticity. Although all actions are basically intentional, no single actor can have the perfect information of the nested system and its operations as a whole (Batty 2007, Portugali 2012). Even with the best available information the actors' location may from another point of view be random. In addition, they are always affected by the heterogeneity of rational, emotional or other preferences. It is implied that a qualitatively new, often surprising, pattern may emerge as the city is observed on a higher scale. The role of the flows also appears in utilizing the comparative advantage of the region. It implies superior market potential or higher accessibility to facilities compared to those of other regions. This process is self-enforcing, and it could start by coincidence and accelerate through the feedback (Batty 2007). Hence, since the self-organizing pattern is a cumulative result of myriads of independent actors, it is hardly controllable on a level of the self-organizing pattern, but the control of each individual would be equally hard.

Circular processes

The numerous networks of transport and telecommunications channeling urban flows are also highly interlinked and mobilize resources in each other in a circular way. Urban form and the social organization of space interact with transportation and storage: Zonings, densities, centrality, axialities, polarization, functional and social segregation depend on these techniques and, conversely, generate and direct their development. After the Second World War the expanding use of private cars and later personal computers and internet have enabled more individual lifestyle choices, and have also gradually become the norm: a certain level of mobility and access to the web is required to be part of society (Ascher 2004, 2007, Castells 2011). The collective effect of myriads of individual choices creates surprising self-organizing

patterns through dissipated decision-making, both in respect of movement and the physical structure of the city (Batty 2007, Sieverts 2003). As feedback, society is increasingly organized around these choices and patterns (Ascher 2004). We have become dependent on numerous gizmo. Individuation means freedom to many, but has another side: people have become responsible for finding a balance in how they use their space and time themselves – Ascher points out that choices are to change the place (delocalization) or time (desynchronization) using tools of mobility and technology, blurring the old concepts of space and time as they become virtual, increasing enormously the complexity, unpredictability and decreasing controllability of cities (Castells 2011, Batty and Hudson-Smith 2013, Townsend 2013). Flexibility is the key concept in business and production, creating a crisis in regulation. In a 24/7 society, with unpredictably changing cycles, we cannot plan in a Fordist manner “just-in-case”, but “just-in-time” (Portugali 1999). The planning needs more flexibility.

Technological revolutions and the city evolution

The city system has developed in many ways as a result of technological innovations, and the following applications in communication and transportation technology (Ascher 2007, O'Sullivan 2007). It is essential that this process is not smooth nor permanently in equilibrium, but has occurred in jumps, boosting urban renewal and producing qualitatively a completely different state (Castells 2011, Portugali 1999, Ascher 2004). Embracing the Metapolis metaphor, it can be considered that the “metabolic rate” of the system jumps to another level as the efficiency of the network to channel flows increases, and consequently its spatial requirements also change. This technological progress resulting in a qualitative leap from industrial to information society, and the coupled development/growth in number of private cars and megalopolitan road network, along with globalization of economy (enabled by and enabling these) have changed the metabolia of the city permanently – the qualitative transitions are irreversible. Changes in urban regions are intrinsically intertwined with progress: actors constantly seek for material advantage, for example regions with affordable natural resources or cheap power. These change over time related to the most effective energy sources available, and the progress in technology, accelerating the progress (Batty 2007). For example, the coal or water power used to be a great comparative advantage for the industrial cities, but the advantage was overridden by the internal combustion engine and oil (Shane 2011, Ascher 2007, Batty 2007). Comparative advantage also changes in time generated by progress in transportation and communication technology which may change the nature of the most accessible – and the most beneficial for the actors – locations (Batty 2007). Both advantages

and their evolutionary nature are implicitly very much related to the competitiveness of regions (Ascher 2004). Furthermore, both these advantages are in a long perspective unpredictable.

Irreversibility and uncertainty

It is necessary to stress again that the changes resulting in Metapolis are irreversible: in a nonlinear⁵ system – progressing in a non-smooth, ruptured manner as cities - the progress cannot be turned back (Gleick 2011). All changes, plans, and further progress will inevitably produce totally new urban typologies or forms of behavior. Such uncertainty is a key characteristic of many dynamic open systems, which is almost ignored in our traditional planning discourse. Hence, for example in modern, mechanistic-rational thinking the concept of danger is often replaced with a concept of risk, implying the possibility to preempt unpreferable incidences by mastering the future with the right type of control/policy/structure in the society (Ascher 2004). In the case of any complex system this is absolutely untrue. Risk and precautionary principle, the key parameters for planners and policy makers, erroneously imply the linearity of complex systems, and often lead to outsourcing the responsibility of our action to decision-makers (Novotny et al. 2010, Ascher 2007).

At the same time our society, the labor markets, and economy are built on a high degree of mobility and extremely flexible individual juggling with time/space⁶, enabling the use of full competition potential (Ascher 2007, Bauman 2013). A flexible response to uncertainty is discovered elsewhere – it is outsourced to individuals. Individuation and a new lifestyle can hence be considered as a response to the complexification of society, but also as a next step in the overall emancipation of citizens from collective rules and norms that has been occurring for decades now, towards a society organized more bottom up. This phenomenon of fragmentation of common interests and shared experience was contemplated already in the turn of the millennium in sociology, for example by Zygmund Bauman, Manuel Castells, and François Ascher. Yet they hardly feature in our planning discourse. Our social groups are weak, numerous, and transitory, and depend on personal choices and networks more than permanent social structures or classes. This is very challenging for many systems in our society, which are built for stability and shared interests, such as representative democracy or planning. The static masterplan aiming at the “best interests of the public” has become a contradiction in terms

⁵ In mathematics, nonlinearity implies that the output of the function is not proportional to the input – generally, the relationship between e.g. process and the pattern it produces is not linear and not necessarily predictable, although it is causal.

⁶ Ascher suggests that individuals can control their lives using delocalization, that is, adjusting their location, and desynchronizing, referring to altering the schedules.

(Taylor 1998). The consensus traditionally implied in participatory activity is impossible as there is no shared realm for various, shifting groups. Conflicts will be inevitable or even necessary in planning, too. Such uncertain configurations need to be accepted as a baseline for planning the Metapolis realm.

Metapolis as a major urban type throughout scales

In recent decades the emergence of the Metapolis described has been a major trend throughout the West, not only the major megapolises or metropolitan areas. Metapolis is assuming a variety of forms reflecting the typical characteristics of each case. This endless variation of types is typical of cities. Cities can hardly be categories according to a single common feature; rather, all cities share certain common characteristics with other cities, but none of these are perceived in all cities (a feature known as *family resemblance*) (Portugali 1999). It is possible to consider that middle-sized European cities very different from huge megalopolises like London or New York share similar features in their “metabolism” (Portugali 1999, Shane 2011), especially within the context of globally networked markets and economy. Metapolis is occurring everywhere, since smaller hubs are also eager to use their maximal economic or competitive potential, and thus they prefer to optimize their connections to the rest of the system. The key factors of the Metapolis (built around flows of people, information, and goods) are related to the connections – ICT and physical mobility (Ascher 2007, Oswald et al. 2003, O’Sullivan 2007). In this thesis the case areas presented in the articles are located in the middle-sized North European cities of Tampere and Vaasa, each facing Metapolis characteristics specific to the region.

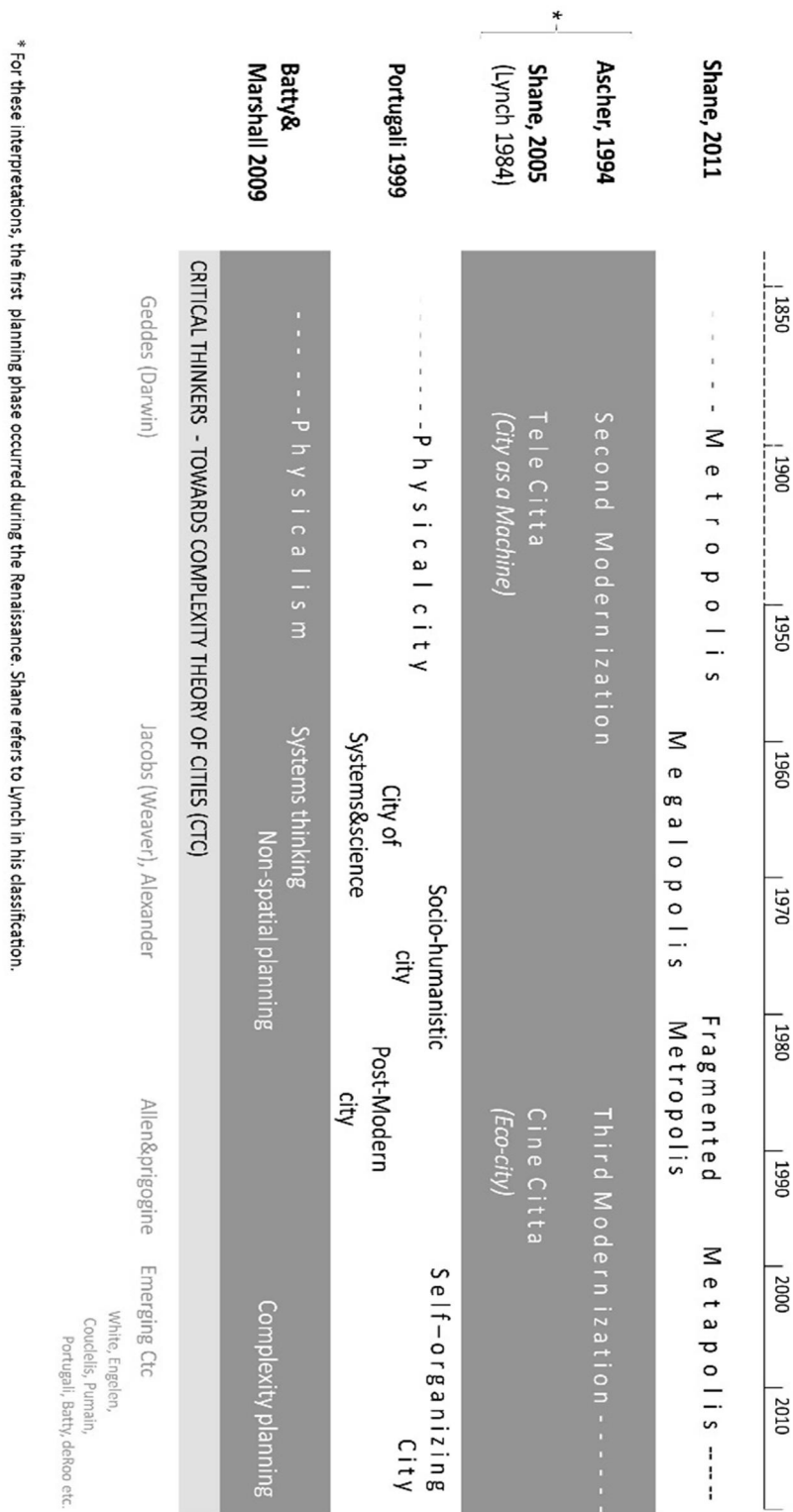
City remains physical

Although the emergence of the Metapolis is intertwined with transportation and communication technologies liberating many locations and digitalizing others, this progress has not challenged metropolitan concentration as such. Cities are probably not becoming totally virtual, but the logics and relations of virtual/physical are changing drastically. Digital tools are right now changing the ways we use the city, and making it even more unpredictable (Batty and Hudson-Smith 2013, Batty 2016). It is probable that physical access and meeting will remain (and perhaps even increase) the priorities in urban locations and their concentrations - the virtuality may even renew the importance of face-to-face experience. New forms of increasing e-commerce will probably change the locations of some retail functions instead of replacing it all; places for information and hands-on experience will still have their

place. Old notions of centrality will be challenged - geometric centers are no longer the most accessible locations; instead there will be multiple centers with a variety of roles (Sieverts 2003, Ascher 2004). The result will not be a virtual city, immobility or introversion, but a new type of mobile telecommunicating city with a new balance between physical and virtual presence yet to be seen (Townsend 2013, Ascher 2004, Batty and Hudson-Smith 2013, Castells 2011). The need for planning of the spatio-functional city will persist, but planning must respond to current and emerging changes. The only strategies to be prepared for these coming manifestations of the digitalizing Metapolis are research, the better to understand them, and based on that, new, more adaptive and flexible forms of spatial planning for increasing complexity.

PLANNING EVOLUTION

Above the emphasis on describing the Metapolis has been on the processes, stressing autonomous progress, dynamics and patterns emerging in the city. However, this is not the whole truth: the formation of cities also results from prior, constantly changing planning decisions and ideals. Basically, the planning paradigms in the West have evolved gradually in 150 years from concentrating completely on controlling the physical form towards an increasingly profound understanding of systems and processes, further embracing social sciences, humanism, and art, and recently considering negotiation and participation, with an embryonic understanding of the bottom up processes described. Along with developing systems thinking, this progress has brought planning from a strictly top-down position towards a richer and more accurate view of urban management, making the planning more capable of responding to the challenges of Metapolis (Taylor 1998, de Roo et al. 2012, de Roo and Silva, 2010). It seems that, as Batty and Marshall (2009) point out, overall the rare yet remarkable addresses promoting evolution, complexity and self-organization of cities along the way, presented by e.g. Patrick Geddes (Batty and Marshall 2009), Jacobs (1961) and Alexander (1965), are gaining more ground backed up by progress in science and urbanism (Figure 1).



* For these interpretations, the first planning phase occurred during the Renaissance. Shane refers to Lynch in his classification.

Figure 1. Timeline of city models and planning paradigms according to authors recognizing complexity or the emergence of Metapolis as a challenge to planning (Batty and Marshall (2009), Portugali (1999), Shane (2011, 2005) interpreting Lynch (1981).

Metropolis planning - control through physicalism

Since the first boom of ideal town planning of the Renaissance (Shane 2005, Lynch 1981), it appeared that the major crises concerning control over cities hit the West in the mid-19th century. Due to industrialization, the urban structure started to expand heavily beyond the traditional city core, stretching toward the countryside around former city borders (Ascher 2004, Lynch 1981, Shane 2005). Although the urban core maintained its role as a central place, in the eyes of the planners this expansion appeared as an alarming anomaly against the traditional compact city, and the monstrous, pathological growth of formerly healthy urban tissue (Batty and Marshall 2009, 2016). This megalomaniac growth was enabled by progress in transportation and communications technology, simultaneously with other revolutionary changes in society following industrialization. These new forms of social organizations and the concept of mass production and consumption rendered the urban system dynamics even more complex, and shifted the urban scale to a completely new level (Ascher 2004, Batty and Marshall 2009, Shane 2011). Undeniably, improving the disastrous hygienic, social and other environmental conditions in cities required urgent actions. However, many planners focused on the process of growth, erroneously considering the very phenomenon unnatural and requiring its prompt taming through a new apparatus, city planning (Batty and Marshall 2016, 2009).

Emerging planning in its early phases⁷ concentrated mostly on maneuvers similar to those in architectural design – the esthetic physical modification of entities, only on a larger scale (Taylor 1998, Shane 2011). The disciplines of planning and design, as they emerged in the 19th century, were about the city as a whole. The underlying physicalistic view implied that social conditions could be improved by altering the physical environment. Here, little attention was paid to the very processes behind the physical formation – such as economic forces (Batty and Marshall 2009). With a focus on the optimal form and restricting the growth, the resulting plans and designs were fairly utopist, imbued with normative ideas and values of how cities *should* be, with little or no understanding of what they had actually become – an attitude not completely absent in more recent planning, either.

As suggested by Batty and Marshall (2009), these brave new ideals of the Metropolis, such as those of le Corbusier and Howard (Corbusier 1929, Howard 1902), were frequently built on analogies between cities and natural organisms, simply assuming natural forms to be the essential features. In these early views the city organism was contemplated as a unified whole,

⁷ this refer to what Ascher has describes to have taken place first, in renaissance (1st modernization) and then after industrial revolution (2nd modernization)

with an optimal form, size and shape (Batty and Marshall 2009). Such planning approaches were hence strictly top-down oriented. A specialist planner or an architect was considered to know the optimal attributes of the city, and to be able to design the city as if designing a machine, with the slightest flavor of natural metaphors. These were often implicit and sometimes only a figure of speech, but sometimes were pushed too far – suggesting rigid, unrealistic optima (Batty and Marshall 2009, Taylor 1998). Concentrating solely on physicalism⁸ the processes promoting the formation of the physical entity - the urban form - were missed, implying idealized impact of human decision making (Batty and Marshall 2009, Taylor 1998). It was crucial that linkages between physical form and socio-economic processes were absent, or even sometimes considered logically flawed. For example, many economic mechanisms and forces were called by Howard (1938) “superstitious” (pp. 488-489), and referred to by Wright (1932) as “artificial” (p. 8).

Planning the city with systems theories and science

The core city model started to erode in the early years of the 20th century following outward stretching transportation routes, first railroads in the 19th century to be soon followed by the anticipation of cars (Shane 2011). However, the center still dominated during this period (Ascher 2004, 2007, Shane 2005, 2011). After the Second World War, the expansion started to accelerate seriously along with new design ideals, and enabled by new available energy sources and means of transportation (Ascher 2004, Shane 2011). Shifts from coal to oil, from rail and docks, to cars, trucks and airplanes occurred, engulfing the surrounding villages as a part of the city system. The redistribution of activities following the new rational planning principles eventually resulted in breaking the hegemony of the center and laid the foundations for the multi-nodal city (Shane 2011, Taylor 1998). Colliding interests to enhance the quality of urban environment and accessibility resulted in the ideals tangibly perceived, for example, in the utopia of the Broadacre city (Shane 2011, Wright 1938).

Consequently, the scale of design grew again, along with the changing scope. The quest for overall control remained in a rational technocratic sense, and even increased; cities were considered to require new methods for manipulating, measuring, optimizing, and engineering their spatial structure in a more efficient manner (Shane 2011, Batty and Marshall 2009). In planning, control was sought by implying rational hierarchical approaches such as scientific

⁸ Physicalism: The doctrine that the real world consists simply of the physical world (Oxford Dictionaries).

planning embracing many quantitative methods including location theory, spatial analyses, and large scale aggregate models; and by management, within which the systems theories⁹ gained ground (Batty and Marshall 2009, Portugali 1999, McLoughlin 1969).

Regarding the understanding of urban system, these approaches provided the remarkably promising new concepts. Cities were considered as *systems*¹⁰ - entities consisting of parts working together, forming a complex whole, operating as a mechanism or an interconnected network. Furthermore, these systems were dynamic and interacting, affecting each other's dynamics. The systems presumably responded dynamically through certain feedback loops, also providing means for steering them. Instead of physical malleable entities, cities were basically seen as dynamic, complex systems – albeit overestimating their simplicity. Although systems thinking - especially its cybernetic branch - made extensive progress compared to prior physicalism, understanding of the labile, transient nature of the urban systems and emergent phenomena across the scales was still limited (Capra 1996, Batty and Marshall 2009, Portugali 1999). Similarly to the approaches implying physicalism, all these systemic views aimed at returning the cities to an imaginary equilibrium state to which they “naturally” belong. Along with the systems view and rational planning, the search for the one and only way to build a good society and a city continued (Batty and Marshall 2009), with implied values emphasizing non-urban aesthetics, a highly ordered view of urban structure which appeared as zoning and orderly hierarchy of the parts, and consensus of common interests (Taylor 1998).

Non-spatial city – the planning of processes

At the turn of the 1970s the critique against rational planning started to emerge from many perspectives. First, emphases on the planning process ignoring implementation (Taylor 1998) and secondly, ignoring of political economy, market forces steering the urban development, and social structures called for attention to the participator collaboration (Taylor 1998, Portugali 1999). Thirdly, humanistic and cognitive views emphasizing the individual experience and the quality of the space of the city emerged, qualitative as a response to allegedly inhuman positivist quantitative approaches in planning and geography (Portugali 1999). In addition, both rational or strictly incremental planning was criticized, and new

⁹ Revolutionary in systems theories was the understanding of cities as interrelated and dynamic systems, and rejecting the end-state plan.

¹⁰ System: an entity consisting of parts working together, forming a (complex) whole operating as a mechanism or an interconnected network.

approaches proposed, for example by Etzioni (1967)¹¹. In short, the focus shifted towards the complexity and diversity of urban social, economic and cultural processes behind the corporeal city. In addition, new approaches in planning and geography emerged, greatly concerned about social structures, underlying forces or the lived space, somewhat abandoning the spatial, visual-morphological aspects of the city, and hence lacking the tools for its management (Batty and Marshall 2009, Portugali 1999). However, the communicative approach which Taylor (1998) proposes to have emerged from the implementation critique succeeded in building a credible discipline, which has even been considered to have become a dominant paradigm in planning by the turn of the 21st century (Taylor 1998, Innes 2010). Yet the communicative planning has also been criticized for doing little to the actual top-down rational paradigm, and only adding a participatory layer to it, remaining incapable of responding to many bottom-up emerging processes in the city beyond issues related to self-governance (Portugali 2012, Rauws 2016). This differentiation is not a minor detail since the common interpretation of self-organization in social sciences as a form of building conscious, deliberate self-governance in human communities has totally different implications compared to self-organization in complexity theories regarding urban planning and governance. Here I contemplate the latter, implying that the emergent outcomes of the urban processes are intrinsically unpredictable and fairly uncontrollable, due to the incomplete knowledge of each actor (Batty 2007).

Planning of city fragments

By the end of the 1970s' economic debris caused pressure to re-evaluate the mixed economy of many Western states, blaming overly burgeoning public services for economic problems and calling for a liberalist economic policy. Economic performance and freedom of the markets became one of the crucial factors in the viability of cities and societies (Taylor 1998). This gave rise to new requirements for the planning praxis, and it was considered that the role of the planner had to be re-evaluated from the perspective of free markets. According to this *zeitgeist*, planning should not have hindered the markets as it was claimed to have done, but instead it should have enabled and generated their operation (Batty and Marshall 2009, Taylor 1998). Transition to a post-Fordist production mode caused enormous changes, such as globalized market and requirement of continuous growth, and in the wake followed a (sometimes brutal)

¹¹ Etzioni (1967) proposed a procedure he called Mixed Scanning to resolve this issue. Mixed scanning is a hierarchically structured method, combining top-down decision-making with a focus on fundamental (societal) issues and incremental mode of action from bottom up, implying feedback between the two. It implies constant revision and evaluation of plans and implementation, and, in spite of the allegedly overly stable structure of the original model, provides interesting viewpoint on planning which has much in common with the so-called adaptive planning approaches in ecology discussed in section 4.

competition of regions (Ascher 2004, Castells 2011). Instead of municipal planning officials, the key players in the game were now the representatives of free markets. In this respect the planner had no choice but to negotiate (or even bargain), keeping in mind the common good – the role which again promoted the participatory/negotiation paradigm in planning (Taylor 1998). These ideals emerged from the praxis, and along with the critique of not being concerned of substantial issues (Taylor 1998). Simultaneously, approaches with a problem centered attitude emerged - these projects, for example, concerned ecology, social equality, participation/democracy, or esthetics of the environment (Shane 2011). Grand theories were abandoned for a more fragmented and diverse view of city planning (Taylor 1998).

From the perspective of the physical city, the design of the fragments of urban structure became a trend. It had to be admitted that it was impossible to completely control the city by a masterplan (Shane 2011). However, the principles of top-down control were not abandoned, but downscaled to the level of urban fragments, either new ones related to global capitalism and often initiated by corporations aiming at developing large-scale urban patches¹², or existing districts, arising, for example, from emerging civic movements for built heritage (Jacobs 1961, Shane 2011, Taylor 1998). It is noteworthy that a remarkable share of these fragments resulted from zoning principles prevalent in the prior rational planning mode, located along the traffic network of the expanding metropolis. Those were the patches of megamalls, sprawling suburbs, office parks, and industrial sites, all connected by highways. The resulting urbanity was a bricolage¹³ on a small scale, a top-down metropolis-model applied in a variety of patches, in a framework of megalopolis network, with no overall schema. This fragmentation created inescapable challenges of how to connect the patches (Shane 2011), and simultaneously finalized the elementary shredded structure of the Metapolis.

Nevertheless, simultaneously the diversity of the resulting urban archipelago enabled more bottom-up oriented progress of certain fragments, and forms of self-organization. Gradually these modernistic fragments (megastructures or larger specialized zones) started to provide a lot of potential space to be utilized for many self-organizing activities and sometimes heterotopic structures boosting urban renewal (Oswald et al. 2003, Shane 2011, 2005). Similarly, from the economic perspective, certain evolutionary, self-organizing principles of decentralized decision-making of actors were proposed, such as those inspired by Friedrich Hayek (Webster and Lai 2003, Taylor 1998).

¹² Such as the iconic examples of Euralille or Postdammerplatz

¹³ Originally, an art work built of available material

However, although some of the fragments managed to serve the needs of economic and local actors, overall this collage city increasingly eluded attempts to be controlled as a whole, resulting in an “irrational conceit of its own” (Shane 2011 p.249). By the turn of the millennium cities had become enormously complex as regards both their structure and their function. A city had become a shapeless, chaotic chimera¹⁴, obeying its own rules – a surprisingly behaving, dispersed anti-city.

The move forward: a call for new theoretical ground

Metapolis challenges our thinking in many ways, requiring us to abandon the modernistic hierarchical perspective on cities and society. Metapolis cannot be understood or planned using static and (in a reductionist sense) analytical, rational, linear thinking, but instead systemic, holistic, and nonlinear views. To better cope with the unavoidable uncertainty, unpredictability, and constant change in cities, a philosophical leap from linear, self-assertive thinking towards a more integrative perception is required, to see the world as a nested network of networks (Capra 1996). We need to see that all phenomena - human, natural, and even as “artificial” as cities – are dynamically interlinked in myriads of ways and on many levels (Capra 1996, Reed and Harvey 1992, Batty 2008, Novotny et al. 2010). In planning, such a transition requires a profound change of the planners’ mindset, and adopting viewpoints enabling better understanding and guidance of the key Metapolis challenges: continuous nonlinear dynamics implying unpredictable, qualitative transitions resulting in a permanent lack of equilibrium, emergence, and self-organization of the urban system. Overall, despite the ongoing, gradually changing perspective in planning described above, planning systems have still basically retained a top-down orientation. The final step is needed to genuinely embrace the bottom-up processes – a step towards understanding the self-organization of many economic and cultural processes. A well-established urban theoretical framework is required for this.

In recent decades the emergence of so-called complexity sciences of cities (Portugali 1999, 2012, Batty 2004, Batty and Marshall 2009, 2016, de Roo et al. 2012, de Roo and Silva 2010), along with the related theory of the resilience of complex adaptive systems (Hollings 1996, Novotny et al. 2010), provide a fairly generalizable theoretical frame for urban studies and planning, with novel insights into previously unsolvable issues such as uncertainty, trans-scalar pattern formation, and sudden qualitative shifts in society and the city.

¹⁴ An individual, organ, or part consisting of tissues of diverse genetic constitution (Merriam-Webster Dictionary)

2. 'THEORIES OF COMPLEX SYSTEMS' AND 'RESILIENCE THEORY'- AN INTELLECTUAL AND METHODOLOGICAL FRAMEWORK FOR COMPLEXITY PLANNING

Although presented as a novel approach in many applied sciences, complexity in fact has its roots in a long history in the science of systems. Science of systems refers to a set of approaches emerging and established during the 20th century, contemplating somewhat coherent entities consisting of parts related to each other. These approaches introduced revolutionary new attitudes and ideas assisting in understanding the dynamics and non-reducibility of the world. However, this discourse can be considered to be part of an underlying, more profound philosophical issue, namely a question about wholeness and integrated understanding of variety of complex phenomena. Fritjof Capra (1995), interpreting Donna Haraway (1976), suggested that this debate can be considered to date back all the way to the emergence of the critique against the mechanistic, Cartesian world view promoting the analytical study of substance (Capra 1996, Haraway 1976¹⁵). Hence the recent theories of complex systems can be considered as a culmination point of this line, or a web, of thinking, integrating the studies of form(ation) and the substance, process and the matter. As Capra (1995), echoing Haraway (1976), points out, suggesting such holistic views of the Universe emphasize the inseparability of matter and form, the “formation” of matter, the continuous flux of matter through an organism, and that the form is maintained, not static (Capra 1996, Haraway 1976).

BACKGROUND: THE EVOLUTION OF SYSTEMS THINKING

Emerging systems

According to Capra (1995) and Capra and Luisi (2014), as the extreme qualitative leap enabling astonishing progress in philosophy, science, and technology took place starting from the 17th century, the prior Aristotelian holistic views were largely abandoned as mystical unscientific thinking. In the 19th century huge progress in science led to the establishing of the mechanistic, analytical world in all science: a firm reductionist belief that living organisms could be explained by simple physics and chemistry (Capra 1996). The critical voices were

¹⁵ Donna Haraway (1976) suggests that a lot of today's systemic views originate in the thinking of Aristoteles, Goethe, and Kant

few, promoting more holistic views from different perspectives - from fine arts and the Romantic movement in literature (for example Goethe), to philosophy (Leibniz introducing the system of interrelated monads), and Kant (the concept of self-organization), later accompanied by “evolution scholars” Malthus and Darwin and the morphologist Georges Cuvier, to be followed by the 1920s Vitalists (Capra 1996, Batty and Marshall 2009, Capra and Luisi 2014). Gradually these views started to gain more ground at the turn of the 20th century, proposing that reductionism was incapable of reflecting essential aspects of life. A variety of key characteristics of holistic structures, networks, and operations of systems (later structured within systems theories) emerged within organismic biology and a related field, ecology, studying, for example, food cycles and chains in animal communities (Capra 1996, Odum and Barrett 1971). These approaches focused on organization instead of reductive function, promoting thinking of systems, configurations, relations, patterns, communities and networks – unreducible entities. Furthermore, progress in quantum physics paved the way for completely new ways of considering the relationality of reality - in quantum physics the nature of particles was discovered to be dependent on the observer (Kumar 2009). This revolutionary finding introduced the world of interconnections to the hardest of all natural sciences, physics, and questioned the very foundations of the mechanistic world view (Kumar 2009, Capra 1996).

In cities the early ideas of biological metabolism in organisms – with constant flows of energy and matter through the system - were mentioned by the mid-1920s (Park et al. 1925, p.211), and later contemplated as *Metacity* by Janice Pearlman in the 1970s and the Dutch architect office MVRDV in the 1990s, referring to extremely large urban systems (Shane 2011, Maas 1999). Patrick Geddes, drawing on Darwin’s work, applied evolution to cities, emphasizing cooperation instead of harsh survivalism in a surprisingly similar fashion to that of the urban evolutionists of today (Batty and Marshall 2009). However, these views remained in the background for decades in planning and urban studies (Figure 1).

By the 1930’s, a new scientific understanding in terms of connectedness, relationships and contexts emerged from this exploration of living systems. Key characteristics were the shift in attention from the parts to the irreducible whole, arising from the relations between the parts. Essential properties were those of the whole, destroyed if broken down into isolated elements: the reductive analyses the mechanistic science was based on became impossible. The whole was qualitatively different from its parts, stressing the necessity to consider the qualitative transitions between levels of observation. The nature of entities as dynamic webs of relations appeared in progress in network thinking, and implied a new processual character of the system. The structure of the system as a whole is always a result of the underlying processes,

organized in multiple loose hierarchies in nature, such as proposed in early emergentism of Charlie Broad in 1936 (Gustavsson 2014, Capra 1996 p.42).

General Systems Theory

The first structured, theoretical proposals of system characteristics started to emerge in the 1930s, first and foremost as the biologist Ludwig von Bertalanffy aimed at uniting the fairly dispersed, holistic ideas in the air, building a more general, combinatory theory of living systems (Capra 1996). He applied elements from the various approaches, for example adopting and applying older but fast progressing concepts of homeostasis¹⁶ and metabolia, and fields of emerging systems and process thinking. He succeeded in establishing the basics of "the science of systems", which later led to a more sophisticated development of systemic applications and methods such as systems engineering, systems analyses and systems dynamics. The implication was that certain general principles applied to various systems across the scientific fields, and the aim was to build a formal, exact "science of wholeness" (Capra 1996, p. 47) which would replace its perceiving yet vague philosophical precedents. Regarding the evolution of systems thinking and later complexity, major progress in general systems theory was the introduction of the concept of "open system", referring to living organisms not obeying the laws of thermodynamics, implying a continuous flux of matter and energy, and self-regulation later referred as self-organization (Prigogine 1978)¹⁷.

Cybernetics

Simultaneously, distinctive from von Bertalanffy's approach, fairly similar work related to the study of holistic entities was carried out by a cross-disciplinary group of scientists combining systemic ideas from control theory, communication, and engineering, which became known as *cybernetics*. Driven by militaristic purposes, the focus was on the study of closed loops and nets for developing self-regulating (similar to homeostasis in organisms) machines, with further attention to patterns of organization, aiming at understanding the general organization of animals, machines and a full description of life including, for example, social systems (Capra 1996). The major achievements of cybernetics did not renew the mechanistic models of living systems (comparison of machine and organisms), yet they were based on a totally new

¹⁶ Homeostasis: a relatively stable state of equilibrium or a tendency toward such a state between the different but interdependent elements or groups of elements of an organism, population, or group. (Merriam Webster Dictionary)

¹⁷ von Bertalanffy is widely credited with the creation of the general systems theory, but it has been pointed out that strikingly similar ideas were published by the politically suppressed scientist Bogdanov in 1912 in Russia by the name "tektology", almost unknown until very recently (Capra 1996).

systemic attitude. A central, revolutionary concept that had a huge impact on complexity thinking, was the concept of *feedback* as a mechanism in which initial cause (*input*) from the first link affects next element in a loop so that finally the last one feeds back to the first (*output*) - "Control of the machine not based on its expected but its actual performance" (Heims 1991, p.19). The novelty was the idea of recursion – the future state of the system depended on the preceding one, not an objective, absolute position¹⁸.

By the 1970s cybernetics had made many scientific breakthroughs in studies of open living systems such as brain research and cognitive science. However, it was considered that a certain stagnation occurred as systems sciences (that is, cybernetics, systems engineering, and systems management) were increasingly used to solve practical problems, leading to criticized solutions for example in planning, and alleged to have lost the original innovative thrust (Capra 1996, Batty and Marshal 2009). However, in addition to remarkable conceptual achievements - feedback, openness, and cybernetic models of neural processes - cybernetics succeeded in creating a new way of thinking, language, atmosphere, and concepts, which helped the more recent advances resulting in complexity sciences (Capra 1996). So-called second order cybernetics in particular renewed the system's theoretical thinking, moving from a mechanistic understanding of systems as machines, towards a more relational view.¹⁹

From a complexity perspective, major limitations in earlier systems approaches appear twofold: a limited understanding of the non-equilibrium nature of open systems, and nonlinear trans-scalar processes making it impossible to study such phenomena discretely (Batty 2007). This situation resulted from lacking nonlinear mathematical techniques. It was impossible to describe the pattern formation in open, complex, emergent systems (Capra 1996, p.79). Only in 1970s did new progress in the mathematics of dynamic systems (May 1976, Gleick 2011), and later increased power in computing made the leap possible in the science of systems, and formulation of the diverse set of the theories of complex systems as they are known today (Batty 2007, Capra 1996).

¹⁸ As Capra emphasizes, it was remarkable that now this was made explicit - such implicit mechanisms had been discussed throughout history, for example regarding self-regulating machines and homeostasis by Walter Cannon, or circular causality in social sciences. He points out that many metaphors implicitly embraced recursive cycles (as in thesis/antithesis of Marx of Adam Smith's invisible hand. Feedback represented the generative force for such systems – negative (as in vicious circle) or positive, re-enforcing mechanisms (Capra 1996).

¹⁹ Second order cybernetics provides an interesting intellectual framework for the study of human systems. However, it is here considered that while developed by the same cybernetic scholars – Mead, von Forrester, Bateson and others - it forms basically a later phase of cybernetics rather than a revolutionary novelty (Heylighen and Joslyn 2001), Hence it is considered beyond the scope of this work focusing on the complexity perspective.

FRAME ONE: THEORIES OF COMPLEX SYSTEMS

Building on this foundation, so-called complexity sciences or complexity thinking²⁰ provides a relatively new, yet in many fields already established theoretical ground for a thorough understanding of the unpredictable and dissipative nature of systems in constant flux. Basically, complexity refers to a set of distinct theories – “theories of complex (adaptive) systems” (Holland 1998). Besides the systems thinking tradition, complexity approaches have emerged within various disciplines. These range from mathematical studies of dynamic systems, fractality, and chaos, self-organization in biology and chemistry, further to information theory and scaling in mathematical statistics. Complexity has also been much influenced by many other disciplines like game theory, network theories and modeling, just to mention a few (Allen 2012, Casti 1994, Mitchell 2009). They provide unique perspectives and theories on open systems, all contemplating fairly similar issues related to dissipated decision-making, self-organizing pattern formation, non-linearity, entropy, fractality or scaling. Hence, to be precise, no single “complexity theory” exists, but instead a variety of theories of complex systems, forming a certain general umbrella explaining many previously challenging features of complex open systems. Although theories of complex systems have their roots firmly in natural sciences (Haken 1980, Eigen 1971, Prigogine 1978, Gleick 2011), it has been realized that actually all open complicated systems - for example social systems, ecosystems or cities - appear to follow fairly similar mechanisms and logics. They are complex systems *per se*. Recently they have been applied in many fields beyond these, for example social sciences, geography, economics, psychology and urban dynamics and many more (Casti 1994, Allen 2004, Mitchell 2009, Krugman 1995, Arthur 1994). Complexity thinking provides a promising theoretical frame and methods for better understanding and managing the Metapolis.

Due to this apparent diversity within complexity views, no consensus on a unified definition for complexity sciences exists (Mitchell 2009, Manson 2003), but generally speaking, certain features can be highlighted in the complex systems. The proposed classification below follows Manson (2001, 2003) and each of these theories/models makes certain assumptions about system characteristics such as system components, interaction, equilibrium, change, system boundaries, self-organization, adaptation, and learning (Manson 2003). Furthermore, the approaches are to an extent overlapping. For example, fractals and power laws return mathematically to each other. Their applications in the real world, such as the semi-fractality of trees or rivers, cities or urban dynamics depend heavily on self-organization (Bettencourt

²⁰ "Complexity" refers in the context to a specific characteristics of the system described above, contrary to the everyday concept referring only to complicatedness of something.

2007). Impacts of self-organization/emergence are often nonlinear (Batty 2007), and dynamic states implied in “edge of chaos” behavior implies attractors and phase transitions (Kauffman 1993). Although the following review is not exhaustive it provides a certain general view of types of complexity (see more for example Mitchell 2009).

First, algorithmic complexity contemplates issues related to the difficulty of solving a mathematical problem, or describing the system in information theory (Shannon 1948, Manson 2003). Complexity in the system reflects the simplest algorithm producing a certain behavior, for example in the case of language or remote sensed images, the complexity increases as new types emerge (be it a land use class, or words) (Manson 2003, Shannon 1948). The apparent limitation in a social context is that data may be incorrectly equated with knowledge (Manson 2003). Meaning and human experience lies beyond algorithmic expression. To an extent, Haken and Portugali (2003) elaborated this issue, introducing relative entropy measures as an extension to Shannon's classical information theory (Haken and Portugali 2003), which is applied in a related article in this thesis (Partanen 2015). Most notably, here the process of entropy reducing is explored in a human system – a feature that involves self-organization, and seemingly conflict with the basic principle of the second axiom of thermodynamics due to the openness of the complex system implying contestant flow of energy through the system.

Secondly, deterministic complexity covers approaches and theories studying non-linear and dynamic systems and chaos. Although these may not be applicable to human systems in a straightforward manner, since open systems, such as cities or weather, are not truly chaotic (for example structurally not self-similar *ad infinitum*), they nevertheless share chaotic features. This class of complex systems provides a valuable perspective on the unpredictability of the systems, still accepting their deterministic, ordered nature. Such viewpoints are crucially important for urban studies since a fair share of real world systems are nonlinear (Casti 1995).

Typically, in a nonlinear system output is not directly proportional to input – the relationship is not linear, nor can it be returned to a series of linear equations (Wong 2013). An illustrative example is the iconic population dynamics model of May (1976)²¹, in which a mapping of a simple second degree function appears as several different dynamic states as the growth rate is gradually increased, from periods of two, three, and four, to a state of chaos with only a very limited set of values (ibid). The changes are non-smooth, implying what in mathematical chaos is called bifurcation – the system jumps to another trajectory²², and remains on that attractor

²¹ Also called a logistic map

²² Originally from physics: a path, progression, or line of development

for a while. This progress is deterministic yet unpredictable (Gleick 2011). Consequently, as regards urban dynamics, it is implied that correlation between cause and effect is often surprising, sudden, self-enforcing through feedback, and occurs within a narrow window of opportunity where sensitivity to initial condition is highest (Gleick 2011, Manson 2001). Small local changes may cause major effects across the scales, or have no impact (Manson 2001, Batty 2007). Mathematical fractals, whose real-world variations are frequently used in the study of urbanity (Batty and Longley 1994), are often so-called strange attractors, graphical representations of deterministic chaos²³. Their value lies in that they help studying processes behind the formation across the scales (Manson 2001, Batty 2007, 2008).

The third class of complexity is aggregate complexity, implying that a cumulative effect of dissipated decision-making of many independent, interacting agents gives rise to (seemingly) non-causal, surprising behavior, responding through feed-back loops (Manson 2001, Manson 2003). The aggregate complexity goes beyond mathematical descriptions of systems, and embraces dynamic and more holistic perspective and is thus of more interest for the study of urban systems.

At the core is system definition. On the one hand, this implies relationships between components and components and their environment along with the internal structure of the system. On the other, in focus is the following dynamics in time. System definition is crucial to how its dynamics is interpreted. In the context of cities, the question concerns the relationships between agents in observed economic, ecological, social systems - how they are delineated and which (energy) flows punctuate them. For example, these may regard physical flows, information or energy. These are all relational and depend on the strategic system definitions of the viewer (see Cilliers 2005). As regards aggregate complexity, the system changes its internal structure to respond to external energy flows through self-organization. This is essential for the dynamics of the system. In self-organization, order emerges from local interactions between disordered components without external guidance (Camazine et al. 2003, Prigogine 1978). Typical for such systems is that the order is self-enforced by internal mechanisms or persistent structures. Systems are able to “learn” as regular dynamics strengthen the same set of relationships (Manson 2001, Holland 1992, Haken 1980). The system changes its environment through self-organization to enforce the very same mechanism. This feature is essential in many ecosystems, since the response of the system (that is, the capacity to enforce novel links) to perturbations depends on the available, yet previously perhaps vast, connections, and they

²³ Systems resembling fractals outside mathematics are strictly speaking not fractals, e.g. not self-similar ad infinitum, but semi-fractals, and hence do not have mathematically exactly similar properties.

could be intensified for self-reparation at the time of crises only if they exist. (Manson 2001, Novotny et al. 2010). Self-organization is often nonlinear or emergent, implying that the overall, higher level qualitative outcome of the mechanism is not predictable from the initial state of its components (ibid). Self-organization also builds the evolutionary capacity of the system: a self-organizing system may embrace dissipative structures which are able to form internal order from disordered state after perturbations. A disordered system becomes “enslaved” by the emerging order within it (Manson 2001, Prigogine 1978, Haken 1980). Hence such a system oscillates between ordered, predictable and disordered chaotic states, which enables the emergence of a new, qualitative different order (Portugali 1999, ibid). Furthermore, the concept of *self-organizing criticality* describes complex open systems that have a critical point (that is, close to phase transition) as an attractor: they gravitate to remain in this state for the higher generative capacity (Bak et al. 1987, Kauffman 1993)²⁴. This is the source of complexity in many natural systems, and typical of many ecosystems with high adaptive capacity.

The key issues, especially in aggregate complexity is agents' interaction causing trans-scalar/emergent self-organization and the non-linearity of this process. This makes it challenging to study these systems spatially. Several self-organization measurements exist, some of which will be scrutinized in Chapter 5 (evaluative methods). However, micro-simulation models, for example cellular automata (CA) used as a part of this work (Partanen 2016A), provides a method for explicit study of higher level impact of neighborhood actor interaction. Other relevant micro-simulation methods, such as agent based or neural network models are beyond the scope of this study.

Cellular automaton as a method of studying self-organization

Basically, cellular automaton is a classical method for studying non-linear emergent features in self-organizing systems, and their capacity for self-reproduction, the emergence of higher-level generative patterns, and universal calculation. Cellular automata (CA) are simple, discrete representations of spatial systems. They operate within a lattice based on simple rules defining the state of the cell (*on/off*) according to its previous state, and the state of its adjacent neighbors. Although very simple, CA can produce various dynamic states²⁵ and complicated

²⁴ Dynamic states of a system following Langton (1994) and Wolfram (1984) - static, periodic, chaotic, and complex, referring to the changing periodic and chaotic states described above – are elaborated in detail in Chapters 3 and 4, and in Partanen (2016A).

²⁵ That is, static, chaotic, periodic, and complex, (Langton 1990, Wolfram 1984))

spatial patterns. Artificial CA enables observing self-organizing patterns and dynamics in the system and the effects of simple interactive rules on general behavior.

CA were originally developed by Stanislav Ulan and John von Neumann in the 1940s using the Turing machine layout for the lattice of cells. This research sought a self-replicating machine, which was discovered in the early 1970s as the so-called Game of Life, proving the capability of a simple artificial system to produce higher-level self-replicating order. In the 1980s Stephen Wolfram managed to demonstrate with CA how local interactions among components generate global changes in space and time, succeeding in producing different dynamic states with this apparatus, resembling Langton's and Kauffman's ideas of complexity as self-organizing criticality or an edge-of-chaos state (Langton 1990, Kauffman 1993, Wolfram 1983, Wolfram 1994, Bak 1990).

Wolfram's work laid the foundations for a discrete theory of CA, and the simulations were soon applied in natural sciences and mathematics, and later in spatial sciences (Santé et al. 2010, Batty 2007). Since the 1990s two dimensional CA has become an established tool in urban modeling (e.g. Allen 2012, Santé et al. 2010, Batty 2007); it can simulate a spatial city in a simplistic manner, making it easy to observe the dependencies between local rules and global outcomes. Urban CA models are often used as educational tools for learning from patterns and dynamics, but they can be also used as policy testing tools or even for short-term forecasting, considering the difficulties of prediction of nonlinear systems. Urban applications of CA are frequently somewhat relaxed using e.g. a combination of CA and free agents, neighborhood configurations, more complex rules or multiple cell states, irregular tessellations or various (growth) constraints (Santé et al. 2010). Modifications may help to solve the limitations typical of CA, for example, isolation or lack of feedback from a higher level, and improve the resemblance with the real world. It is, however, necessary to keep the modifications reasonable, to maintain the basic clarity and readability of CA.

Dynamic states, scaling, and fractals: a brief overview

Scaling, fractals, and dynamic states are essential theoretical concepts in complexity sciences, among others. Here I selected them for a closer look since they provide fairly established methods for complex science for cities, and since scaling and dynamic states are applied in this work (Partanen 2015 and Partanen 2016A respectively). The concept is elaborated in Chapter 4 (evaluative methods) in the context of cities and planning.

Dynamic states and entropy

The dynamic state of the system re-emerges from the work of Wolfram, Langton and others studying mostly artificial computational systems, but applying the findings in natural computing as well (Langton 1990). According to this approach, a dynamic system can remain fairly resiliently on a highly organized, predictable (periodic) level, disordered, mathematically chaotic state, or a balance between the two. The transition from one state to another is not smooth, but implies a phase transition, a jump from one to another, manifesting a qualitative change in the system.

From a computational, evolutionary perspective this transition zone is important: computation requires capacity for the storage and transmission of information. Information storage involves lowering entropy, while transmission involves raising entropy (Langton 1990). For maximal computing capacity which would enable the system's evolution, the system must be both, and this optimal state is located near the transition (Langton 1990, Cruthfield and Young 1988). Actually many complex real world systems vacillate between chaos and order (Kaufmann 1993, Mitchell 2009, Levin 1998).

The thermodynamic perspective helps to understand some of the reasons for this quest, and provides measurements to evaluate the state of the system. Thermodynamics is a field studying basically systems as regards the relationship between temperature and energy, with many applications across disciplines.

Entropy is a central concept in thermodynamics, and also a measurement of the system state (Langton 1990). Since the aim here is to evaluate the complexity and especially the level of self-organization in CAS as regards self-organization, there appears to be a paradox. Basically, according to the second law of thermodynamics, entropy increases in the systems over time. This is in contrast to the basic understanding of self-organization, which requires entropy to decrease.

In the classical work of Prigogine (1978) dissipative, evolutionary systems form temporary self-organizing structures. Extending Prigogine's approach to non-equilibrium systems, Schneider and Kay (1994) emphasize the search among open, dissipative structures to balance the differences in gradients (temperature, energy or material) by self-organizing structures

(Schneider and Kay 1994). The structures, for example in the case of convection, balance the gradient very efficiently. They emerge at a certain transition point as the gradient increases, and disappear as the system becomes overly chaotic. The key is the trans-scalarity of the system (considering thermodynamics observing dissipation of the whole, and statistical mechanisms studying the fluctuation of the parts (Kugler et al. 1987)). While overall entropy may increase, locally in these self-organizing structures it temporarily decreases dramatically (Langton 1990).

Furthermore, according to Kugler et al. (1987), the system is bound to this trans-scalar interaction: it cannot maintain a steady state on both levels simultaneously. While systems remain on the edge through gradient minimization, they simultaneously stay in this intertwined circular process, balancing on the dynamic state with competition between higher level order and fluctuation (Kugler et al. 1987). The range of the generative state is typically very narrow, indicating sensitivity to initial conditions (Langton 1990, Crutchfield and Young 1990).

Scaling and Fractals

Scaling or power laws describe systems with certain nonlinear relations between their components. These may be spatial relations or associated with other numerical/temporal attributes such as sizes or frequencies (Pumain 2004). Scaling implies that systems organize without overall guidance, with the emerging order exhibiting a certain regularity – often of an exponential type - as the components, subsystems or their features are ranked from largest to smallest²⁶. Presumably, certain underlying mechanism(s) are at work making the system follow the perceived trajectory. Scaling laws are scale invariant: a property adapts throughout scales (Kello et al., 2010, p.224) similarly to fractals they reflect regularities and dependencies within the system beyond scales in a dynamic manner.

Fractals are representations of chaotic systems, but they are also very common features in nature (unlike, for example, normal distributions.) Hills, trees, rivers and coastlines have fractal characteristics, similarly to cities (Batty and Longley 1994, Liebovitch and Scheurle 2000). Building on the work of Gaston Julia, Felix Hausdorff and Waław Sierpiński (Gleick 2011) among others, fractal mathematics was developed by Benoit Mandelbrot starting from 1950s', and expanded due to computerization in 1970s' (Gleick 2011, Batty and Longley 1994).

²⁶ Mathematically, the system follows the rule $F(x) \propto x^\alpha$, $\alpha \neq 0$

Fractals are intertwined with power laws: systems “producing” fractals entail scaling. Order in both emerge from the same principle of organization remaining the relation between the few large and multiple small entities across the scales. Generally, a power law can be perceived as a plot of a fractal system on a double-logarithmic scale (Liebovitch and Scheurle 2000). In fractal systems, this relationship is often called the fractal dimension, and its value can also be returned to the slope in any power law plot. Furthermore, while fractality and scaling laws emerge as a result of self-organization across the scales, they suggest that the systems may be near the edge-of-chaos or phase transition where its generative capacity is highest. Hence, if the system is scaling/fractal, it indicates that certain self-organizing mechanisms are at work, holding the system near instabilities, that is, in a complex state (Kello et al., 2010, Kauffman 1992).

FRAME TWO: RESILIENCE – ANOTHER READING OF COMPLEX ADAPTIVE SYSTEMS (CAS)

While complexity provides a wide variety of viewpoints to tackle Metapolis, another more coherent frame might be necessary for building a robust²⁷ frame for planning. Resilience theory, originally from ecology and explicitly contemplating complex adaptive systems, provides an applicable mental model describing the overall behavior of the system while embracing essential complexity features. Resilience theory developed from late 1960s’ simultaneously with so-called complexity theories, contemplating similar, theoretical issues in socio-ecological systems. Resilience relates to the problems of the understanding and management of systems, inherently co-evolving, dynamic and unpredictable, with multiple equilibria and inbuilt, unavoidable phase transitions; irreversible dynamics and self-organization – that is, of complex adaptive systems *per se* (Levin 1998, Novotny et al. 2010). Most importantly, resilience theory emphasizes the exploration of the complex systems’ capacity, on the one hand, to absorb perturbations and stay on a dynamically steady attractor (analogical to dynamic states elaborated by Longley (1994) and Wolfram (1984)), and on the other, the capability of the system to reorganize itself after the qualitative transitions the system inevitably faces. Briefly, resilience reflects the system’s capacity for self-organization in a

²⁷ Robustness refers to the features of a system which make it capable of performing without failure under a wide range of conditions; such a system is firm yet adaptive and resilient, and tolerates certain levels of uncertainty (Merriam-Webster Dictionary).

similar manner to approaches in aggregate complexity - that is, balancing on the fine line between order and disorder.

Today, resilience theory explicitly contemplates complex adaptive systems and implies analogical features. These include a constant flow of energy through the system; open systems in constant flux, punctuated with sudden, qualitative, and irreversible transitions triggered by unpredictable, rare events at vulnerable times; non-linearity and trans-scalarity; large and slow variables (system's stable state) control the small and fast ones with feedback regressed from time to time; and lack of equilibria. The system can be far from a state of equilibrium, have multiple or no equilibrium. Systems constantly balance between stabilizing (productive, cyclical, predictable - static states) and destabilizing phases (producing diversity, resilience, opportunity - chaotic, unpredictable states), sitting on a critical state with excessive generative opportunities, evolving through extinctions and emergence of new "species" (Kauffman 1993, Bak 1996, Pickett et al. 2004).

What makes resilience theory eminently applicable to spatial planning is that, besides providing coherent extensive concepts and mental models helping to better understand and encourage self-organization, it provides an applicable framework for managing maneuvers for planning in CAS²⁸ .

Ecosystems and cities

As resilience is applied concerning human systems, it is usually firmly coupled with ecological processes (often affected by human actions) and rightfully so due to their apparent role in the survival of our species. However, since resilience theory explicitly contemplates CAS and is widely applied in human (social, urban) systems, it is considered applicable to the study of urban systems focusing on economic and cultural processes with certain conditions - reflecting the view of "creative destruction"²⁹ in economics (Batty 2016), and various studies concerning the life cycles of firms and enterprises in business management (Novotny et al. 2010). These conditions are related to the use of the definition of the concept of a related notion, ecosystem.

²⁸ Contemplating the correlation of CAS and resilience, it is necessary to point out that actually the question is about so-called *ecosystem or evolutionary resilience* embracing ideas of constant flux, emergence, and non-equilibrium. *Engineering resilience*, in turn, describes linear systems near equilibrium, emphasizes the system's ability to absorb perturbation, and implies continuous production and controllability. In this work resilience refers explicitly to *ecosystem resilience* (Holling 1996).

²⁹ As Batty (2016) discusses, the creative destruction is a term originally introduced by the economist Joseph Schumpeter, and is applied today e.g. in business management, ecology, and urban studies. Creative destruction implies that the progress of the system eventually leads to a collapse, which enables a new beginning for the actors from bottom up.

Ecosystems

The theories of resilience and CAS emphasize the relational nature of systems components and its linkages between agents, subsystems, and their environment (Pickett et al. 2004). This view is not only holistic - implying roles of components in the operational whole, but also provides a generally wider understanding of dynamic multiple nested and interlinked systems of systems and their environment, ecosystem view (Capra 1996). Hence the concept receives a wider connotation: in addition to the components of natural systems, it embraces human systems (social, economic, and cultural) as well. Consequently, the concept of ecosystem provides a new reading of a city in two respects. On the one hand, cities *are* ecosystems: they are an intrinsic part of networks of nested networks of human-natural systems (Capra 1996, Reed and Harvey 1992, Levin 1998, Pickett et al. 2004). On the other, urban systems are metaphorically similar to the “traditional” ecosystems in Nature (Levin 1998). Ecosystems are, first, by definition, assemblages of actors interacting with each other and with their physical environment within a specified area (Levin 1998, Odum and Barrett 1971). Secondly, they are characterized by historical dependency, nonlinear dynamics, threshold effects, multiple basins of attractors and limited predictability – that is, fundamental features of CAS (Folke et al. 2004).

Metaphors can transfer an idea or an approach from one field to another, thus assisting in mental model building and extending our renewed comprehension of reality (Pickett et al. 2004). Metaphors from Nature stressing process dynamics (not only the form) are not completely new in the history of urban planning, forming a parallel sidetrack deviating from all the dominant forms of the top down paradigm. The perspectives of, for example, Patrick Geddes, Jane Jacobs, and Christopher Alexander, and since the 1980s the mounting scientific interest in urban complexity (see more, for example, in Batty and Marshall 2009, Allen 2012, Portugali 1999, Jacobs 1992 (1961), Alexander et al. (1977)) emphasized the inherent complexity and evolution of cities, processes similar to “natural” systems despite operating within a human artefact. Within the urban discourse the ecological metaphors have been established by the 2010s’, promoting cities as dynamic self-organizing systems, recursion of processes, constant change, and self-regulatory nature of urban processes.

It is essential that these approaches heavily stress the similarities between the systems and processes in nature and cities, among them urban evolution, metabolia, self-organization, and networks (Oswald et al. 2003, Portugali 1999, Batty and Longley 1994, Ascher 2004). This means that in those mental models the formalistic similarities are not reflected, but the aim is to

explore similar analogical or functional features in natural and human ecosystems. The central mechanism defining the future spatial form of the system in these approaches is the circular function/form or process/pattern loop, a fairly well established concept in ecology implying an inherent and recursive relationship between actions, processes or dynamics and the resulting structures, patterns and forms in the dynamic complex adaptive systems. Actor-born processes produce certain spatial manifestations, but as the actor produces corporeal structure or form, it soon starts to restrain or define the actor's future behavior, producing certain inertia and stabilize the process, setting it on a certain trajectory (Pickett et al. 2004, Batty and Marshall 2009, Levin 1998), similar to dissipative or self-organizing structures.

Echoing ecosystem resilience thinking Batty and Marshall (2009, 2016) have proposed that the strength of complexity thinking is its ability to provide tools for understanding and managing this continuous two-fold process. This is expressly true since self-organization, the basic mechanism responsible for order in many complex systems, is the interaction between the structure and the process in time *per se* (Gunderson 2000, p. 430). Hence understanding in urban studies and planning can be widened by adopting metaphorical concepts like ecosystem or ecosystem (evolutionary) resilience from ecology. Furthermore, this conceptual shift opens up new viewpoints and perhaps seminal readings of the city, processes behind their formation and the spatial characteristics.

Adaptive cycle – self-organizing criticality revisited

Resilience provides powerful models helping to understand the overall dynamics of complex systems as regards especially their cyclical, nonlinear nature. The groundbreaking, much applied concept introduced by Crawford S. Holling (1973, 1996), *adaptive cycle*, delves into some of the most essential characteristics related to CAS: inevitable (necessary) transitions and flexible, appropriate precautions for them. It can be considered as another more advanced reading of the concept of “complex dynamic state”, stressing the evolutionary aspects of the theory and the autonomous renewal of the system through self-organization. The strength of this model is that it helps essentially in expanding the rather general (or in physics, extremely particular) aspects of shifting dynamic states in complexity thinking towards proposing actual maneuvers and management of the systems to promote self-organization (Walker and Salt 2012).

Generally, the adaptive cycle describes the dynamics of human/natural CAS as a cyclical process, experiencing certain phases of progress from establishing, decay, collapse, and reorganization with slight variations in the order. Eventually the system reverts to the initial

state to start over again, evolving qualitatively in time. Although this principle was conceptualized by Holling (1973), implying the idea of the “creative destruction”, Capra (1995) points out that similar ideas of intrinsic, repeated qualitative renewals of systems through collapse have also been discussed by Castells and Harvey building on Marx (Castells 2011). The discourse has recently been established in the field of evolutionary economic theory intertwined with complexity thinking (Boschma and Frenken 2011, Fujita 2007). Conceptually, all these contemplate disturbances that periodically disrupt the stability of the system, and release resources for innovation and reorganization. For example, theories of business cycles, developing production modes, and cultural evolution are examples *par excellence* of the creative destruction.

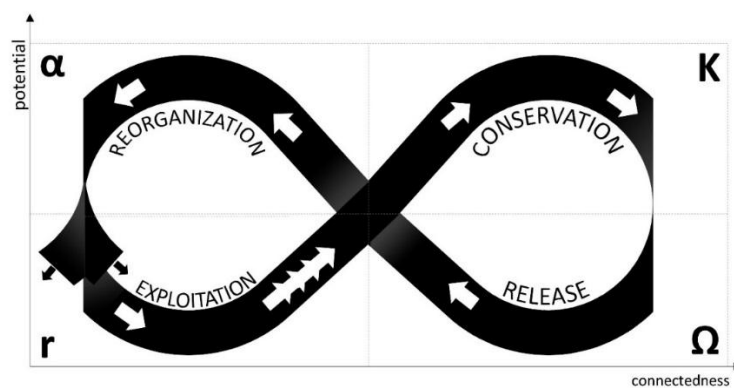


Figure 2. Adaptive cycle.

At the beginning of an adaptive cycle (Figure 2), a two-fold *fore loop* of growth and stabilization occurs. In the rapid growth phase actors tend to seek and exploit new opportunities and available resources and niches in the system whose components are typically weakly regulated. In (urban) economic systems these actors may be innovators and small entrepreneurs seizing upon opportunity. The rapid growth phase is associated with the emergence of new “species”: firms, societies, institutions - even nations. Next, as the energy is stored in the system, material accumulates and the system becomes more and more rigid, losing its flexibility. The competitive edge moves from the flexible utilization of opportunities to specialists reducing the impact of variability, reinforcing by investments the existing regime, networks and order – enslaving the prior system of many competing orders. In this *conservation phase* (*K*) the system is extremely stable - but only within a certain range of conditions, and sensitive to either shocks from the environment or turbulence emerging within the system.

It is essential that the system – a city, a company, an ecosystem - cannot stay in this conservation phase forever. Unless they are guided to a new growth phase or to reorganization (with minimal harm), they will eventually collapse, possibly causing economic, social or other crises. The release may be fast, and the longer the K phase is, the smaller the shock needed to end it. Connections break and human, social, and capital resources leak out of the system for a while in this chaotic phase opening all options – at this stage even the smallest actors can shape the future, new “species”, may find new niches in the absence of the strongest big competitors. The system comes undone and open to innovations, inventions, and experimentation until it starts to reorganize, producing again many competing orders and so on. This *back loop* or reorganization loop might be destructive for a short time and feared for its inherent uncertainty and unpredictability but it also opens up new possibilities, and provides a window of opportunity for the system to change the trajectory – to settle into a new equilibrium for a while. Certainly the new state will be different, but it is impossible to know in what sense. This inherent uncertainty is the key challenge in guiding and managing of CAS (Holling 1973, 1996, Walker and Salt 2012). What was described here briefly is the “classical” adaptive cycle. However, not all systems necessarily follow this model. The system cannot go from the release phase straight to the conservation phase, but all other moves are possible: from K to release phase, or to new growth with minor perturbation.

In the context of system management, it is noteworthy is that the K phase is very often mistakenly assumed to be the systems’ default state – a seemingly linear, relatively long lasting phase benefitting from efficiency, optimization, and specialization, causing a misconception of systems being inherently linear, and on/close to a single equilibrium. The interest in this phase is understandable since indeed this so-called fore loop or development loop (organization and conservation) is essential for capital accumulation and the increase of human well-being. In addition, the fore loop is profoundly slower than the back loop (the releasing phase), and most of the systems are currently in that phase. The back loop, in turn, is often ignored in management, neglecting the fact that as the system becomes more mature, different ways of performing certain tasks disappear and the growth slows down, eventually becoming increasingly dependent on existing structures and processes, and hence increasingly vulnerable to disturbance. Hence in management, the aim of managing is usually to avoid a late K to facilitate the transition (Walker and Salt 2012).

What are then the consequences of understanding this cyclical, evolving nature of CAS in the context of self-organizing cities and their planning? The key lies in the mechanisms of how the system manages to stay on a certain (predictable) trajectory for the time being, and how the

system builds new (coming) dominant order - that is, remains generative, complex or “on the edge of chaos” (Kauffman 1993, Holland 1992) – essential questions in this thesis. This two-fold resilience appears as, first, the *adaptability* of the system, indicating the agents’ capacity to change responses to changing drivers and processes, building certain inertia and maintaining the system on its trajectory, “the steady state” (Folke et al. 2004, Haken 1980, Walker et al. 2004). Secondly, it manifests as the *transformability* of the system - its continuous capacity to cross thresholds entering new steady states as one of the potential orders “enslaves” several competing ones in the chaotic phase (Folke et al. 2004, Haken 1980, Walker et al. 2004). Both adaptability and transformability actually reflect the system’s ability to self-organize across scales.

Consequently, we can say that allowing, guiding, and supporting positive self-organizing mechanisms in CAS, for example cities, strengthens their ability to build wealth and well-being in the conservation phase on the one hand, and to recover, reorganize, and create new innovations in the reorganization phase after the (inevitable) release of resources on the other. However, we still know very little about these generative spatial-functional mechanisms in cities, which is one of the main motivations of the research here. Note that it is necessary to focus on multiple sources of capital and skills: there is no single mechanism responsible for resilient progress overall, but an interlinked variety of them. Strategies adding renewal capacity and “requisite variety of purposes” are required (Gunderson 2000 p.436) – to remain in the state in which dynamics of myriads of variables are derived to a single key variable holding the system dynamically stable (Gao et al. 2015). Hence, to learn and channel self-organization, it is necessary to explore variety of mechanisms with relevant methods recognizing complexity, which is the core of the appended articles (Partanen 2015, Partanen and Joutsiniemi 2015, Partanen 2016A, Partanen 2016B).

Moving from sheer metaphors towards a more practical level, another question emerges – echoing Carpenter and colleagues asking in the title of their paper “resilience of what to what?” we want to increase (Carpenter et al. 2001) – resilience implying the capacity to self-organize. As Carpenter et al. (2001) suggest, undoubtedly it is necessary to study specific mechanisms for supporting the systems adaptability, that is, increase *specified resilience* assisting the inertia of the system (such a case is contemplated, for example, in the related article Partanen and Joutsiniemi 2015). However, due to the inherent uncertainty of the system, building *general resilience*, that is, enforcing mechanisms holding the system complex, is as important (see for example articles Partanen 2015 and Partanen 2016A) to respond to changes or crises of a new, unknown kind (Carpenter et al. 2001, Folke et al. 2010).

HOW TO KEEP THE SYSTEM COMPLEX: THE DO'S AND THE DON'T'S

In the light of complexity and resilience theories, enhancing the operation of many essential processes in cities it is more about encouraging their preferable dynamics and mechanisms instead of producing new ones. The literature and empirical research regarding resilient systems in evolutionary economics and ecology, along with complexity sciences, and empirical work carried out within the framework of this thesis and presented in the appended articles, supports the view that it is possible to adopt particular strategies for encouraging - or discouraging - resilience (and self-organization) in complex systems (see for example Walker and Salt 2012, Levin 1998, Novotny et al. 2010, Shai et al. 2014, Holling 1996, Boschma and Frenken 2010, Boschma 2015; Partanen 2015, Partanen 2016, Kuusela and Partanen 2016). Next, based on this prior work, I propose a two-fold synthesis of appropriate means for the treatment of resilience, along with maneuvers to be preferably avoided for successful self-organization. Such means would consist of those concerning the system's internal structure for enhancing its resilience, and means of providing "safety valves" for channeling pressure emerging within the system.

How to build resilience

1. Enhancing self-organizing capacity

To retain resilience in a general sense, the adaptability and transformability of the system must be supported. Since both are based largely on self-organization, they cannot be forced from outside, but need to emerge within the system. Particularly, I consider three factors to enhance them (Walker and Salt 2012, Levin 1998, Novotny et al. 2010): *Modularity, functional and response diversity and tight feedback*.

First of all, modularity refers to weakly linked small, tight units. Such a structure is typical of complex, self-organizing networks (Shai et al. 2014). Complex networks are beyond the scope of this study. However, the modularity is implicit: the self-organizing case areas are by default fairly autonomous *enclaves*, certain isolated yet porous pockets in the city structure, with internal linkages and lacking strong hierarchical control from above. These conditions are further elaborated in the appended articles (Partanen 2015, Partanen and Joutsiniemi 2015, Partanen 2016A, Partanen 2016B).

Secondly, functional and response diversity is essential, both implying functional redundancy. Functional diversity refers generally to a situation in which a lot of “species” occupy the system, (e.g. variety of economic and cultural actors (Partanen 2015, Walker and Salt 2012, Novotny et al. 2010). It clearly correlates with the viability of the city or region. For example, technologically related industries are more likely to emerge from a wider variety of existing industries, or from interaction among these (Boschma 2015). Response diversity refers to functionally similar actors who respond to changes differently (e.g. responses of different types of urban actors appear as adaption to production modes Partanen 2015) (Walker and Salt 2015, Novotny et al. 2010). The response diversity of the CAS is analogical to risk insurance or portfolio investment in financial markets, and critical to the general resilience – keeping the options open (Walker and Salt 2012). A lack of diversity may limit options and reduce the capacity to respond to disturbances. Increasing efficiency (optimization) inevitably leads to a reduction in diversity (Walker 2012, p.121).

Holling (1996) proposes that we could adopt an idea of a *soft redundancy* typical of many complicated natural systems. It reflects the overlapping operation of species in joint action in ecosystems, which do not necessarily aim at optimal performance overall as regards conserving resources - it is far from optimal. Instead, the risks and benefits are dispersed throughout the system to generally achieve a better consistency in the performance of the whole, although fluctuations within single species may occur. Self-regulation of variability is promoted by functional diversity enhancing the robustness of the resilient process by operating where the opportunities are the greatest – near the edge of instabilities, generating qualitative novelty and enhancing adaptive capacity (Kauffmann 1993), with the greatest capacity for self-organization of information. Hence I consider that in the city, the survival and progress of cities could be supported by encouraging diversity of agents and their nested networks along with this “complex” dynamic state since, echoing Holling (1996) and Kauffman (1993, 1994), appropriate guidance in the systems’ internal dynamics at the edge of instabilities generates the most preferable outcomes.

Thirdly, tight feedback from the system level back to the actors is required, also typical of complex networks, implying short path lengths and tight clusters. For example, tight geographical linkages and proximity of similar firms typically play a key role in the early phase of their organization (Boschma and Frenken 2010). The constant emergence of such structures in time may refer to the area’s capacity for renewal (Partanen 2015, Partanen and Joutsiniemi 2015), simultaneously implying less top-down control (Kuusela and Partanen 2016).

Excising institutions and local social, cultural and economic networks are important in the formation and operation of complex nets (Partanen 2016B). Centralized governance and globalization weakens it, as feedback is delayed in these extended systems and causality between factors and phenomenon is obscured – the timely higher scale examples could be the rise of global temperature or extensive population growth. Supporting and even recognizing these factors in planning is not straightforward; it is plausible that totally new insights into how the urban systems are guided and managed³⁰ are needed – the current perspective is rather narrow and often concentrates in optimization.

2. *Building safety valves for urban processes – heterotopias and the scale*

Another aspect of how to maintain the resilient trajectory in CAS related to the scale can be derived from work of the philosopher Michel Foucault³¹ (1997), interpreted by David Graham Shane (2011). This approach, echoing traditional, primitive knowledge of ecosystems' operations has also been recognized by resilience scholars (Gunderson 2000, Folke and Berkes 1995). Albeit focusing on spatially delineated area or place, this mechanism operates through multiple scales (Shane 2005). According to theories contemplating resilience and complex systems, while cities are in a temporary equilibrium state, their dynamics is fairly predictable. However, this equilibrium is in practice an “autonomously managed” though specific mechanism: from time to time certain anomalous enclaves emerge within the city structure, with rules differing from those prevailing in the city (Portugali 1999, Shane 2005). These temporary structures channel and order the turbulence occasionally emerging within the system (in cities, this may be related, for example, to social tension or economic pressure). They are of importance though for the sake of the whole. The logical consistency of the system is possible only through the exclusion of nonconforming items and processes – those conflicting with the current regime (Shane 2005, Foucault 1997). These enclaves are necessary for facilitating the smooth dynamics of the city, and they can be considered either from the perspective of the system and their autonomous, self-organizing dynamics, or the system management.

Foucault's (1997) original philosophical concept of *heterotopia*, elaborated further by Shane (2005) provides a theoretical lens for contemplating emergence of such areas. Heterotopias refer to specific, porous yet semi-isolated areas or nodes in the city, used by the actors basically

³⁰ Note that even though I contemplate explicitly planning in this work, as has been repeated in previous chapters, today the majority of urban issues are yielding control typically intertwined with traditional planning, and in many cases means and viewpoints that could be labeled under urban management are necessary. Therefore, in this work these two approaches aiming at guiding to urban progress are inevitably converging on each other, also on the level of terminology (Ahlava and Edelman 2014).

³¹ Foucault's original paper on heterotopias was published in 1967.

to accommodate change in society. Although some types of heterotopias are specifically built by those in power, their mere existence can be considered to result from intrinsic urban change, and many of them embrace generative features, self-organization, their own exceptional rules and reversed codes compared to the surrounding urbanity (Shane 2005). Thus heterotopias can be considered to both emerge as a result of transitions in the society, and to represent means of steering them.

Foucault introduces three types of heterotopias, namely *heterotopias of crises* - enclaves voluntarily used for healing and adapting in traditional societies; *heterotopias of deviation* based on forced re-education and rehabilitation of those unfit for the modern society, and more recent *heterotopias of illusion*. In the postmodern society the heterotopia of illusion forms an increasingly frequent and salient urban element, providing actors with an illusionary sense of freedom from the controlling forces of society (Foucault 1997, Shane 2005). Increasingly, these are nodes specialized in some form of entertaining (often commercially), such as malls or theme parks (Shane 2005). However, another type is related to the decay of prior heterotopias of deviance, resulting from transitions in the society and production mode.

These dynamics are intertwined with the emergence of knowledge based society starting from the 1990s, along with the (ongoing) decline of the welfare society (Shane 2005, 2011, Oswald et al. 2003). These changes left (and leave) considerable amounts of urban 'fallow' structures - empty, derelict buildings, areas and infrastructure, which provide excellent potential for heterotopias of illusion, either through design or self-organization of a variety of diverse cultural and economic interacting actors ordering space according to their needs (Shane 2011, Oswald et al. 2003)³². Through the concept of heterotopias, and their role in facilitating urban processes throughout scales, it becomes meaningful to explore self-organization also in smaller scales, as is done in this thesis (Partanen 2015, Partanen and Joutsiniemi 2015, Partanen 2016A, Partanen 2016B).

Although heterotopias of illusion often emerge autonomously, they could be used intentionally as a means of steering the urban dynamics. They are undeniably able to provide a seedbed for self-organizing actors, adopt to transitions in society and probably also facilitate the adaptation of the system (Partanen 2015, Partanen and Joutsiniemi 2015), but furthermore, their existence could also be recognized, permitted and gently supported for the sake of channeling the pressure for the city to remain resilient. Such steering of non-preferred or unavoidable processes is actually what Berkes et al. (1995) consider to be a traditional form of guiding ecosystems in primitive societies. By allowing small perturbations, large ones may be

³² Iconic examples of such places could be Camden Market in London, or Cristiania in Copenhagen.

prevented and the resilience of the overall system is maintained (Gunderson 2000, Berkes et al. 1995).

This very process has unintentionally occurred in Nekala old industrial area, scrutinized in Partanen (2015) and Partanen and Joutsiniemi (2015). Along with several other districts close to the city on the southern side of Tampere also originally planned for heavy industry, Nekala is considered as one of specific “waiting areas” about to be developed in the undefined future, and thus currently lacking investments and interest from the city administration, consequently keeping the potential development plans on hold (Kuusela and Partanen 2016). Coincidentally, this decision has offered the area enough weather shore for unique ecosystem to emerge – but such a policy could also provide means for intentionally looking away and hence “un-planning” such areas. Nekala, an example of an evolution from a mono-functional area produced by modernistic zoning to a diverse, self-organizing enclave, can be considered to have become a pure heterotopia of illusion. For Pispala (the case area for the fourth appended article Partanen 2016B) as an informal settlement it originally fell into the category of heterotopia of crises – according to Shane (2011) manifested as places for people to utilize the adjacent city voluntarily, but (for now) lacking the ability to adapt to the prevalent city regime. Despite the gentrification of the area by the 2000s’, and due to its unique history (Partanen 2016B), Pispala still embraces a certain illusion of freedom, and shares many features associated with endeavors towards autonomy and self-governance resembling those prevalent in heterotopias of illusion (Shane 2011).

How to reduce resilience: the maneuvers to avoid

Basically, for decades in human-nature systems we have tried to maximize the profit of certain components in human related systems by strictly controlling others, to derive maximal returns by optimizing the economic, agricultural or even cultural processes. This may be a good solution on a short time span, and explicitly so in the conservation phase of the adaptive cycle. However, conceptually, optimization implies the existence of a certain (semi)permanent equilibrium. It is assumed that reaching an end state and holding the system there would be possible and yield maximal benefits, in a state of “eternal K phase” – continuous and stable, never ending growth. Nonetheless this is an illusion.

In city planning the top-down oriented planning approaches have more or less implied such illusionary linearity of the city system, considering shifts in equilibrium as “flaws”. Echoing Walker and Salt (2012), planning basically aims at organizing urban functions in a most

efficient and optimal manner. This may concern production, proximity, and disturbance of actions, social issues and services, city economics or logistics in cities. It is assumed that the change is always incremental, linear, and predictable. While these often succeed, they nevertheless ignore the fact that the system is usually reconfigured by extreme events, not average conditions. As we speak about sustainability in the context of cities, this has also often been the case until very recently: We seize the maximally sustainable static state of the economic, ecological, social or urban system - most likely implying continuous increase in benefits, forgetting the intrinsic nature of the underlying adaptive cycle (Walker and Salt 2012, Holling 1996, Novotny et al. 2010).

Here the paradox is that optimization aims at maximal efficiency, not allowing redundancy and response diversity. It implies intolerance of "useless" or overlapping activities in the system actually operating as a form of insurance policy of cities for crises. But optimization applied to only a limited set of interests – a certain industry, firm, institution, cultural facility, maximal returns or savings in the process - results in inefficiency. Such action would mean, for example, supporting heavily only one or a few industries in the city, or investing in a certain cultural institution ignoring the myriad small self-organizing networks. It leads to the elimination of the vast redundancies, keeping only the actors and processes considered (with a limited scope) having direct, linear causal benefits for short-term, often economic, efficiency. This may push the system onto an undesirable trajectory. Urban dynamics are far more complex, and there is no optimal sustainable state of a complex adaptive system – not for social, ecological or urban system, or for the world. It is an illusion.

The problems emerging from such optimization principles - for example self-organizing urban processes apparently yielding general planning (Kuusela and Partanen 2016) - the useful response would be to revise the mental model used, resisting the urge to exert even greater control over systems. Seeking tighter control may work against itself. The more optimal and efficient certain components of a system are, the less capable the whole system is likely to be of responding to sudden, extreme occurrences. The total system becomes more vulnerable to shocks. Any policy that does not recognize that the systems dynamics requiring resilience is an intrinsic feature of complex systems will most probably eventually fail. The only way is to enhance the ability of the system to change. As such, change is neither good nor bad. There are many possible states for any system - even in extreme cases such as the drastic climate changes or the collapse of society or economic system, a new temporary state will emerge as systems continually strive to adapt to change through an adaptive cycle. It is just that some states are more preferable for humans than others (Walker and Salt 2012, Novotny et al. 2012).

Hence, generally speaking, three possible reactions exist to altering stability domains (that is, the temporary equilibria): waiting until the system returns to the prior mode (it may not); adapting to it; or trying to manage the system's state (Gunderson 2000). In human systems the last one is the only relevant option since, as said, alternative states may be unpreferable or unbearable³³. Since the complex urban system does not respond well to control, more tactful forms of planning and management would be required to be able to guide the uncontrollable urban system, to avoid the unfavorable states of the system. Consequently, and considering the intrinsic features of CAS, I would suggest that instead of static planning interested in how to prevent autonomous, non-planned change, a more appropriate course of action would be to shift the focus towards smooth guidance of change and preparation of uncertainty through experimentation, locally developed, considering rules and observing of dynamics, to foster innovation helping to further adapt to change (Portugali et al. 2012, Kuusela and Partanen 2016).

³³ Although unfortunately at some point if we react too late, the second option becomes necessary, too.

3. EPISTEMOLOGY OF COMPLEXITY

The approach to complexity proposed - coupled with the resilience theory - is here considered as a mental model or an interpretation of the world (Manson 2001, 2003), not a strict description of the world as it is (Manson 2003, Reitsma 2003). Hence it provides a lens through which we can pursue a new reading of complex cities, revealing many unintuitive features otherwise hidden, instead of providing plain complexity measurements. Epistemologically, a fairly strictly positivist attitude is often implied in the objective interpretation of the world, while the “mental model complexity” embraces a more relativist perspective, yet accepting the use of complexity metrics and methods within this mental frame (*ibid.*, Lloyd 2001). Hence, accepting complexity as a mental model, it is necessary to explore under which conditions and by what means knowledge can be gathered of such counterintuitive, nonlinear phenomena, and consequently, what would be the essence of the complex reality.

Complexity sciences, and implicitly evolutionary resilience theory, have been considered to provide an overarching philosophy combining different epistemological grounds in science, yielding requirements for both objective and subjective positions in knowledge production (Portugali 1999). Typically, to study human systems, multi-methodology and both quantitative (requiring certain objectivity, realism) and qualitative (subjective, semi-relativistic) approaches rising from different epistemological foundations are used. Hence in an epistemological sense we live in two worlds. On the one hand, in the world of pure rationalistic (scientific) realism believing in objectivity, and that we can get direct knowledge of absolute reality through scientific method. On the other, we are part of a world in which there is no absolute reality nor absolute knowledge, but only a possibility to extract it from a personal or culture specific perspective accepting that it can never be universal.

Scientific knowledge has been largely considered to be objective, realistic “hard” science, but during the last century (or even longer) the hegemony of positivist objectivity has been repeatedly challenged in the philosophy of science, with critique ranging even to physics and mathematics (Rosen 1996, Capra 1996). Gradually, midway postpositivist approaches have gained ground, especially in social sciences but also in planning (Allmendinger 2002), proposing constant reflection of conceptions. These do not abandon the reality but consider it can only be known imperfectly and probabilistically. Therefore I consider that a postpositivist view provides a frame for elaborating epistemology with complexity sciences - with their origins in natural sciences - in mind.

Complexity can be considered as a unifying mode of thinking on two levels: On the one hand, on the level of methodology (quantitative and qualitative approaches), and on the other, on the level of epistemology, i.e., how to produce knowledge of the world. On the methodological level complexity thinking has been considered to have a potential to bridge the gap between the two scientific cultures with distinct epistemological grounds (Portugali 1999). Although it originates in “hard”, quantitative sciences, for example in an urban context, complexity shares many similar characteristics with approaches in social sciences. First, both take a systemic view abandoning analytical reduction. Secondly, in social science and complexity thinking the inherent dynamic progress is irreducible and not smooth; the system progresses via ruptures or revolutions to a qualitatively novel state. Finally, it has even been suggested, for example by Portugali (1999), that many social scientists from Giddens to Castells consider space to be a social production. This resonates with the prior discussion about the circular causal relation between the pattern and processes (ibid., Batty and Marshall 2016). According to this view, space would operate as an order parameter controlling and “enslaving” the parts producing it (Haken and Portugali 2003, Haken 1980).

Furthermore, complexity thinking may have potential for a new epistemological postpositivist approach. Cilliers (2005) considers the properties enabling this are inherent characteristics of complex systems, reaching beyond subjective/objective dichotomy³⁴. Complex system is by definition constituted through a large amount of nonlinear interactions, and cannot be separated from its environment. Therefore, a complete analytical description of it is impossible. The ‘incompressibility’ of the complex system implies that it cannot be simplified – the representation of a complex system is as complex as the system itself. The nonlinearity of the system becomes an issue as regards this compression - the impact of eliminated factors is impossible to predict. However, in practice, a certain reduction – comparable to temporarily closing the system - is often needed to enable any research maneuvers. The system must be defined, or framed for description - “separated” temporarily from the environment a part of which it inherently is (Cilliers 2005, Manson 2003).

Since the absolute isolation the system from its environment is impossible, a purely objective view of an observer is impossible. The limits we draw cannot be objective, but they are intuitive or strategic decisions of the observer influenced by the individual world view. In the

³⁴ Therefore, according to Cilliers, the relation between knowledge and the network producing it is dialectic: it is impossible to define first the system (or context) and then the knowledge it produces – these two emerge within a recursive, interconnected process. Both the nature of knowledge and the system that produces it are in a constant state of flux. In other words, the system cannot be uncoupled from its context due to its history. The identity is produced by their unique history, making them also unique and singular entities (Cilliers 2005).

complex system knowledge is relational in the way it is constituted in the network within which it emerges, not atomized objective facts. However, knowledge is not subjective, either - the knowing subject does not exist prior to the network of knowledge, but is constituted within the network: the observer exists in relation to the observed system, which emerges as it is delineated from the unlimited dynamic web (Cilliers 2005).

This postpositivist, relational-rational mid-way position is not easy to maintain as soon as we start computerizing³⁵. This is a salient point since computers have had a remarkable role in development of theories of complex systems – revealing chaotic, fractal, self-organizing features of systems (de Rosnay 2011, *idib*). For digital computing, knowledge needs to be objective and the subject may not intervene in data gathering, storing and manipulating (Cilliers 2005) leading easily back to “brutal positivism”. This impression can be challenged though – even in the process of dynamic modeling the model and the modeler can be considered to be in interaction through strategies, aims and decisions of the modeler and her reactions to the model behavior (Crooks et al. 2007).

EMERGENCE: SOLVING THE MYSTERY

One of the most essential characteristics for complex systems is the trans-scalar pattern formation process resulting from interactive parts (dissipative structure, reflecting back to the parts from the “enslaving” whole) (Haken 1980, Prigogine 1978). Such a process is often referred to with a concept of emergence³⁶ implying that the whole is qualitatively different from the sum of its parts, and irreducible³⁷. The basic, logical nature of emergent structures becomes apparent as our understanding of them increases: the more we study the interactions and patterns in these processes, the more causal they appear. Many emergent processes are

³⁵ I want to emphasize here a distinction between computation - that is, relational adaptive ‘calculation’ between entities, not necessarily digitalized, and computerization, referring to digital processing, storing, and digital computing of data. This distinction will be elaborated more in coming chapters.

³⁶ Here I want to stress that self-organization and emergence are not synonyms: self-organization emphasizes the dynamic increasing of order, while emergence focuses on the novelty of macro-level behavior from micro-level interaction, and irreducibility of the whole (De Wolf and Holvoet 2005, pp.12-13). The system can self-organize without emergence, or vice versa, or emergence and self-organization can occur simultaneously (De Wolf and Holvoet 2005), which results often the most interesting cases in cities.

³⁷ Since the introduction of the concept at the beginning of the 20th century, some philosophers have criticized the term for implying a “mystical” moment at which qualitatively new, previously unobservable features appear to the system as observed on the higher level (“weak emergence”). Tragically, what the early emergentists wanted to prove was actually quite the opposite, trying to argument against the mystical “élan vital” theory, claiming that the emergent novelty is actually a very natural consequence of the system’s dynamic interactions (deLanda 2011).

today understood in detail and are thus largely demystified. For example, the emergence of the qualitatively different, complex pattern of a thunderstorm as a result of convection and leveling off the temperature gradients³⁸ is today fully understood, indicating that emergence may imply surprising elements (until they are better understood), not mystical ones (deLanda 2011).

BALANCING BETWEEN OBJECTIVITY AND RELATIONALITY: SUBSTANTIALLY REAL

Since there are no absolute boundaries in the universe the question is how to derive knowledge of a system if no system exists. Despite the non-existence of boundaries, we can assume that certain relatively resilient and stable temporary structures or patterns emerge. These can be treated as if they had a “limited existence”, as if they almost existed (Richardson 2005). The level of their limited existence depends on their relational position on the *distribution of boundary (entity) stabilities*, a conceptual spectrum describing the stability of patterns in various types of systems (Figure 3).

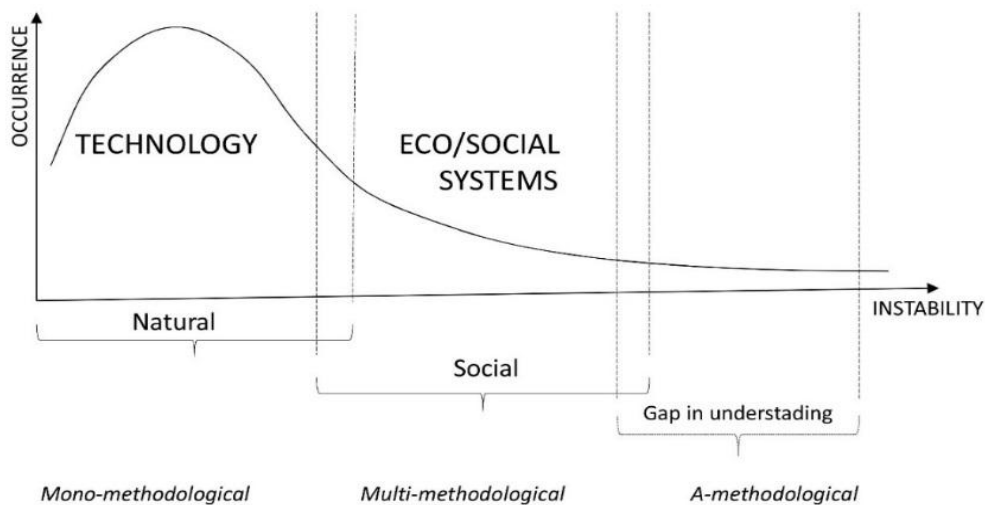


Figure 3. *Distribution of boundary (entity) stabilities*. Source: Richardson (2005).

In the left hand side of the stability spectrum structures or boundaries are relatively stable and it is safe to say they are real, providing a foundation e.g. for science-based technology. As we move towards the other end there is increasingly noise, and the borders result more and more from the interpretation of the observer, and patterns emerge and decay much faster. (Richardson 2005) Urban and social systems range in between the two extremes, occupied by patterns relatively stable for observation and research. The boundary definition is in a decisive

³⁸ Gradient is the difference between energy, concentration, temperature etc. levels in the different parts of the system that acts as an energy storage device.

role. Borders, temporarily closing the system, are necessary for the meaning without which the knowledge does not exist. Borders are strategic considerations, but they have subjective/intersubjective components – they are dependent on the observer. Because of the conditional and historical nature of a complex structure, constant revision and interpretation of the system (of both boundaries and strategies) is required.

Consequently, although there is no absolute reality, due to the resilient patterns the world as we see it can be considered *substantially real* for scientific treatment, particularly in the (natural) scientific or mono-methodological area of the spectrum (Figure 3). As the borders are (re)defined, it is important to realize that borders are not necessarily inclusive but sometimes enabling such as the eardrum, or *ecotones*³⁹ in nature. According to Cilliers (2005), the border is not even necessarily spatially continuous; it may be fragmented or even virtual, and dynamic. In some cases, the actors of such a complex web are never far from the edge – the system may be folded, or consist only of boundaries (Cilliers 2005). But as the turbulence of the system increases, the question is how we can produce knowledge with any general use, and not only about a particular, unique system.

SINGULARITIES AND GENERALIZATION THROUGH PATTERN ISOMORPHISM

The emergent patterns are dynamically stable only temporarily; using scientific analogy, until the gradient is cancelled and the pattern decays. They have most probably a tendency to behave in a certain way, to gravitate into an attractor in a space of all possible actions. Once on these attractors, the systems are surprisingly resilient against perturbation – if disturbed they soon return to their prior trajectory. Many of the emergent systems are independent of the mechanism: materially completely different systems may settle on the same attractor, i.e., share similar dynamics (deLanda 2011). These entities deLanda calls (2011) *singularities* are here considered in a more general manner, as pocket of probabilities reflecting typical behavior of the system, not as mathematical attractors.

This form of structural (scientific) realism⁴⁰ implying the mechanism independence has consequences. First, we can reflect our observations of reality (referring here to “substantially

³⁹ A border between two ecosystems with often remarkable diversity of species, or unique species ecosystems

⁴⁰ A form of scientific realism which relies only on the structure of the scientific theories instead of their empirical content (avoiding both meta-induction and no-miraculous –arguments, pro and against “pure” scientific realism) Stanford Encyclopedia of Philosophy.

real”) against certain formalizations – mathematical formulae, models, statistics, and so on. The reality can be reflected through these structures, or singularities (deLanda 2011). Secondly, we can compare systems to each other ignoring their material qualities making observations based on potential (partial) overlapping singularities (in the space of possibilities). This enables the extraction of more generalized knowledge of real world systems the dynamics of which is structurally similar. In an urban context, for example, scaling laws, fractality or dynamic states (stable, periodic, chaotic, complex), or adaptive cycles form structurally coherent representations of dynamic systems, and they have been used to estimate the success of urban dynamics, evolution, and transformation (Bettencourt 2007, Pumain 2012, 2004, Walker and Salt 2012). We can assume that a certain “law” (be it a scaling law or fractal dimension) reflects the maximal capacity of self-organization of the system, and if the system in reality follows the same law (with other words, gravitates to the same attractor) they share the generative features.

Since human systems are extremely complex trans-scalar interlinked networks of networks, in these the interpretations of both systems and temporary patterns must be pliable. Due to the inherent turbulence in the system certain robust “general laws” may not apply or apply only in certain cases or conditions (Arcaute et al. 2014, Pumain et al. 2004), or novel patterns and regularities may emerge (Batty 2006). Formally speaking, due to the independence of the mechanism, only the “degree of freedom” counts – that is, how many variables affect the dynamics (deLanda 2011). Since very simple systems can produce fairly complex dynamics⁴¹, considering very complex systems such as cities we can easily expect that the ratio increases exponentially (*ad infinitum*), bringing the issue back to the relationality, interpretation and system definition and eventually deLanda’s singularities are after all discussed rather metaphorically.

COMPUTERS AND THE PRODUCTION OF KNOWLEDGE

Computers and increased computing capacity have played a crucial role in the development of theories of complex systems. These systems or their mathematical formalizations are not necessarily beyond human capacity, but possibility for visualization and simulation have been key elements of digital computing, helping to discover the universality and revealing unintuitive features of complex phenomena, and to formulate hypotheses crucially affecting

⁴¹ With only two variables, four dynamic classes may emerge (Langton 1994)

progress in science and the resulting world view (de Rosnay, 2011). Good computer models or algorithms are not only rooted on relevant theories, but increasingly also assisting in theory formulation (Crooks et al. 2007). DeRosnay highlights that computers and numerical analyses have enabled the groundbreaking work of e.g. Lorenz, Mandelbrot, Kauffman and Holland (de Rosnay 2011) among others. It is thus relevant to ask what the role of the computer is in knowledge production (e.g. in case of simulations or genetic algorithms).

The computer, however, is a black box, which Cilliers (2005) considers similar to an abstract or divine source of which we can never have knowledge. This is not necessarily a problem since we only need to admit the limits of our understanding (Cilliers 2005). On the other hand, the computer is comparable to certain other tools for observing phenomena which are far beyond human cognition. The microscope acting as a tool for observing infinitely small entities and the telescope for infinitely large/remote entities, a computer can be considered as a “*macroscope*” which helps us to study “infinitely complex” entities. The macroscope does not produce knowledge as such since - at least if we abandon strict positivism - for data to become knowledge, meaning imparted by a human is required. However, its role is very similar to a laboratory experiment: a laboratory test is not reality, but real world phenomena can be tested in a (virtual) laboratory by a computer – “in silica” - to gain new insights into their perhaps otherwise unperceivable aspects based on which we can produce knowledge. This raises another question about the relationship between simulation and reality (de Rosnay 2011).

SIMULATION AND KNOWLEDGE

Computer-aided micro-simulation has been a central method in the study of self-organizing systems enabling the observation of dynamic trans-scalar patterns emerging from multiple lower level interactions (Batty 2007, Cilliers 2005, de Rosnay 2011). For the first time it was possible to construct systems from smaller parts instead of analytically breaking them apart. Computer simulations of complex systems serve as exploratory, educational or theory constructing tools. At their best, they may reveal general principles of organized complexity, similarities of structures, optimal zones of evolution, and rules of construction for networks (de Rosnay 2011). There are, however, several key challenges in using computer models. These are related, first, to the abovementioned issues in system definition and agents, and aggregation of data for building blocks/variables for higher level processes. Secondly, challenges concern the representation of reality as nonlinear, unpredictable, and incompressible complex systems.

The first challenge is related to the way model dynamics are represented in terms of agents and agent interactions. These definitions of an agent and the process(es) it is involved in are intertwined with the interpretation of the system (borders) and patterns – artificially closing the webs of the webs of the webs. Since agents are theoretically always aggregations of lower-level entities, our decisions can unintentionally change the processes they enable. It also becomes more difficult to define relevant processes - these are aggregations of lower-level behavior as well. Furthermore, the vast number of agents, attributes, and processes causes problems with our ability to deal with the resulting exponentiation; sampling is a poor alternative since it is simplifying, and probably skews the model behavior (Crooks et al. 2007). However, as stated, once on the attractor, emergent patterns can be considered resilient enough to form substantially stable entities - this feature enables science in the first place since we do not need to construct the universe every time from the quarks (Richardson 2005). In addition, model construction is possible based on these entities constructed of other entities (deLanda 2011). The question of interpretation and coupled subjective/objective –nature of the system is revisited - it is again all about interpretation and the two-way relationship between model and the modeler.

Particularly, the second issue refers to the extent to which the model can be verified, e.g. with another model type, and replicated, which in social sciences is questionable due to difficulties in controlling for all the variables in a particular situation, but most importantly, the ways the model can be calibrated (i.e., modified to correspond to reality) and validated (i.e., how well it achieves the intended goals (Torrens 2011). This raises an important question of how the model relates to the system it represents (reality). This is a salient point since the (dissipated) model structures are often too rich and data needed for complete validation is likely to be too poor (Crooks et al. 2007, Batty et al. 2006). It is possible to validate the model qualitatively – to estimate if the visualized output “looks right” (Mandelbrot 1983). In a more quantitative manner, the validity of the model can be evaluated by running it exhaustively: observing the complete range of possible outcomes with particular specification - exploring the space of possibilities (Couclelis 1997, Torrens 2011).

With this in mind, and echoing deLanda, we can say that if the space of possibilities is structurally similar (i.e., enables the existence of similar singularities) with the real-world system, it can probably produce dynamics whose singularities are (partly) overlapping with singularities in reality, and it can represent the reality as regards the quality of the dynamics but not necessarily the material details. For example, dynamic states of cellular automata can be analogical to the types of real complex system dynamics – the complex, generative state can be

considered analogical to the most preferable, self-organizing state able to create new qualities and renew itself in a resilient manner. Such a high level of conceptualization should cause the simulation to remain on a relatively abstract level, as a tool for visualizing and exploring the (level of isomorphism of) spaces of possibilities of the model and the world. In city planning, this could mean learning more about the triggers which might push the system to another attractor, to facilitate the most preferable self-generating dynamics and leave the rest of the system intact to operate autonomously (Partanen 2016A).

EPISTEMOLOGICAL CONCLUSIONS

Complexity thinking provides guidelines for an epistemological frame capable of accommodating both objective-realistic aspects, and more relativist, interpretational and constantly changing world views. The suggested *substantial structural realism* implies that although no objective, absolute reality exists, the world is considered *substantially real* to study emergent, temporary patterns as if they did exist. However, these need constant revision due to their turbulent characteristics, and the ambivalent nature of border definition (increasingly as one moves towards the right end of the stability spectrum (Figure 3)). In complex cities rich in turbulence this implies that we need to increase our understanding of the structures, processes, and dynamics of the self-organizing⁴², emergent processes and patterns in cities (Partanen 2015, 2016A, Partanen and Joutsiniemi 2015). In urban systems it is likely that these patterns are fairly instable yet resilient, emerging, and decaying according to their own logic and therefore general stable knowledge of them is not possible, but constant revision is needed.

Many of these emergent patterns are mechanism independent and very resilient, and they can form a relatively stable basis for scientific procedures and computer simulations (Partanen 2016A). Their behavior may be reflected against general singularities, and compared to each other, or with the results of simulation with regard to their potential gravitation to the same attractor.

In addition to actual patterns, the “space of possibilities” needs constant revision. Similar to the system definition, singularities can be considered to emerge from interpretations of

⁴² Self-organization and emergence are not synonyms: self-organization emphasizes the dynamic increase in order, while emergence focuses on the qualitative difference of macro-level behavior from micro-level interaction (De Wolf and Holvoet 2005, pp.12-13). The system may self-organize without emergence, or vice versa, or emergence and self-organization may occur simultaneously (De Wolf and Holvoet 2005), which is often the most interesting case in cities.

phenomena, against which these phenomena are again reflected. Singularities represent a generalized reading of the world, providing reflections of how systems might behave under specific conditions. This suggests that the nature of knowledge of cities is “good enough” and pluralistic, instead of objective (rational) or idealized (implying consensus). Consequently, in city planning, it would be absurd to aim at comprehensive control and optimization of the city based on “objective” truth.

4. RESULTS INTERPRETED: PLANNING FOR COMPLEXITY, A TWO-FOLD APPROACH

From embracing the complexity and resilience views it follows that the most considerate way to plan as regards complexity is based on understanding the dynamic dependencies between spatial patterns and the processes responsible for them (Levin 1998, Ndubisi 2002, Gunderson 2000 p.430, Leitão and Ahern 2002, Batty and Marshall 2009). Hence, the responsibility of planners in this adaptive process would be to discover what the actual self-organizing socio-economic and cultural processes are in general and/or in a particular case, their frequency and intensity, and how to build adaptive capacity to respond to the inevitable disturbances and to remain resilient by enhancing the factors promoting self-organization in these processes⁴³ (Leitão and Ahern 2002, Partanen and Joutsiniemi 2015, Partanen 2015, Partanen 2016A, Partanen 2016B). Shifting the balance from an attempt to control the anticipated outcomes towards managing the continuity of the unpredictable processes is challenging since we usually have very limited knowledge of these processes due to their non-linearity. It is necessary to look beyond the precautionary thinking (Ascher 2004), and embrace the uncertainty intrinsic in the system.

Thus a more adaptive way to guide and manage the city is required, conceiving of each planning decision “*as an experiment, based on the best available knowledge, structured by reasonable assumptions and monitored over time to gain the 'results' of the experiment*”. (Leitão and Ahern 2002, p.81). However, this should take place in a larger frame assessing and guiding the overall behavior of the urban system. A challenge that follows from the requirements of adaptability and transformability (ibid.) is that we need to plan simultaneously for the routine, the steady-state predictable processes, and for the uncertainty, surprises and change (Novotny et al. 2010).

Since ecology and landscape planning have long roots in spatial planning related to complex, networked ecosystems, many rather structured proposals emerge among these disciplines. *Adaptive management* is originally an integrated, multidisciplinary approach for natural resource management introduced by Crawford S. Holling (1978), and applied and developed later in a variety of ecosystem studies (see for example Walters 1986, McConaha and Paquet 1996, Rist et al. 2013). It considers constant change, nonlinearity of the system, and that humans must adjust their actions in response to the change in the system in a constant state of

⁴³ Such as tight feedback, emergent complex networks and diversity/redundancy

flux. The inherent uncertainty and unpredictability can be tackled only by constant learning as the system changes. In adaptive management it is acknowledged that policies must satisfy social goals and measures, but also be flexible for surprises. Policies can be considered more as hypotheses – they are often more questions than answers, and guiding actions resemble experiments seeking answers or solutions to them. In a nutshell, the adaptive approach accepts the intrinsic processes of the system and their interlinkages, highlights uncertainty, and develops hypotheses concerning system outcome and structured actions to test and evaluate the ideas by trial and error (Gunderson 2000, Holling 1978). In this context, Gunderson (2000, p.432) stresses the importance of understanding complex adaptive systems, and developing means to maintain and restore resilience and self-organizing capacity in these systems. Presumably, an adaptive management perspective could provide a robust model for pinpointing essential features for planning of complex cities (Kuusela and Partanen 2016).

Ahern (1999), Novotny et al. (2010) and Leitão and Ahern (2002) have elaborated central principles for the planning of complex ecosystems, building on earlier spatial planning approaches contemplating issues common to all CAS. Conceptually, these are considered applicable in urban ecosystems as well. The main features of adaptive management models are presented in Table 1 (referring to resilience and complexity, and promoting adaptive management). The conceptualizations of these prior proposals for a novel application in urban planning are classified in Table 2 (Kuusela and Partanen 2016).

In the following sections of text, I will elaborate on the conceptual phases in the light of spatial planning of complex cities. Overall, due to the inherent cyclical nature of (urban) complex systems, the proposed spatial planning processes are also continuous, and cyclical. A two-fold structure can be perceived: a certain slow cycle addressing overall goals and aims, analyses, and processes, mapping, modeling these, and (in the case of an apparently approaching shift in the stability domain) scenario work (Novotny et al. 2010). This phase aims at an overall understanding and guidance of the behavior of the system on the global level. The slowness refers to the relative pace of required updates: goals and strategies are naturally to be updated regularly following local processes, trends and global progress, but presumably less frequently than maneuvers in the following “fast” cycle. Essential differences from current top-down planning are that the focus is explicitly on the continuity of the planning process, and accepting the limitations in the prediction and control of the autonomous processes. Otherwise, conceptually, the slow cycle resembles to an extent the present planning process. The distinguishing feature here is the rapid cycle of implementation and evaluation, which could be considered somewhat lacking in today’s planning praxis.

Table 1. Classification of spatial planning procedures in landscape and ecological planning and management. Source: Leitão and Ahern (2002).

Comparison of planning phases or stages in several ecological-based physical planning methodologies								
Planning phases								
Landscape planning	Landscape ecology	EIA	Ecosystem management	Rural planning	Landscape ecological planning	Sustainable land planning (our proposal)		
Fabos, 1985	Steinitz, 1990	Forman, 1995	Zonneveld, 1995	Morgan, 1998; Trewick, 1999	McGarigal, 1998a	Golley and Bellot, 1999	Ahern, 1999	
Identification of issues/needs	Representation: how to describe the landscape?	Structural and functional analysis	Initial consultations: objectives, data, etc.	Scoping	Definition of goals	Setting goals and objectives	Goals	Focus
Assessment of environmental and socio-economic resources	Process: how does the landscape work?	Establishing relationships between structure and function	Surveys: (a) land use requirements and limitations, (b) land qualities	Description of the study area: environmental, socio-economic, cultural	Characterization of the study area: environmental, socio-economic and cultural	Inventory phase, public participation	Assessment of ABC resources, public participation	Analysis, public participation, e.g. SWOT
Goals and objectives	Evaluation: is the current landscape functioning well?	Evaluation based on two attributes: (a) rarity and (b) recovery	Land suitability studies comparison, matching of (a) and (b), socio-economic analyses, EIA considerations	Identification and description of environment, impacts	Needs assessment: identifying the issues	Diagnosis of the problem	Identification of spatial conflicts and design of spatial concepts	Diagnosis
Development of alternative plans	Change: how the landscape might be altered?	Synthesis: setting land protection priorities	Presentation of results, discussion of management scenarios	Prediction of environmental impacts (sometimes includes development of alternatives and its evaluation	Finding solutions alternative plans and its evaluation	Alternative solutions, its evaluation and contrast, and cost-benefit analysis	Definition of planning strategies	Prognosis: alternative plans and evaluation, public participation, e.g. SWOT
Selection of an alternative	Impact: what differences might changes cause?		Implementation: recommended use	Mitigation, public participation	Implementation: includes monitoring	Instrumentation	Scenario development and its evaluation, public participation	Synthesis: implementation and monitoring
	Scenario evaluation Decision: should the landscape be changed and how?		Post-project evaluation	Monitoring		Monitoring	Implementation	Monitoring

Table 2: *Conceptualizations of potential adaptive planning phases – fast and slow cycles*

SLOW	conceptual stage	Ahern (1999)	Leitão&Ahern (2002)	Novotny et al. (2010)
	1. AIMS PROCESSES	<i>Goals</i>	Focus: Setting goals	<i>setting goals exploring/learning from processes; trends, drivers</i>
		<i>resource assessments, identifying spatial conflicts, spatial concept design</i>	Analysis	
	2. STRATEGIES	planning strategies	"Diagnosis"	<i>Strategies for guiding processes towards goals</i>
	3. SCENARIOS	<i>scenario development</i>	"Prognosis" estimation/ "prediction"	<i>Scenarios of possible futures</i>
FAST	4. EXPERIMENT/ IMPLEMENTATION	Implementation	Synthesis: Implementation & Monitoring	Adaptive implementation of plans. Experimentation
	MONITORING/ EVALUATION	Monitoring		Monitoring of key indicators to yield new knowledge. Continuous re-direction.

PHASE ONE: SPECIFYING THE SCOPE OF PLANNING – *THE SLOW CYCLE*

The first step, *aims and processes*, would be to basically define the system (ibid.) (Table 2). This includes analyzing and describing the system in the context of various environmental, social, and economic dimensions; recognizing the functions, elements and their influence on the system; and defining the processes. Additionally, it is defined how we benefit from them culturally, economically or ecologically. This could include, for example, pinpointing economic structures promoting growth, improving the region's competitive position, or producing financial returns; recognizing cultural actors or networks enhancing wellbeing, social sustainability or economic innovations. Furthermore, it would be necessary to identify the clusters, patches, and other patterns and their connectivity or proximity, and how to support or develop these in a desirable manner (Leitão and Ahern 2002, Novotny et al. 2010). This data could be mapped (GIS), and/or be used as a basis of simulation models.

Next, based on the above system definition, would come an estimation of the (dynamic) state of the system, and how we want it to be in the future. Problem identification, explicit goals and objectives would then be determined, be they either political agendas, planners' goals, or those emerging within city processes – naturally keeping in mind the inherently experimental nature of the maneuvers. (Novotny et al. 2010, Leitão and Ahern 2002). Since in this work the focus is on general resilience, the goal is to enhance self-organization, and explore methods helping to hold the system(s) on a desired (complex) trajectory – and stay resilient. Goals and aims circle around this issue, while processes (and patterns) are defined in the context of each case (Partanen 2015, Partanen and Joutsiniemi 2015, Partanen 2016A).

Secondly for *strategies*⁴⁴, the essential question would be by what means we can guide the processes towards the desired goals defined above. Urban planning is (at its best) inherently strategic activity. At the core of planning is an attempt to understand and manage the forces causing the change, and less using the tactics to respond to the changes themselves. Hence, planning is proactive, not just reactive responses to surprises (Sijmons 1990). Strategic thinking is required to determine the forces behind the change (the processes), and how to influence these proactively. The strategies for complex systems need to embrace the abovementioned factors - diversity and redundancy; (existing) emergent complex actor networks, and, consequently, enhance adaptive capacity. I could conclude that strategies should favor *diversity and multi-functionality*, which produces functional *redundancy*, enabling *adaptive capacity* enhancing *resilience* (see also Walker 2006, Folke et al. 2010)

The third step (Table 2), *scenarios*, links goals and assumptions to spatial changes, and provides an unconstrained perspective on the future. Novotny et al. (2010) emphasize that scenarios are vignettes of possible futures, not predictions. Scenarios help in exploring alternative directions for the system emerging from varying occurrences in the surrounding world. The aim is to present the spectrum of alternatives. They should include a description of the prevailing situation, potential future states, drivers of change and means of implementation not to be utopian. The fundamental questions behind scenarios are “what if” and “if –then”. Scenarios are most useful if a transition is anticipated - on a stable trajectory constant update is not necessary (Novotny et al. 2010, Schumacher 1995). The process is cooperative in nature and participation is implied throughout the system. Actor analyses (e.g. the roles of municipal or lay planners, specialists, and other stakeholders) in the planning process are not the focus of

⁴⁴ Strategy is a higher level plan for achieving specific goals while considering the uncertainty. A strategy is a larger, overall plan that can comprise several tactics. These are more specific, smaller partial plans. Tactics have often less impact and they are more local than strategies. Tactics may be organized bottom up, while strategies are top down.

this conceptualization and are not scrutinized; however, some challenges to cooperative planning, and a novel method for such a bottom-up approach are described in the appended article (Partanen 2016B).

PHASE TWO: ADAPTIVE PLANNING - THE FAST CYCLE OF IMPLEMENTATION AND EVALUATION (IMPEVA)

In this second phase, the cycle would be more rapid to truly respond to the requirement for an experimental, educational planning mode. Since the impact of implementations cannot be fully predicted, monitoring and reacting need to be swift for the next correcting maneuver. Implementations should be small to better enable the evaluation of their results (Allen 2012, Kato and Ahern 2008). Here, the plan can be considered as a hypothesis of how a certain policy impacts the actual urban processes (Novotny et al. 2010). As a plan is implemented, it becomes an experiment through which professionals may gain new knowledge of the policy/process relation (Kato and Ahern 2008, Allen 2012). Such an adaptive plan is based on the best available knowledge, structured as an experiment, and monitored to learn how the system responds within a framework of overall guidance (the slow cycle). Potential failure is implicit, and the need to respond rapidly (Allen 2012). The implementation-evaluation (IMPEVA) process (Partanen 2015) also reflects the epistemological nature of CAS – it provides a model for urban planning for systems with constantly evolving, non-generalizable knowledge (ibid.).

In cities trans-scalar self-organization is more interesting and problematic due to surprising emerging properties, reflecting the CAS characteristics as nested networks. Guiding urban processes thus takes place necessarily on multiple scales. For example, in this research, emergent properties can be contemplated on the level of actor interactions, pattern formation on a neighborhood scale, and conceptually on a regional level assuming the role of the waiting areas (Partanen 2015, 2016A, B; Kuusela and Partanen 2016). It is also possible to embrace the context of heterotopic structures especially understood as a modernistic urban fallow enclaves with the potential to facilitate urban evolution, and to promote self-organization (ibid., Shane 2005, 2011). In intrinsically trans-scalar complex systems, implementations should preferably be local (small scale). However, the monitoring needs to take place in several scales. It should consider evaluating actor dynamics and interaction; neighborhood scale patterns; and on the

regional scale, evaluating urban self-organizing processes, trends, and patterns⁴⁵. It is necessary to remember that whatever system definition is used, the system border is dynamic and not necessarily spatial, but many variations exist.

I could conclude that in the core of the adaptive cyclic planning are

- 1) learning and understanding the self-organizing processes and factors presumably affecting them (the slow cycle)
- 2) smart small implementation as “experiments”,
- 3) constant monitoring and evaluating (against certain general dynamic goals/strategies and preferable directions) and
- 4) rapid shifts especially between 2) and 3) (the IMPEVA cycle). This rapid cycle is of more concern in this work since it is absent in traditional planning praxis with respect to complexity.

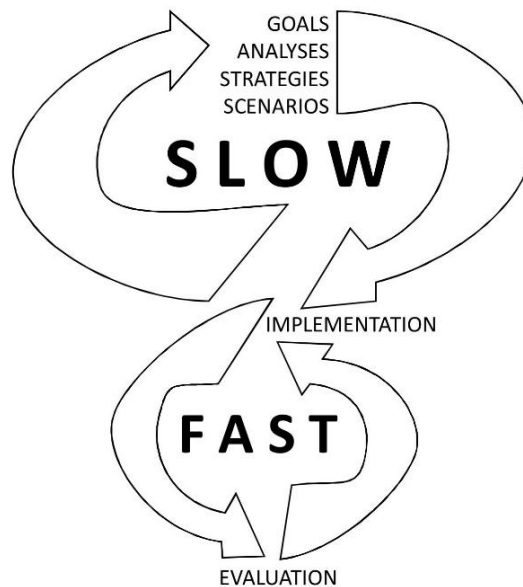


Figure 4. The two-fold cyclic planning process: Slow cycle (above) and fast IMPEVA cycle (below). The cycles interact through feedback. Strategies etc. are updated when necessary, reflecting urban processes, and they form a frame of action for the IMPEVA cycle.

⁴⁵ This not explicitly the scope of this work, but enabling of the local processes is.

Next, it is necessary to explore the actual methods for implementation and evaluation along with the necessary metrics for assessing the complexity of the system (Leitão and Ahern 2002). Such methods should be able to reflect the essential characteristics of complex systems, that is, dissipated decision-making, (trans-scalar) self-organization and fractality, and nonlinearity and non-equilibrium nature or uncertainty. These features and the planning methods applying them are explicitly contemplated in an increasingly established discourse called *complexity planning* introduced by deRoo and Silva 2010 and deRoo et al. 2012, and also discussed, for example, in Partanen 2015. Next a selection of these methods and their applicability is scrutinized in relation to the IMPEVA cycle.

COMPLEXITY PLANNING TOOLS

As has been discussed in preceding chapters, planning for complexity differs from traditional rationalistic planning implying control in that it is based on understanding and guiding phenomena towards preferable dynamics instead of static control. Planning that enables complexity thus requires new tools: both measurements capable of assessing complexity in cities, and methods for guiding bottom-up implementation processes. We should be able to perceive which trajectory is preferable, and have means to gently guide the urban dynamics towards it.

The methods are applicable for both of the two phases – the slow, top-down (emergent) frame for guiding and assessing overall urban development, and the fast cycle for constant evaluation of smaller-scale, bottom-up implementations. For example, assessing goals and strategies, levels of self-organization could be estimated, either regarding real world dynamics or simulations. Furthermore, invert codes can serve tools for setting overall frames for neighborhoods or districts.

However, in this thesis I concentrated on exploring these on a smaller scale for I consider the fast cycle is currently more neglected in urban planning. Hence the experiments in the related articles (Partanen 2015, Partanen and Joutsiniemi 2015, Partanen 2016A, Partanen 2016B) and the tools below for implementation and evaluation have their focus on the neighborhood scale, although the tools naturally also serve the regional scale well.

Methods related to plan implementation

So-called implementation methods are related to the corporeal aspects of the city, and are thus located perhaps more towards the physical “design” end of the spatial planning/design spectrum. Design traditionally implies the idea of the designer’s total control over the components of the schema, and an optimal solution as a result of a conscious design process. Since Metropolis planning the limitations of designing the city as a physical whole have been conceded, but still the city overall consists of myriads of small scale designs and plans generating the corporeal city in a very physical way (Portugali 2012, Alfasi and Portugali 2007, Marshall 2012). The cumulative effects of local, intentional designs appear on the level of the city as a self-organizing chimera, where no one has complete knowledge or control of the whole. Thus design oriented approaches are very much intertwined with planning, specifically so regarding a more process-oriented planning which actually comes close to management (ibid.).

The selected methods of implementation emerge within various traditions in architecture and (urban) design, and they all relate to reality in a relational, dynamic, and bottom-up/feedback oriented way, making them applicable as complexity planning tools. In these approaches, relationality is reflected in the general scope of what I call here the *rules*. Rules reflect a set of factors restricting or steering the operation of the system.

The rules are either defined by the planning actors (based on research on the environment), emerge within the system (in a self-organizing manner), or both. Rules may or may not change or adapt during the operation, but in both cases their emergent impact causes the system to change recursively (either until the computing is halted or the project implemented), or it provides a frame for autonomous (computational) transformation. It is essential that the rules concern *relations*, – a key component in aggregate complexity and self-organization, between various entities/agents, depending on the case.

The planning maneuvers may manipulate either these *descriptive*, discovered or emergent rules on various levels. These could contemplate, for example, prevalent relationships between buildings, and building and neighborhood level, or in relation to wider networks. It is also possible to propose new ones, which would form *normative* rules guiding future implementations. This distinction sheds light on the role of the methods in general in fast and slow cycles: the emphasis in a slow cycle is on learning from the system dynamics emerging from the descriptive rules, while in the fast cycle, the normative rules are put into action (or allowed to operate) as a form or “virtual planning”, and implementation. This classification follows the threefold model for planning proposed by Alfasi and Portugali (2007): *first*,

defining (built) elements; *secondly*, discovering existing relations (analogical to descriptive rules); and *thirdly*, proposing planning guidelines (here normative rules) for the urban code. At the core are actors or components, and their interactive relations. These relations are discovered, descriptive rules of the system. To guide the model, or implementation, normative rules are required: these are either chosen modified relations, or new “artificial” rules guiding the dynamics and concerning the interaction of components on various scales.

I have classified the implementation-focused, space producing methods as

- 1) *basic blocks or coding approach*,
- 2) *algorithmic, evolutionary approaches*
- 3) approaches implying *human computing*
- 4) *invert coding*
- 5) *self-organizing planning approaches*, namely self-organizing city games and liquid planning.

The aim here is to provide a brief overview of these as regards their applicability in complexity planning, and not an exhaustive literature review. Many of these approaches actually originate in the design or architecture sphere, but they embrace features (dynamics, relationality or evolution) which make it possible to learn from these in spatio-corporeal planning as well.

1. Basic blocks, coding, and beyond

In the self-organizing city spatial order emerges as a result of multiple simultaneous interactions between local scale plans (Alfasi and Portugali 2007, Portugali 2012). Since the overall general plan is a contradiction in terms, it is noteworthy that planning should build a spatial, relational code which directs the actors involved in planning. The order of these would thus be planned (despite the inherent role of “local planning” (Portugali 2012)) by coding generic components that constitute “basic blocks”, and the main central relationships between these (Marshall 2012).

This approach has emerged from the legacy of Pattern Language by Alexander et al. (1977). Pattern Language is a robust theory about relations, suggesting hundreds of patterns, with rules for connections with other patterns across the scales. Alexander et al. actually propose a structured language with fairly strict syntactic and grammatical rules between basic components; the new approaches are not aiming to build a new language, but to explore a possible dynamic system of elements or a web of their relations.

The codes concern not only elements of the plan or design, but necessarily the relations between them on multiple scales, perhaps from building parts to the district scale. The basic elements, contemplated widely in traditional urban design literature (for example Shane 2005) might, depending on the case, include streets, roads, squares, buildings, urban blocks, parks, neighborhoods or city districts, and other discrete elements of the built environment. (Alfasi and Portugali 2007, Parolek et al. 2008). Despite the intrinsic dynamics in the complex city, it is usually considered relevant to use existing urban elements – many of these are relatively permanent configurations (streets, squares or urban blocks). Furthermore, their non-frequent revision is in any case implied in the cyclical system. As the relationships are emphasized, the codes could be used in a generative sense, producing constantly evolving urban configurations and wider patterns (Marshall 2012). Here the basic elements are by no means only formal: they are the actual spatial (resilient yet turbulent) patterns emerging from everyday urban activities and processes – flows, concentrations and other elements channeling the flows.⁴⁶

2. Algorithmic Architecture and Evolutionary Planning

Algorithmic architecture is basically a 1990s philosophical design movement which originally aimed at formulating a new paradigm contrasting modernism while contesting the traditional, stable Euclidian paradigm in architecture, pure form, and the supremacy of the architect. Its proponents considered the world dynamic and evolutionary, and that architecture is not separate from it, but should be able to reflect the very nature of the transient realm. Algorithmic approaches were considered capable of embracing the multiple environmental factors or “forces”, as these are often called, affecting the project formation, which was

⁴⁶ Another rather different application of ideas of “basic block” with grammatical rules is a computer-aided design approach Shape Grammar. In Shape Grammar the basic blocks are abstract, 2- or 3-dimensional geometric shapes, with certain rules concerning their transformation - changing the location, orientation, reflection, or size of a given shape, and operations concerning interactions. Since the groundbreaking work of Stiny et al. (1980), Shape Grammar has provided a very advanced system of form giving in architectural and product design, and despite the basic block principles the computerized applications actually belong to the next category, evolutionary design with slightly different ontological orientation, however bridging these two.

considered to resemble the processes in nature – emergence of structures of species in evolutionary processes. The forces in this discourse represent a myriad of factors affecting the project⁴⁷. The built form emerging from a digitally computed formation process is considered “autonomous”, based on the forces introduced by designers and stakeholders and the “grammatical” rules of interaction of basic components (Lynn 1998, Terzidis 2006, Novak 2001, Hensel 2013, deLanda 2011).

In algorithmic architecture, the design project, and even the implementation is not a static entity, but an integral part of its environment. The algorithmic approach allows not only non-conservative design solutions, but, more importantly, makes it possible for all-embracing, truly sustainable, or resilient solutions to emerge. Computerized processes enable, for example, forms and structures self-sufficient with water, heat or energy. Similarly to urban models, time is a parameter. Thus these models can serve as platforms for experimenting with form, but also as educational tools for observing how the “forces” impact on the formation (Terzidis 2006).

The original roots of algorithmic architecture lie not in complexity theories, but in Leibnizian philosophy and the paradigm of mathematical topological space (Lynn 1998). However, as in the case of resilience theory, the profound ontological similarities were eventually noticed, appearing in more recent discourse – for example Michael Weinstock (2004) in his text below uses concepts explicitly similar to those prevalent in complexity sciences:

“The system—is maintained by the flow of energy and information through the system. The patter of flow has constant variations, adjusted to maintain [temporary] equilibrium by feedback from the environment. Natural evolution is not a single system but distributed, with multiple systems co-evolving in partial autonomy and with some interaction.” Weinstock 2004.

The terminology adopted from complexity is often used in a fairly metaphorical manner, but the essential characteristics in the algorithmic paradigm make it a plausible option for a complexity planning tool. These characteristics include the interactions between components and with the environment; dynamic processes; and the potential for evolutionary rules (both descriptive and normative). The dynamic configuration allows the interplay of multiple forces in a smooth process guided by the rules, operating recursively as a function of time, resulting in the emergent outcome. The planner in an algorithmic project could be either a public or private

⁴⁷ Including, for example, topography, micro- and macroclimate circumstances such as sun and wind, energy production/consumption, materials, regulations, architectural programs and use, political decision-making, participation, accessibility or connectivity of elements.

sector professional planner. The algorithmic methods are, however, promising not only regarding the adaptive form of top-down planning, but also as methods promoting and enabling co-creation in architecture and planning with lay and professional planners and designers (Keskisarja 2016). In this sense these methods come to an extent close to self-organizing planning methods introduced below, and some of them could be labeled as such.

3. Human computation

Although these algorithmic methods use computation explicitly, computation can be understood more broadly concerning how urban spatio-corporeal processes operate in general. Salingaros (2012, 2000) suggests that actually all human endeavors regarding built environment are “computation” in a specific sense. Computation is responsible for the dynamic emergence of urban fabric through series of single continuous and interactive adaptations of built elements, with feedback from the environment, producing an adapted urban form as a result of restrictions and conditions dictated by human needs. This urban morphogenesis takes place as a sequence of extended computations iteratively. Each building action adjusts to unique, current circumstances, considering flows, topography, existing buildings and their uses, weather patterns, micro-climates; individual needs and cultural habits, privacy or social connection needed for the use.

This is how traditional settlements have been constructed as late as until 1930s in the West, and they remain the primary mode of planning in informal settlements in many countries, thus actually being a very common tradition in building. In the urban morphological tradition these principles have been recognized and respected, stressing, for example, the typical procedure of the emergence of a settlement (Caniggia and Maffei 2001). This is partly intuitive activity – on one hand, the human mind has a powerful capacity for calculation (Salingaros 2012). On the other, to a great extent these maneuvers have been carried out spontaneously as in vernacular architecture, applying existing building types.

Salingaros (2012) points out that the only way to guarantee the operation of the (small scale) plan is to implement it – to an extent even informal settlements actually manage to operate in the sense of everyday activities due to this formation through generative computation. This is not a minor detail, but an essential issue coming to the fore in the proposed IMPEVA thinking. While sophisticated planning and design instruments are proposed here, the essential nature of urban ecosystems highlights again the experimental nature of adaptive planning, as has been

suggested, through trial and error. However, it needs to be noted that the overall guidance and assessments, the slow cycle, are required to avoid the harmful emergent implications of such incremental lower level maneuvers.

In Salingaros' (2012) classification, all types of human settlement reflect certain modes and levels of computation. These range from non-computational or random approaches of little use in producing adaptive, vital cities; non-interactive computing with fixed rules (producing e.g. ideal cities); to interactive computing producing and generating ordered complexity. According to Salingaros, this sets requirements for algorithmic methods: to serve as a design and planning method truly embracing complexity, it is not enough just to apply an algorithm, but the algorithm must be able to evolve, that is, to learn and adapt, similar to human cognition or neural networks. Non-adaptive methods just lead to formal planning, or unnecessary randomness of form unrelated to the urban processes, whereas solely computerized (implying just digital design) methods, no matter how sophisticated configurations or forms they might produce, do not compare with computed, adaptive and generative plans in the context of complexity. Salingaros suggests that successful computing makes the city more livable for people (Salingaros 2012, Alexander 2009). We could extend this to apply the basic blocks – approaches: the rules must evolve.

The key is to start to recognize and appreciate this traditional way cities come into being. As regards planning, we might also need to guide this spontaneous calculation one way or another – self-organization as a mechanism is value-free and might also lead to undesirable outcomes like inequality or other socially intolerable situations. Next, two possible methods are presented in which the above human capacity to “compute” is utilized: “invert coding” and self-organizing planning.

4. Invert design code

Idea of invert coding is based on a 1990s manifesto FAXMAX by the Dutch architecture office MVRDV (1998). In this book they wanted to debate about the quality of architectural design allegedly enslaved by the pursuit of a maximal floor area ratio. They introduce a concept of *datascape* – a certain force field consisting of a collection of variables affecting the projects, fairly similar to the ‘forces’ in algorithmic design. In FARMAX the selected datascares (emphasizing for example noise, vistas, social mix and so on) are represented as specific border conditions or even spatial limits, “envelopes” delineating the sphere of maximally built volumes. The idea is to propose architectural innovations instead of bulk. However,

conceptually and planning-wise, we can extend the idea of using (in this case) dynamic, evolving datascares as certain border conditions, restricting undesired elements, directions, uses, patterns, and allow the rest of the human computed processes to take place within it. These datascares can be corporeal, but also immaterial – suggesting a mix of activities/actors or level of services (MVRDV 1998).

Normative rules for invert coding would be chosen by the planner, and form the restrictive envelope and the means by which it may transform in time. Descriptive rules would be those steering dissipated human computing. Codes would basically be set top-down by a municipal planner, but they should strongly reflect the local processes and needs through direct and constant feedback from the ground. Hence they would resemble specific patterns, only interpreted by a planner.

5. Self-organizing planning

City games

In self-organizing planning the plan/design is produced within a computational, not necessarily computerized, process - that is, via calculation and a relation-based dynamic process. Individual planners (both professionals and expert citizens) would produce urban environment during a collective process, within which the rules and patterns emerge. (Tan and Portugali 2012, Webster 2010). These rules would reflect the simulated human computing of Salingaros – yet here individuals calculate the “forces” intuitively, or in interaction with each other. Self-organizing planning approaches are based on a more sophisticated conceptualization of human computing, Synergetic Inter-Representation Networks (SIRN) by Haken and Portugali (2003), providing a more structured conceptualization of human computing in evolutionary design. This model describes exactly how the information is cognitively processed in the human mind, within interpersonal (subject to subject) relations, and in the context of eventually collectively established structures and form, such as a city.

The SIRN thinking in a framework for planning has been illustrated in a theoretical context under the label of city games (Portugali 2012), and later in a more pragmatic platform, in collaborative design experiments (Tan and Portugali 2012, Tan 2016). Originally, these approaches extended the idea of collective dynamic urban design first introduced by Alexander et al. (1987). In this work an experimental “game” in San Francisco carried out in 1978 is described. Alexander et al. (1987) propose that their approach forms a completely new theory

of design, emphasizing the importance of the process behind the whole city, emerging in time through collective interactions. This thinking apparently resonates with the key points in the human computational approach (Alexander et al. 1987, Salingaros 2012, 2000). Originally, and along with the general trend in studies of urban complexity, these SIRN based self-organizing gaming methods have been mostly used for exploring and learning various space-producing mechanisms in cities. Yet recently, a trend concentrating on exploring the potential of complexity methods as a design and planning tool has emerged (Tan and Portugali 2012)⁴⁸.

Liquid planning

Liquid Planning (Partanen 2016) is a certain extension of serious games, and it could also be played as such. However, the strength of it, as it was experienced in the appended article Partanen (2016) concerning the case of Pispala, was the real planning context: in a way it was a “reality game” for citizens and stakeholders, based on an actual planning process about to begin (Partanen 2016). Consequently, participants may have been more committed to the process, acting according to their “true” profile instead of one assigned to them, but also have lot more at stake as the results were likely to really impact the planning decisions concerning their everyday environment, property rights, and values affecting the “game”. In such approaches utilizing so-called crowdsourcing it is important to note that in case of demanding tasks a mere increase in the number of participants does not help – proper problem formulation, methods, and hypotheses are required (Ball 2014, Silvertown 2009).

Some complex planning and design projects are undoubtedly demanding. For example, in the case of Pispala (Partanen 2016), a need for professional steering and assistance was recognized

⁴⁸ In this classification of complexity planning methods, and as regards self-organizing planning tools, the notion of gamification is not in focus – self-organization of information and emerging patterns are - but a relevant one regarding co-creation in planning. Gamification refers to so-called serious games, in which games are used to commit people to cooperate for specific aim often concerning scientific, technical or public issues. The game mechanics is thus applied in non-game contexts, and often applied among industries such as defense, education, scientific exploration, health care, emergency management, city planning, engineering, and politics (see for example Susi et al. 2007). Computerization has naturally accelerated gamification, but analogical “serious” board or card games have existed since the 1970’s (Abt, 1970), and the thinking could also be perceived in the old idea of collecting items attached to products. Usually the modern serious games motivate participants well due to humans’ natural desires for socializing, learning, mastery, competition, achievement, status, self-expression, altruism, or closure, and may be increased by e.g. offering progress or achievements (layers), points or virtual “money” (Susi et al. 2007), As in Tan’s city game, participants may assume certain roles according to which they behave in the game.

– but this is not necessarily always the case. This leads to the key issue, also pointed out by Tan and Portugali (2012) and elaborated via City games. How much do we need to plan and design top down, and especially, how much can be left intact, to take shape within these intrinsic, emergent processes of human computation? This is actually the fundamental issue in all these approaches involving complexity and self-organization. Since many of the self-organizing mechanisms (small cultural networks, clusters of firms, underground social hubs) may be very sensitive as regards their internal logics - hence defining, classifying, exploiting, and nurturing the autonomous processes might work against the good intentions and result in loving self-organization to death.

It is evidently impossible to provide a general answer to this question. I think the power of this final category, self-organizing planning, is exactly that they could be used explicitly for studying this relationship - what type of rules does and does not emerge within the self-organizing process – and apply this tentative knowledge by trial and error in planning, being prepared to evaluate the consequences - both as regards the realization of design goals and the level of complexity - and to react if necessary. Here the evaluation of design goals concerning perhaps patterns of buildings or activities, urban blocks, routes, ecology or diversity, quality and usability of environment, can be carried out using conventional assessment methods, whereas evaluation of the level of complexity and self-organization is not as straightforward and requires special methods – methods able to measure and replicate systems which are intrinsically unpredictable, nonlinear and far from equilibrium. As was elaborated in the preceding chapters, the ability of an urban system to self-organize is the key to the success of urban regions, but its monitoring is not basically part of conventional planning praxis, the complexity evaluation methods are brought into focus here.

Methods related to evaluation:

Monitoring the level of complexity or self-organization

Evaluative methods aim by definition at providing tools and measurements for monitoring whether the system is in a complex state and/or self-organizing, and the dynamic trajectory it is on (for example the increasing or decreasing of complexity, or whether its level of fractality, self-organization or dynamic state is drastically changing). Complexity refers here again to the aggregate complexity, systems dynamically evolving and sitting “at the edge of instabilities”, with a high capacity to self-organize. Furthermore, it is good to note that complexity is not used as a synonym for self-organization. What is essential here is that if the state of the urban

system is complex, it provides optimal conditions for self-organization, which in many cases inevitably occurs – the system balances between chaos and order using this mechanism *per se*.

Complexity metrics in general are extremely rich (see e.g. Lloyd 2001); here I concentrated on a limited number of measurements which are already fairly well established in the research of urban complexity for their capability to explicitly contemplate spatial configurations and/or the level of urban self-organization. These include measuring methods, such as applications based on scaling, rank size and fractality, entropy and dynamic states. These methods can be used to estimate the level of complexity and self-organization in the urban reality, simulated systems (such as cellular automaton, agent based models), or a plan.

Scaling and fractals

As discussed in Chapter 2, scaling refers to systems with certain nonlinear, self-organizing relations between their components, for example spatial relations, sizes or frequencies (Pumain 2004). Power law structures were already noticed in mathematical statistics at the turn of the 20th century by Auerbach and Gibrat, and popularized by Zipf in the 1940s (Richardson 1970). It was soon noticed that they apply in many natural but also human systems, including cities. Scaling is generally applied to a variety of fields, from the study of frequency size statistics and the frequency-mass distribution of earthquakes and meteors, allometric biological systems, fractal networks of streams and biological branch structures, to time series of river flows and stock markets (Kaye, 1994; Kello et al., 2010, Pumain 2004).

Fractals, representing chaotic systems, are common features in cities (Batty and Longley 1994, Liebovitch and Scheurle 2000) The urban applications broke through after the mid-1990s'. – However, according to Richardson (1970) and Batty and Longley (1994, vii), many of the basic principles emerge from theories of power laws, scaling, and central place theory or location theory. Similarly to scaling, fractals emerge bottom-up in a trans-scalar manner, and imply an underlying mechanism responsible for their organization.

Fractality often relates to geometry, but it can also refer to a process in time (for example larger fluctuations, and smaller amplitudes), or numbers (Liebovitch and Scheurle 2000). In cities, fractality is often used for two-dimensional physical form (in relation to underlying processes), although cities are fractals also, for example, as regards their silhouettes (Batty and Longley 1994, Watanabe 2002). The key is that in cities, fractals explicitly tie the processes to the dynamic interaction of patterns between entities throughout the scales (Batty and Longley 1994).

Fractals and power laws are coupled as the mechanisms behind fractals entail scaling. In fractal systems, this relationship is often called the fractal dimension, and its value can also be returned to the slope in any power law plot, and, for example, in the science of cities, considered as an indicator of the level of self-organization of the processes in the system (see e.g. Bettencourt 2007). Typically, the system is self-organizing with fractal dimension⁴⁹ between 1-2. It has been suggested that cities generally have a fractal dimension approximately $F=1.7$ (Encarnação et al. 2012). Naturally this is a rough generalization - not all parts of the cities behave similarly, and not all cities or all aspects of a certain city scale universally (Arcaute et al. 2015; Cottineau et al. 2015). However, fractality provides an appropriate tool for estimating the continuity of urban processes in time and on various scales considering local characteristics and processes.

No single reason can be deemed responsible for scaling or fractal behavior. However, it has been considered that the such city size distributions emerge from evolutionary processes of mutation, adaptation, cooperation, selection, and competition (Pumain 2004, Bettencourt and Lobo 2015). Distributed decisions of individuals result in fairly persistent patterns on a global scale (Batty and Longley 1994).

The accessibility constraints - a collective "rationality" of the actors' balancing their space-time budget (Pumain 2004, Ascher 2004) - could be a key ordering principle of the spatial structure, causing competition between areas. This, in turn, may be the mechanism behind the slow adaptation of urban structure and evolution, and hence the consistency of scaling, implying that a certain order and rules lie deep in the messiness of the city system. For example, for fractal forms, many processes seek a dynamically optimal way of using material or filling space (Batty and Hudson-Smith 2013). Hence perhaps underlying processes are responsible for the form, be it the erosion of coastlines, agglomeration economics for cities, or the evolution for living systems. (Batty & Longley 1994). Bettencourt (2013) emphasizes that in fact cities may be fairly simple – the global behavior probably results from a handful of key socioeconomic and cost factors related to infrastructure. However, the relations and explanations of these still remain largely unresolved. The simplicity of complex systems is also discussed in Gao et al. (2016). These approaches emphasizing the evolutionary nature of the order are reminiscent, first, of resilience theory – a single slow variable is analogical to the fact that a certain resilient, globally continuous state (or attractor) is necessary to keep the system from falling into chaotic states with no order. Secondly, this view is in line with Zipf's original ideas of "principles of least effort" behind scaling (Zipf 1949). Humans (and other animals) tend to act economically, saving their effort; actually self-organizing, "pre-evolutionary" entities do that as well, but not

⁴⁹ $d = \text{Log}(N) / \text{Log}(1/r)$

consciously (Eigen 1971). It is noteworthy that these mechanisms do not indicate that city systems aim at optimal equilibrium, but instead they gravitate towards the edge of instabilities, thus performing dynamic nonlinear "optimization" of their operations (for example, there is no optimal size for complex cities since it would be a paradoxical permanent equilibrium state). Although considered as fairly common dynamics in cities and reportedly a good fit for European and especially US cities (Pumain 2004, Bettencourt 2007, Bettencourt and Lobo 2013), scaling is not universally applicable to cities overall, but depends on chosen measurement needs to be established through theories and knowledge of cities (Shalizi 2011, Pumain 2004).

As noted, in urban studies these approaches have been applied both to scaling and fractality. Typically, for scaling, variants of *Zipf's law* have been used for exploring the ranking of cities according to their sizes in a system of cities, or in a variety of approaches covering different processes in cities, for example innovation, crime or economic actors (Bettencourt 2007, Batty 2012, Bettencourt and Lobo 2013), or expanding the scope of the study of power law, scrutinizing various conditions, situations, and measurements for it (Arcaute et al. 2015, Cottineau 2015). In studies of scaling, urban areas can be classified using metrics such as population, daily commuting, physical form or production. Strong regularities in the behavior of power law models have been discovered between population, surface/density, travel time (Pumain 2004). In turn municipality borders or static physical metrics (such as 200 or 500 meters between buildings) are considered poor measurements due to their arbitrary nature or increased range of daily interaction (ibid.).

Regarding fractals, physical forms can be scrutinized in many ways as measurements of patterns (intertwined with processes) in cities or simulations. Fractals are often used to explore boundaries, networks or population densities, although "classical" measurements in spatial fractals are borders and so-called box-sizes. Borders follow Mandelbrot's classical study of measuring a coastline repeatedly, using each time a "measuring stick" 1/10 of the length of the previous step (Bettencourt and Lobo 2013, Gleick 2011). Box size dimension can be used to measure the surface, and instead of changing the scale of the ruler the scale of observation is changed (using an arbitrary grid, the number of boxes containing objects is calculated as the box size is decreased by 1/10 at each step). The fractal dimension represents a relational value which remains the same throughout the scales.

Dynamic states and entropy as complexity measurement in the city

The concept of dynamic state refers to the behavior of the dynamic system. These range from static, to periodic, complex and chaotic. Complexity – the system's resilient balancing between ordered, dynamically static state and chaotic state - has been considered to provide a somewhat general characteristic for a complex adaptive system. Hence measuring these states could be considered to provide measurements for the level of complexity in the system (Langton 1990, Kauffman 1993).

Many natural and also urban systems behave according to such complex dynamics, gravitating and remaining near the edge of instabilities. This can be considered analogical to systems on a successful adaptive cycle (Kaufmann 1993, Mitchell 2009, Levin 1998). The system is capable of self-organizing, growth, until eventually it becomes unstable due to internal or external causes, and releases the resources and reorganizes again. The system manages to constantly oscillate “between chaos and order” (Langton 1990, Cruthfield and Young 1988). Such progress is typical for complex systems, including human systems and cities (Portugali 1999, Castells 2011 etc.). The type of dynamics can be estimated visually, but more precise measurements are also available, contemplated for example in Partanen 2016.

Thermodynamics studies systems as regards their temperature and energy levels. However, it has been applied to many fields concerning energy and material flows through the system, such as chemical and biological systems, but also to ecosystems and cities (Kugler and Turvey 1987, Bristow and Kennedy 2015). Thermodynamics may actually provide a complementary perspective for Metapolis dynamics, describing the evolutionary dynamics of the cities built around the flows of people, information, and goods (Ascher 2004, *ibid.*). Furthermore, entropy as a measure of “dis-organization” in the system provides metrics for evaluating the state of the system. Basically, an ordered state has low entropy, disordered high (Langton 1990). Although the emergence of self-organizing structures seems to challenge the second axiom of thermodynamics, the solution lies in trans-scalar observation (*ibid.*). The system cannot be in equilibrium on higher and lower scales simultaneously, but open dissipated systems balance gradients between these two by local self-organizing structures.

In cities this approaches metaphorically the concept of specific enclaves in a city serving as safety valves for social tension (Shane 2005, Portugali 1999), or the traditional, primitive knowledge of guiding ecosystems' operation through pockets of less control (*ibid.* Gunderson 2000, Folke and Berkes 1995). Conceptually, these structures appear as the gradient increases, be it social or economic pressure, and disappears in time (Portugali 1999, Shane 2005).

The resistance of the system against equilibrium on two levels also has other consequences related to the adaptive cycle and evolution. The global steady state amplifies lower level fluctuation, until eventually local fluctuations may amplify, breaking the equilibrium and a new steady state emerges. This is discussed by Herman Haken and Juval Portugali (Portugali 1999). Eventually, in steady state potential orders start to compete, one of these wins and enslaves the other, and a new regime emerges. For example, Manuel Castells suggests that transitions of production modes follow this logic, along with the evolution of species and businesses in resilience theory (Novotny et al. 2010), or in the case of creative destruction (Batty 2016).

Hence these self-organizing structures emerge and exist at or near the narrow transition zone between chaos and order, in which the entropy is essentially between the two extremes. For urban dynamics (in reality or simulation) entropy may provide a measurement to estimate the system's dynamics, perhaps giving guidelines on the level of complexity. Such measurement is presented in more detail in Partanen (2016A).

5. DISCUSSION

In this thesis my preliminary aims was to divert the view from traditional, top-down -oriented and rational (communicative) planning aiming at prediction and control towards a more thorough understanding of autonomous self-organizing phenomena emerging from bottom up. Such a view implying a high level of unpredictability is neither stochastic nor uncontrollable. The change of viewpoint helps to perceive the role of formerly hidden or obscure bottom up dynamics in urban processes, and to explore planning methods embracing self-organization and continuous evolution, while aiming at guidance and preventing undesirable outcomes.

At the core of this shift from a mechanistic to a complex view of urbanity is to acknowledge dynamic relationality in the world: the relationship and interaction between entities, and entities as such are often equally important. Adopting complexity thinking, which emphasizes dynamics emerging from interaction, encourages planners' exploration of such relational principles for planning applications, often manifest as rules between entities, or an entity and its environment. Although applications that adopt relational planning principles are still rare in urban planning praxis, examples of these can be discovered both in academic thought experiments and in the real world. For example, an explicit collection of fundamental policy rules that define the planning realism is presented in Lehnerer (2010) in a playful manner, concerning the imaginary island of Averuni. Despite the fictitious touch, this thought experiment - in which some examples are actually from real cities - highlights how such rules could be applied in real life.

As regards the cases presented in the related articles that form this thesis, for example in the case of Nekala or Vaasa a relational view would lead to defining the rules on neighborhood relations and allowing uses, activities or volumes conditional upon neighboring features, approaching dynamic, computational and conditional rule types, often in the form *what-if*, or *if-then*. In Pispala (Partanen 2016B) such rules could concern visibility, the envelope of building heights or vegetation, or limited building protection/diversity with the rest left intact and so on.

Due to the limited number of cases presented in this thesis, the scope of selected rules and relations is limited. It is, however, evident that the actual rules selected or emerging in urban planning process could and should have much more variety. Naturally, in real world planning, the relationships and interactions (and rules) would cover all aspects of urban life, ranging from entities related to social and economic equity and democratic principles to other crucial issues concerning overall health, (deep) ecology, culture and art, human rights, and beyond.

It is necessary to highlight that despite an emphasis on aspects not usually recognized in planning praxis such as complexity, self-organization and evolution, I naturally do not advocate the so-called “naturalization” of cities and their planning, which is often erroneously associated with a certain (impossible) *laissez-faire* attitude: there is no causality between the two. Planning is and must be value-laden activity, and although the use of the metaphors from natural sciences aims at shifting the perspective to accept the existence of such emergent processes, urban dynamics must be guided for a better quality of urban life. The direction of the guidance always depends on the values and political decision-making in society. In other words, self-organization is never good nor bad as such. Self-organization may result in destructive or malfunctioning organizations as well as in culturally or economically beneficial ones. It is a necessary task for planners and decision-makers to make a distinction between these, to impose limitations on undesired activities, and allow the desired ones to emerge.

On the other hand, adopting metaphors and recognizing mechanisms in cities, which also appears elsewhere in the world, is not very different from applying statistics in urban studies. Human systems differ in many ways from some natural ones, but they also have similarities. Normal or log-normal distributions are frequently used in the study of biology or population dynamics across the species (including humans), and, in principle, hardly differ from scaling laws or other complexity measurements. Naturally, it is necessary to keep in mind the limitations of any method or measurement we use. Due to the cumulative nature of science, we aim at an ever better understanding of phenomena (such as scrutinizing the uniqueness of urbanity regarding scaling) while still operating with the knowledge we currently have.

Therefore, reverting to the Nekala case discussed in two of the related articles (Partanen 2015, Partanen and Joutsiniemi 2015), the scaling behavior, if revised, could yield different results with different definitions of activities, or if changing the nature of the agents overall (instead of activity, e.g. individual, social network, or a structural element like a building), or definition of the area. This is an aspect that should and could be considered in a complexity planning process, which would enable constant evaluation and revision of processes and their resulting patterns and dynamics. Such relationality is actually unavoidable regarding the worldview embracing complexity and constantly revised strategic system definitions.

Another limitation of this work emerges from the fact that the methods in each case are limited, and thus enable us to reflect only the features measured. However, in the real world planning context, for example in the case of Nekala or Vaasa (Partanen 2015, Partanen 2016A), the results could be revised or triangulated using other, perhaps traditional statistical or qualitative methods, and lead to the discovery of phenomena or features beyond the scope of the

explorations presented. These could include social, psychological or emotional aspects, or subjective experiences like belonging, empowerment or self-governance. Likewise, in the Pispala case (Partanen 2016B) it could be possible to discover self-organizing mechanisms and dynamics using statistical methods, or to apply simulation models to explore the impact of tentative planning rules.

Thirdly, due to the decidedly explorative nature of this thesis, it is probable that the results of the cases are not generalizable as such: cities, districts, and enclaves probably differ qualitatively from each other to a remarkable degree. However, this work could open the planners' eyes to take a look at the bottom up -processes in the city with a wider scope, beyond sheer participatory activity: self-organization is a much more diverse, unpredictable, and powerful mechanism than expected, perhaps with a pervasive impact on all aspects of the urban realm. We must learn to perceive it in all its variance, since it is necessary to guide it with appropriate tools. Finally, despite the focus on complexity adopted here, the aim of this work is not to completely replace but rather to complement the existing scope of planning. This will be elaborated more thoroughly in the Epilogue.

6. EPILOGUE - COMPLEXITY PLANNING: A PARADIGM SHIFT

In the well-known concept of paradigm evolution Thomas Kuhn (1962) suggested that science progresses through revolutions. Although planning is not science, the major shifts in planning may be referred to as paradigm changes in a looser sense, as dominant characteristics in praxis and theory - as “normal science” - occasionally transitions to a new mode, as the dominant mode becomes widely challenged. This appears actually similar to bifurcations in complexity science, or *furcative* change (Figure 5); the prior mode remains, but adapts to the present one. (Kuhn 1962, Taylor 1998, Portugali 1999). As complexity science shows, the future mode emerges from transition as a qualitatively new state occurs. This process is continuous, but not smooth.

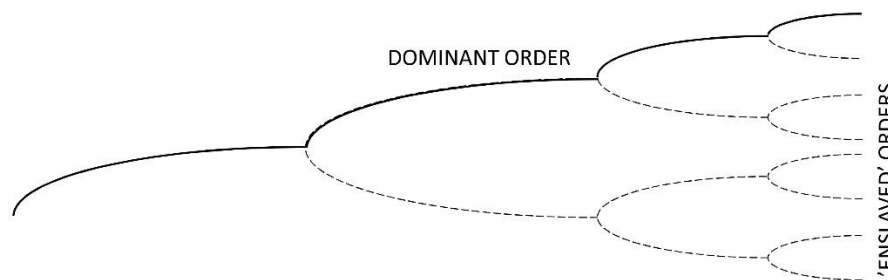


Figure 5. In furcative transition the former order does not disappear, but adapts to the coming dominant mode. For example, in changes of production modes, industry has adapted to the knowledge based society for example by adopting means of automatization and robotization, instead of having been replaced (Castells 2011, Portugali 1999).

Taylor (1998) proposes that the major paradigm shifts – or furcations – resulting in completely new attitudes and methods in planning have been the following (Figure 6). First, the transition from an artistic design-oriented approach concentrating on the physical form of the city in the 1960’s, implying major changes in large scale planning in aspects of 1) physicalism and morphology replaced by systems in constant flux and art by scientific engineering (from artist planner to scientific planner); 2) esthetics was replaced by social and economic activities; and 3) the focus shifted from end state to process. However, the status of the specialist planner (first the artist, later the scientist) remained, and was only questioned by the end of the 70’s,

resulting in the emerging view of a planner as a mediator or facilitator (in advocacy or communicative planning) and leading to a second paradigm change, as in the 70-80's the role of the planner changed from that of a specialist towards that of a facilitator. There are similarities between many authors' ideas of the planning evolution with those of Taylor (see above). Furthermore, several authors, such as Michael Batty, Juval Portugali and David Graham Shane (Figure 7) consider that we are entering a new paradigm in planning revolving around the unsolvable issues of the Metapolis and its planning; and, a decade after Taylor, that theories of complex systems provide a robust theoretical frame for such new planning.

In this endeavor, a firm theoretical ground is needed most: although planning is a practical discipline, theory is necessary. First, namely because planning *is* practical, impacting people's environment and everyday lives, we need a relevant theory to inform it. Practical "common sense" is not enough. Secondly, planning is about making value judgments (Taylor 1998, p168). We need analyses and a theory of the qualities of the built environment we want to support and enhance. In light of the complex, already maturing Metapolis, those qualities may not perhaps be only traditional esthetic or configurational. Features related to dynamics, continuity, and supporting the renewal capacity of cities - operational characteristics keeping the cities alive, in a culturally, socially, ecologically and economically resilient manner should be brought into focus.

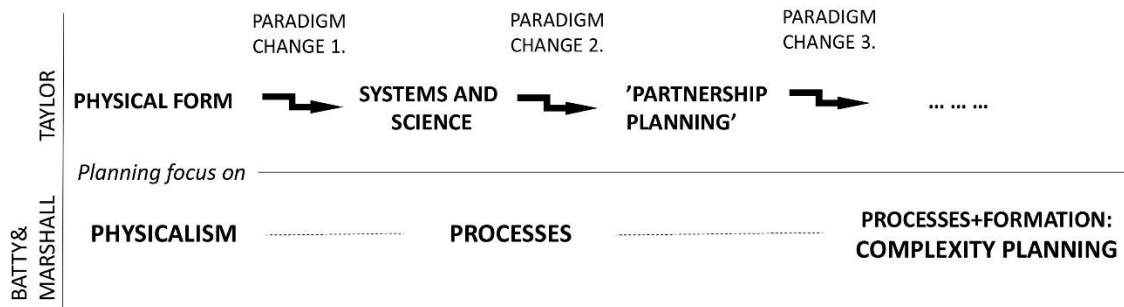


Figure 6. Paradigm changes according to Taylor (1998). For comparison, the emergence of the complexity planning paradigm according to Batty and Marshall (2009).

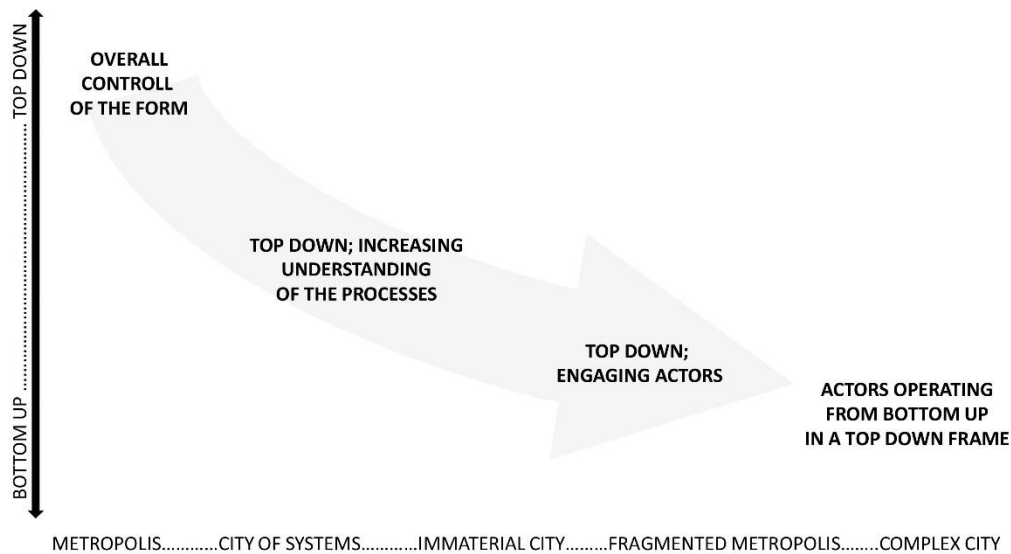


Figure 7: A proposal for planning paradigms and changes following Batty, Portugali, and Shane. Needs for a new paradigm considering the transformed dynamics and complexity of the metropolis, its unpredictability, complexity, self-organization and city evolution were discussed in the mid-late 90's, for example by Ascher (1995), Taylor (1998, p.165), Portugali 1999). On the other hand, progress is from hierarchical, top-down specialist planning toward more tolerant and adaptive guiding of urban processes and form.

Overall the capability of top down -paradigms to respond to the inherently bottom-up characteristics of society and urban life has been observed within both academia and praxis suggesting that there is a sea change coming in planning. Complexity plays a role in two respects. On the one hand, it provides an essential theoretical frame (see Taylor 1998). On the other, along with urban progress, planning has gradually been changing towards a better understanding of stakeholders and other actors, and the dissipative decision-making typical of them - as a part of the general individuation and liberation of individuals (Ascher 2004). From the perspective of the evolutionary, complex city, the progress towards the more emancipatory, demographic approaches in planning is already under way, but the major paradigm shifts from top-down approaches to genuinely bottom-up planning are yet to come. For these prior progress (such as systems thinking and participation/co-operation between stakeholders) has paved the way. Complexity as a planning paradigm would assist in explaining many features of

what the city has become, and what planning is to a certain extent already approaching (Figure 8).

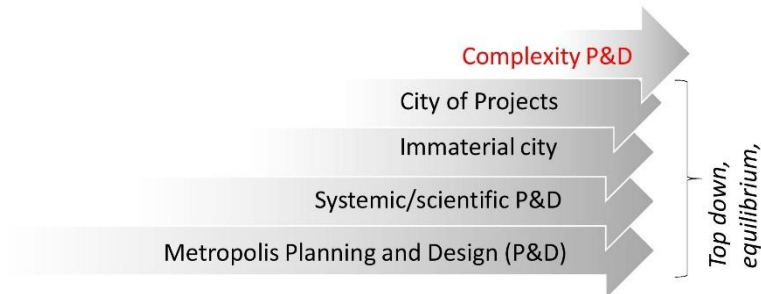


Figure 8. Emergence of complexity planning parallel to current mode(s) of planning.

Batty and Marshall (2009, 2016) point out that since the beginning the history of planning has been drawn from complete emphases on physicalism to a non-physical city, and along, for example, with Portugali and Shane they consider that now the progress and applications in complexity have enabled the fruitful combination of the two. We have been building the science of complex cities for decades, to finally starting to understand how the physical, corporeal city emerges from social, economic processes, which in their turn, enslave and guide the very processes which created them in the first place, in a circular causality.

REFERENCES

- Abt, C. C. (1970). *Serious games: The art and science of games that simulate life*. New York: Viking.
- Ahern, J. (1999). Spatial concepts, planning strategies, and future scenarios: a framework method for integrating landscape ecology and landscape planning. In *Landscape Ecological Analysis* (pp. 175-201). Springer New York.
- Ahlava, A., and Edelman, H. (2014). *Urban Design Management: A Guide to Good Practice*. Taylor & Francis.
- Alexander C., Ishikawa S. and Silverstein M. (1977). *A pattern language*. New York: Oxford University Press.
- Alfasi, N. and Portugali, J. (2007). Planning rules for a self-planned city. *Planning theory*, 6(2), 164-182.
- Allen, P. M. (2012). *Cities and regions as self-organizing systems: models of complexity*. Routledge.
- Allmendinger, P. (2002). Towards a post-positivist typology of planning theory. *Planning Theory*, 1(1), 77-99.
- Arcaute, E., Hatna, E., Ferguson, P., Youn, H., Johansson, A., and Batty, M. (2015). Constructing cities, deconstructing scaling laws. *Journal of The Royal Society Interface*, 12(102), 20140745.
- Arthur, W.B. (1994) *Increasing Returns and Path Dependency in the Economy*. Ann Arbor MI: The University of Michigan Press.
- Ascher, F. (2004). Métapolis: a third modern urban revolution. Changes in urban scale and shape in France. In: Bölling, Lars & Sieverts, Thomas (eds.): *Mitten am Rand. Auf dem Weg von der Vorstadt über die Zwischenstadt zur regionalen Stadtlandschaft. Zwischenstadt Band 1*, 24–37. , Wuppertal: Verlag Müller + Busmann KG.
- Ascher, F. (2007). Section 2: Landscapes of Capital-Multimobility, Multispeed Cities. *Places*, 19(1).
- Bak, P., Tang, C. and Wiesenfeld, K. (1987). Self-organized criticality: an explanation of 1/f noise. *Physical Review Letters* 59 (4), 381–384
- Bak P. (1990). Self-Organized Criticality. *Physica A*, 163, 403-409.

- Ball, P. (2014). Crowd-sourcing: Strength in numbers. *Nature*, 506(7489), 422-423.
- Batty, M. (2006). Rank Clocks. *Nature*, 444, 592-596.
- Batty, M. (2007). *Cities and Complexity*. Cambridge: MIT press.
- Batty, M. (2008). The size, scale, and shape of cities. *Science*, 319(5864), 769-771.
- Batty, M. and Marshall, S. (2009). Centenary paper: The evolution of cities: Geddes, Abercrombie and the new physicalism. *Town Planning Review*, 80(6), 551-574.
- Batty, M. (2012). Building a science of cities. *Cities*, 29, pp.9-16.
- Batty, M., and Marshall, S. (2016). Thinking organic, acting civic: The paradox of planning for Cities in Evolution. *Landscape and Urban Planning* (in Press).
- Batty, M. (2016). Urban Resilience: How Cities need to Adapt to Unanticipated and Sudden Change. *Perspectives on Complex Global Challenges: Education, Energy, Healthcare, Security and Resilience: Education, Energy, Healthcare, Security and Resilience*, 169-171.
- Batty M and Hudson-Smith A (2012), Discussions on Systemic Architecture: The Liquid City, in M. Poletto and C. Pasquero (Eds.): *Systemic Architecture: Operating Manual for the Self-Organising City*, London: Routledge, 18-20.
- Batty, M. and Longley, P. A. (1994). *Fractal cities: a geometry of form and function*. Academic Press.
- Bauman, Z. (2013). *Liquid modernity*. John Wiley & Sons.
- Berkes, F., Folke, C., and Gadgil, M. (1995). Traditional ecological knowledge, biodiversity, resilience and sustainability. In *Biodiversity conservation* (pp. 281-299). Springer Netherlands.
- Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., and West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the national academy of sciences*, 104(17), 7301-7306.
- Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the national academy of sciences*, 104(17), 7301-7306.
- Bettencourt, L. M. (2013). The origins of scaling in cities. *Science*, 340(6139), 1438-1441.

Boschma, R. and Frenken, K. (2010): "Spatial evolution of innovation networks proximity perspective" in Ron Boschma and Ron Martin (eds.): *Handbook of evolutionary economics*. MA, USA: Edward Elgar, 120-135.

Boschma, R., and Frenken, K. (2011). The emerging empirics of evolutionary economic geography. *Journal of Economic Geography*, 11(2), 295-307.

Boschma, R. (2015). "Smart Specialization and Regional Innovation Policy" in R Antonietti, Coró G and Gambarotto F (Eds.): *Uscire dalla crisi. Città, comunità, specializzazioni intelligenti*, Milan: FrancoAngeli, 29-34.

Bristow, D., and Kennedy, C. (2015). Why do cities grow? Insights from nonequilibrium thermodynamics at the urban and global scales. *Journal of Industrial Ecology*, 19(2), 211-221.

Camazine, S. Deneubourg, J-L., Franks, N.R., Sneyd, J., Theraulaz, G. and Bonabeau E. (2003). *Self-organization in biological systems*. Princeton University Press.

Caniggia, G., & Maffei, G. L. (2001). *Architectural composition and building typology: interpreting basic building* (Vol. 176). Alinea Editrice.

Capra, F. (1996). *The web of life: A new synthesis of mind and matter*. HarperCollins.

Capra, F., and Luisi, P. L. (2014). *The systems view of life: A unifying vision*. Cambridge University Press.

Carpenter, S.R., B.H. Walker, J.M. Anderies, and N. Abel. (2001). From metaphor to measurement: resilience of what to what? *Ecosystems*, 4, 765-781.

Castells, M. (2011). *The rise of the network society: The information age: Economy, society, and culture* (Vol. 1). John Wiley & Sons.

Casti, J. L. (1994). *Complexification explaining a paradoxical world through the science of surprise*. New York: HarperCollins.

Cilliers, P. (2005). Knowledge, limits and boundaries. *Futures*, 37(7), 605-613.

Corbusier, L. (1987 (1929)). *The city of to-morrow and its planning*. NY: Dover Publ.

Cottineau, C., Hatna, E., Arcaute, E., and Batty, M. (2016). Diverse cities or the systematic paradox of Urban Scaling Laws. *Computers, Environment and Urban Systems* (in Press).

Crooks A, Castle C, and Batty M (2007): Key Challenges in Agent-Based Modelling for Geo-Spatial Simulation. *CASA Working paper series*, paper 121.

- Crutchfield, J. P., and Young, K. (1990). Computation at the Onset of Chaos. *SFI Studies in the Sciences of Complexity, VIII, Addison-Wesley, Reading, Massachusetts*, 223-269.
- De Wolf, T. and Holvoet, T. (2004). Emergence versus self-organisation: Different concepts but promising when combined. In *International Workshop on Engineering Self-Organising Applications* Berlin Heidelberg: Springer, 1-15.
- Eigen, M. (1971). Self-Organization of Matter and the Evolution of Biological Macromolecules. *Die Naturwissenschaften*, 58(10), 465-523.
- Encarnação, S., Gaudiano, M., Santos, F. C., Tenedório, J. A., and Pacheco, J. M. (2012). Fractal cartography of urban areas. *Nature Scientific reports*, 2.
- Etzioni, A. (1967): Mixed-scanning: A “Third” Approach to Decision-making. *Public Administration Review* 27, 385-392
- Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses, *Global Environmental Change*, 16, 253–267
- Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., and Holling, C. S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics*, 557-581.
- Foucault, M. (1997). Utopias and heterotopias. In Leach, N. (ed.): *Rethinking architecture: A reader in cultural theory*. London: Routledge, 330-336.
- Fujita, M. (2007), Towards the new economic geography in the brain power society. *Regional Science and Urban Economics*, 37, 482 – 490.
- Gao, J., Barzel, B., and Barabási, A. L. (2016). Universal resilience patterns in complex networks. *Nature*, 530(7590), 307-312.
- Graham, S., and Marvin, S. (2001). *Splintering urbanism: networked infrastructures, technological mobilities and the urban condition*. Psychology Press.
- Gleick, J. (2011). *Chaos: Making a New Science* (Enhanced Edition). Open Road Media.
- Gustavsson, K. (2014) "Charlie Dunbar Broad", The Stanford Encyclopedia of Philosophy (Winter 2014 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/win2014/entries/broad/>. accessed on 5.12.2016

Haken, H. (1980). Synergetics: Are Cooperative Phenomena Governed by Universal Principles?. *Die Naturwissenschaften*, 67, 121-128.

Haken, H. and Portugali, J. (2003). The face of the city is its information. *Journal of Environmental Psychology*, 23, 385–408.

Haraway, D. J. (1976). *Crystals, Fabrics, and Fields: Metaphors of Organicism in Twentieth-Century Developmental Biology*. New Haven: Yale University Press.

Heims, S. (1991) *The Cybernetics Group 1946–1953*. Cambridge, MA: MIT Press

Hensel, M., Menges, A., and Weinstock, M. (2013). *Emergent technologies and design: towards a biological paradigm for architecture*. Routledge.

Heylighen, F., & Joslyn, C. (2001). Cybernetics and second order cybernetics. *Encyclopedia of physical science & technology*, 4, 155-170.

Holland, J. H., (1998). *Emergence – from chaos to order*. Cambridge, MA: Perseus Books.

Holland, J. H., (1992) *Adaptation in natural and artificial systems*. Cambridge, MA: MIT Press.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, 1-23.

Holling, C. S. (1996). Engineering resilience versus ecological resilience. *Engineering within ecological constraints*, 31-44.

Howard, E. (1902). *Garden cities of tomorrow*. London: Swan Sonnenschein SC Co Ltd.

Innes, J. E., and Booher, D. E. (2010). *Planning with complexity: An introduction to collaborative rationality for public policy*. Routledge.

Jacobs J, (1992 (1961)). *The Death and Life of Great American Cities*. NY: Vintage Books.

Kato, S., and Ahern, J. (2008). ‘Learning by doing’: adaptive planning as a strategy to address uncertainty in planning. *Journal of Environmental Planning and Management*, 51(4), 543-559.

Kauffman, S. (1993), *The origins of order: Self-organization and selection in evolution*. Oxford University Press.

Kauffman, S. (1995) *At home in the universe: The search for the laws of self-organization and complexity*. Oxford University Press.

- Kaye, B. H. (1994). *A Random Walk through Fractal Dimensions*. Weinheim, Wiley-VCH Verlag.
- Kello, C. T., Brown, G. D. A, Ferrer-i-Cancho, R., Holden, J. G., Linkenkaer-Hansen, K., Rhodes, T., and van Orden, G. C. (2010). Scaling laws in cognitive sciences. *Trends in cognitive science*, 14, 223–232.
- Keskisarja, E. (2016): Participatory design challenges in the digital age. A conference paper in *Inter-University Seminar on Asian Megacities*, Sapporo Japan, 02-03, July 2016
- Krugman, P. (1996). *The Self-Organizing Economy*. Cambridge: Blackwell.
- Kugler, P. N. and Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Routledge, 52-53
- Kumar, M. (2008). *Quantum: Einstein, Bohr and the Great Debate about the Nature of Reality*. Icon Books Ltd.
- Kuusela, K. and Partanen, J. (2016): Plenty of Planning, Scantly Guidance: the Case of Tampere. Conference paper in *the 14th AESOP Planning and Complexity Thematic Group Meeting*, 11.-12.2.2016, Bamberg, Germany
- Langton, C. G. (1990) Studying Artificial Life with Cellular Automata. *Physica D*, 22, 120-149
- deLanda, M. (2011). *Philosophy and Simulation: The Emergence of Synthetic Reason*. NY: Continuum.
- Lehnerer, A (2010) The 115 Rules of the City of Averuni in Finnish. *The Finnish Journal of Urban Studies*, 48 (4), 29-45 (Translation by A. Joutsiniemi)
- Leitão, A. B. and Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and urban planning*, 59(2), 65-93.
- Levin, S A (1998): Ecosystems and the Biosphere as Complex Adaptive Systems. *Ecosystems*, 1, 431-436
- Liebovitch, L. S. and Scheurle, D. (2000). Two lessons from fractals and chaos. *Complexity*, 5(4), 34-43.
- Lloyd, S. (2001). Measures of complexity: a non-exhaustive list. *IEEE Control Systems Magazine*, 21(4), 7-8.

- Lynch, K. (1981). *A good city form*. Cambridge MA, MIT press
- Lynn, G. (1998). *Greg Lynn: Folds, Bodies & Blobs; Collected Essays*. La Lettre Volee.
- Maas, W. (1999). *Metacity Datatown*. 010 Publishers.
- Marshall, S. (2012). Planning, design and the complexity of cities. In J Portugali, Meyer H, Stolk E, Tan E, (eds.) *Complexity theories of cities have come of age (191-205)*. Berlin Heidelberg: Springer.
- May, Robert M. (1976). Simple mathematical models with very complicated dynamics. *Nature*, 261(5560):459-467.
- McConnaha, W. E. and Paquet, P. J. (1996). Adaptive strategies for the management of ecosystems: the Columbia River experience. In *American Fisheries Society Symposium*.
- McLoughlin, J. B. (1969). *Urban & regional planning: a systems approach*. London: Faber&Faber.
- MVRDV (1998). *FARMAX - Excursions on Density*, 010 Publishers.
- Ndubisi, F. (2002). *Ecological planning: A historical and comparative synthesis*. JHU Press.
- Novak, M. (2001). Liquid~, Trans~, Invisible~: The Ascent and Speciation of the Digital in Architecture. A Story. In Schmal, P. (Ed.): *Digital Real*, Germany: Birkhauser Pub., 214-247.
- Novotny, V., Ahern, J., and Brown, P. (2010). *Water centric sustainable communities: planning, retrofitting and building the next urban environment*. John Wiley & Sons.
- Odum, E. P. and Barrett, G. W. (1971). *Fundamentals of ecology* (Vol. 3). Philadelphia: Saunders.
- Oswald, F., Baccini, P., and Michaeli, M. (2003). *Netzstadt*. Springer Science & Business Media.
- O'sullivan, A. (2007). *Urban economics*. McGraw-Hill/Irwin.
- Pakarinen, T. (2004). From the City of Distribution to the City of Production. In: Alppi, S. & Ylä-Anttila, K.(Eds.): *City Scratching, Polemic Interpretation, Tampere University of Technology, Institute of Urban Planning and Design*.
- Park Robert, E., Burgess Ernest, W. and McKenzie Roderick, D. (1925). *The City*. The University of Chicago Press, 1984, 239.

- Parolek, D. G., Parolek, K., and Crawford, P. C. (2008). *Form based codes: a guide for planners, urban designers, municipalities, and developers*. John Wiley & Sons.
- Partanen, J. (2015). Indicators for self-organization potential in urban context. *Environment and Planning B: Planning and Design*, 42(5), 951-971.
- Partanen J, Joutsiniemi A (2015): "Complex patterns of self-organized neighbourhoods" in Boelens, L & G. de Roo (eds.): *Spatial Planning in a Complex Unpredictable World of Change: Towards a proactive co-evolutionary type of planning*, InPlanning, Groningen.
- Partanen J, (2016A): An Urban Cellular Automata Model for Simulating Dynamic States on a Local Scale. *Entropy* 19(1): 12. Published online.
- Partanen, J. (2016B). Liquid planning, wiki-design—Learning from the Case Pispala. *Environment and Planning B: Planning and Design*, 43(6), 997-1018.
- Partanen J. and Wallin S. (2017). Bridging soft and hard - Towards a more coherent understanding of self-organization within urban complexity research. *Finnish Journal of Urban Studies (Accepted 07/2017)*
- Pickett, S. T., Cadenasso, M. L., and Grove, J. M. (2004). Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and urban Planning*, 69(4), 369-384.
- Portugali, J. (1999). *Self-organization and the city*. Berlin Heidelberg NewYork: Springer-Verlag.
- Portugali, J., Meyer, H., Stolk, E. and Tan, E. (eds.) (2012), *Complexity Theories of Cities Have Come of Age: An Overview with Implications to Urban Planning and Design*. Heidelberg: Springer.
- Prigogine, I. (1978). Time, Structure and Fluctuations. *Science* 201(4358), 777-785.
- Pumain, D. (2004). Scaling laws and urban system. *Santa Fe working paper* 2004-02-002.
- Rauws, W. (2016). Civic initiatives in urban development: self-governance versus self-organisation in planning practice. *Town Planning Review*, 87(3), 339-361.
- Reed, M. and Harvey, D. L., (1992), The New Science and the Old: Complexity and Realism in the Social Sciences. *Journal for the Theory of Social Behaviour* 22, 356-79
- Reitsma, F. (2003). A response to simplifying complexity. *Geoforum*, 34(1), 13-16.

- Richardson, K. (2005). The hegemony of physical sciences: An exploration in complexity thinking. *Futures*, 37.
- Richardson, H. W. (1970). Introduction I. *Regional economics: a Reader*. Springer. 1-14
- Rist, L., Felton, A., Samuelsson, L., Sandström, C., and Rosvall, O. (2013). A new paradigm for adaptive management. *Ecology & society*, 18(4), 63.
- de Roo, G., Hillier, J and van Wezemael, J, (Eds). (2012). *Complexity and Planning: Systems, Assemblages and Simulations. New Directions in Planning Theory*,
- de Roo, G. and Silva, E. A. (eds) (2010). *A Planner's Encounter With Complexity. New Directions in Planning Theory*, Farnham: Ashgate,
- de Rosnay, J. (2011). Symbionomic evolution: From complexity and systems theory, to chaos theory and coevolution. *Futures* 67, 304-315.
- Salingeros, N. A. (2000). Complexity and urban coherence. *Journal of Urban Design*, 5(3), 291-31.
- Salingeros, N. A. (2012). Urbanism as Computation. In *Complexity Theories of Cities Have Come of Age*, 245-268. Berlin Heidelberg: Springer.
- Santé, I., García, A. M., Miranda, D., and Crecente, R. (2010). Cellular automata models for the simulation of real-world urban processes: A review and analysis. *Landscape and Urban Planning*, 96(2), 108-122.
- Schoemaker, P. J. (1995). Scenario planning: a tool for strategic thinking. *Sloan management review*, 36(2), 25.
- Shai, S., Kenett, D. Y., Kenett, Y. N., Faust, M., Dobson, S., & Havlin, S. (2014). Resilience of modular complex networks. *arXiv preprint arXiv:1404.4748*.
- Shalizi, C. R. (2011). Scaling and hierarchy in urban economies. *arXiv preprint arXiv:1102.4101*.
- Shane D G, (2005) *Recombinant Urbanism – Conceptual Modeling in Architecture, Urban Design and City Theory*, London: John Wiley & Sons ltd.
- Shane, D. G. (2011). *Urban design since 1945: a global perspective*. London: Wiley.
- Shannon, C. E. (1948). A Mathematical Theory of Communication. *The Bell System Technical Journal*, 27 (3), 379–423

- Sieverts, T. (2003). *Cities without cities: an interpretation of the Zwischenstadt*. Routledge.
- Sijmons, D. (1990). Regional planning as a strategy. *Landscape and Urban Planning*, 18(3), 265-273.
- Silvertown, J. (2009) A new dawn for citizen science. *Trends in Ecology and Evolution*, 24, 467–471.
- Schneider, E. D., and Kay, J. J. (1994). Life as a manifestation of the second law of thermodynamics. *Mathematical and computer modelling*, 19(6-8), 25-48.
- Susi, T., Johannesson, M., & Backlund, P. (2007). *Serious Games—An Overview*, 2007. URL: <http://www.diva-portal.org/smash/get/diva2,2416>. Accessed on 12.12.2016
- Tan, E., & Portugali, J. (2012). The responsive city design game. In *Complexity Theories of Cities have come of Age*, Berlin Heidelberg: Springer, 369-390..
- Tan, E. (2016). The Evolution of City Gaming. In *Complexity, Cognition, Urban Planning and Design*, Springer International Publishing, 271-292.
- Taylor, N. (1998). *Urban planning theory since 1945*. Sage.
- Terzidis, Kostas (2006). *Algorithmic Architecture*. Amsterdam: Elsevier.
- Torrens, P.M. (2011) Calibrating and validating cellular automata models of urbanization. In Yang, X. (Ed.). *Urban Remote Sensing: Monitoring, Synthesis and Modeling in the Urban Environment*, Chichester: John Wiley & Sons, 335-345
- Townsend, A. M. (2013). *Smart cities: Big data, civic hackers, and the quest for a new utopia*, WW Norton & Company.
- Walker, B., and Salt, D. (2012). *Resilience thinking: sustaining ecosystems and people in a changing world*. Island Press.
- Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and society*, 9(2), 5.
- Walters, C. (1986). *Adaptive management of renewable resources*. NY: McGraw Hill.
- Watanabe, M. S. (2002). *Induction design: a method for evolutionary design*. Springer Science & Business Media.
- Webster, C. J., & Lai, L. W. C. (2003). *Property rights, planning and markets: Managing spontaneous cities*. Edward Elgar Publishing.

Webster, C. (2010). Emergence, spatial order, transaction costs and planning. In *A Planner's Encounter with Complexity: New Directions in Planning Theory*, Farnham: Ashgate, 117-132.

Weinstock, M. (2004). Morphogenesis and the Mathematics of Emergence. *Architectural design*, (3), 10-17.

Wright, F. L. (1932). *The disappearing city*. WF Payson.

https://www.siteations.com/courses/edgeops2014/readings/wk9/wright_disappearing.pdf

Wolfram, S. (1983). Statistical mechanics of cellular automata. *Reviews of Modern Physics* 55(3) 601-644

Wolfram, S. (1994). *Cellular Automata and Complexity: Collected Papers* (Addison-Wesley, Reading, Massachusetts)

Wong, C. W. (2013). *Introduction to Mathematical Physics: Methods and Concepts*, Oxford University Press

Zipf, G.K. (2009 (1949)). *Human Behavior and the Principle of Least Effort*. Cambridge, Massachusetts: Addison-Wesley

OTHER SOURCES:

Online dictionaries:

Oxford Dictionaries <https://en.oxforddictionaries.com/>

Merriam Webster Dictionary, <https://www.merriam-webster.com/>

ORIGINAL PAPERS

I

INDICATORS FOR SELF-ORGANIZATION POTENTIAL IN URBAN CONTEXT

by

Partanen, J. (2015) in *Environment and Planning B: Planning and Design*, volume 42, pages 951–971.
Copyright © 2015 (SAGE Publications)

Reproduced with kind permission by Sage Publications Ltd.

Abstract

Self-organization is a basic mechanism by which complex urban systems organize themselves. This mechanism emerges from individual agents' local interactions, often with unpredictable consequences at the regional level. These emergent patterns cannot be controlled by traditional hierarchical methods, but they can be steered and encouraged towards desirable goals. Self-organization is still today often used as an allegory for all "unplanned" activity in cities. It is important to study the actual mechanisms of self-organization in cities to link the theory of self-organization to planning praxis. This work builds on ongoing work exploring novel complex planning tools and methods.

Here I explore the key features of open dynamic systems identified in the literature as indicators of self-organizing capacity. I study their applicability in urban spatial planning, and propose three measurable characteristics for estimating the self-organization potential of urban activities. Flow reflects generic accessibility, and is measured using space syntax. Internal order refers to autonomously organizing entities, in this case the clustering tendencies of activities. The enriching rests upon increasing complexity and is measured as changes in degrees of entropy over time. The results indicate that first, the study area meets the criteria for self-organization, and secondly, these characteristics can be applied to discover nodes of higher potential for self-organization in a city.

Keywords: self-organization, complexity, urban evolution, innovation, planning

1. Introduction

In recent decades, theories of complexity have become perhaps the most explanatory paradigm in urban discourse (Batty 2007, Portugali 1999). Within this framework, self-organization is the most important internal mechanism according to which complex systems organize. From the viewpoint of complexity myriad non-equilibrium states are not flaws in the system but characteristic to complex systems (Kauffmann 1995, Wolfram 1984). Similarly, self-organization of cities is very typical in their mature phase. (Caniggia and Maffei 2001, Portugali 1999). Cities are unpredictable, organized bottom-up, far-from-equilibrium, dynamic and self-organizing, interlinked, trans-scalar systems. (Batty 2007, Allen 2004, Portugali 1999, Reed and Harvey 1992). In cities, self-organization explains urban dynamics, and it has a major impact on the cultural, social and economic life. One re-organization mechanism occurs in local scale enclaves, affecting overall urban dynamics (Oswald and Baccini 2003, Shane 2005, Portugali 1999).

Innovations play a crucial role in urban evolution. Innovations entail diversity and unrestricted creative processes. Innovations evolve by mutating, imitating and replacing previous innovations (Jacobs 1984, 1992). On the threshold of cultural economy, the role of innovations is becoming even more important. (Fujita 2007, Florida 2000). In city planning, understanding of these self-organizing processes enhances the utilization of the regional innovation capacity.

The ongoing work in building complexity planning praxis (see e.g. de Roo et al. 2012, Portugali et al. 2012) is still in progress. In addition to proposed planning innovations more effort is needed to explore the actual self-organizing processes in the city to improve the accuracy of these planning tools

In this paper I will ask

What is self-organization and what are the basic characteristics defining it? How can they be applied in the urban context, and especially, how can these indicators help to estimate the potential for self-organization of activities in an old industrial area?

These questions are studied theoretically and empirically in a seemingly self-organizing area, Nekala, an old Finnish industrial area in the city of Tampere. This study provides further empirical evidence of self-organization in the target area, and based on this empiria and the theoretical work, indicators for estimating potential for self-organization in other similar areas.

2. Concepts

2.1 Complexity and planning

Theories of complex adaptive systems imply that numerous interactions of the parts affect the system's behavior overall in unpredictable ways. The complex system is characteristically far from equilibrium: Chaotic behavior - irreversibility, sensitivity to initial conditions and a deterministic yet unpredictable behavior - are typical of these nonlinear systems. They evolve in seemingly stochastic series of revolutions; the dynamics of more and less predictable periods alternate, following the principles of path dependency. Self-organization is a core mechanism of these open complex systems.

Today complexity theory provides planning with a paradigm that can integrate in a credible manner qualitative and quantitative studies, and diverse social-economic dynamics and the

spatiality of the physical city (Reed and Harvey 1992, Portugali 1999, Batty and Marshall 2009).

The call for complexity planning dates back to the early 60's, work of Jacobs (1992) and Alexander and colleagues (1977). Agent- and CA-based urban models were perhaps first approaches to comprehend the complexity and the dissipativeness of the spatial city, starting from Paul Allen's work 1980's and followed by expansion of applications in 1990's (Allen 2004, Batty 2007).

Building the theory of planning in the context of complexity has progressed recently (see e.g. de Roo and Silva 2010, de Roo et al. 2012), towards developing the actual tools and planning/design methods (Portugali et al. 2012). Yet, more empirical work is needed to enrich these approaches. The most prominent lines of thought can be classified within the following non-exhaustive overlapping and complementary categories, consisting of productive and evaluative methods. Productive methods

In rules based planning rules form the predefined border conditions for the actual project, by defining a context specific framework for a design, relations between certain basic elements or shapes, or producing actual form. (Alexander et al. 1977, Alfasi and Portugali 2007, Marshall in Portugali 2012, MVRDV 1998, Duarte 2011, Lynn 1998, Hensel et al. 2004).

In self-organizing and computational planning the plan/design is produced within a computational process. Individuals produce urban environment during a collective process, with rules emerging within the process. (Tan and Portugali in Portugali et al. 2012, Webster in de Roo and Silva 2010).

Revised "systems dynamics" approaches build on traditional, single-level systems dynamics thinking, but have a lot of potential combined with agent interaction (He et al. 2006), and e.g. adaptive planning –framework (Ahern 2011).

Evaluative and educational methods

Dynamic models reveal how the choices affect the future outcome. These "planning experiments" implement rule based thinking: the modeler-planner experiments with various future configurations by altering the "planning rules" (Batty 2007). *Evaluative methods* analyze functional features of the city, such as fractality or scaling laws, implying that certain common complexity measurements reflect the preferable functionality of the city, resulting from dynamic computation between entities (see e.g. Salingeros 2000, Batty and Longley 1994, Pumain in Portugali et al.2012).

Within this framework, we continue to plan to make the world a better place, but with an awareness of the limitations of planning, and the nature of evolutionary urban change (Batty and Marshall in Portugali et al. 2012 p.44; Marshall 2009, p.266) to build an interdisciplinary theory of cities that links their morphology and their function, and connects the complexity paradigm to a new planning praxis (Batty and Marshall 2009) Here I study the nature of this evolutionary change, aiming to enhance our understanding of self-organization. This method is evaluative, forming the first step towards the modeling experiment and rule based planning.

2.2 Self-organization

Self-organization refers to the capability of systems to autonomously form an internal order without external guidance. Typically, self-organization emerges from interplay between bottom-up processes and multiple scale feedback forming a complex, nested network of networks. Its dynamics may be promoted or prevented, or the system may lock in. In the city, the border conditions (built environment, natural, social, economic environment, regulation, laws etc.) provide a certain frame for generative processes. Since the modernistic planning paradigm has ignored the bottom-up processes, the illusion of top-down control collides seriously with complex reality. Nevertheless, both are needed for successful city evolution.

2.2.1 A brief chronological review of self-organization

The origin of self-organization lies in the tradition of studying non-linear systems dating back to A. M. Lyapunov's work at the turn of the 20th century. Growing interest first started to emerge in the West in the 1950s in the field of control theory, rapidly expanding in the 1960s e to mathematics, physics, meteorology, and biology. (Keller 2009). Among the most groundbreaking of these studies are perhaps Eigen's concept of *hypercycle* in biology, Haken's *synergetics* approach, Prigogine's *dissipative structures* and Varela's *autopoietic* systems. They suggest that unanimous matter in complex, high entropy systems may have certain "pre-Darwinian", evolutive features according to which a spontaneous internal order can emerge. (Eigen 1971, 1977, Haken 1980, Prigogine 1978, Prigogine et al. 1984, Varela et al. 1974).

Due to its origin, complexity thinking was first applied in quantitative studies, but it actually provides a common ground for "hard" and "soft" disciplines (Reed and Harvey 1992, Portugali 1999, Castells 2000). Today concepts of complexity and self-organization are applied across disciplines, such as social studies, economics, and technology, in the study of ecological, social

or urban systems (see more for example Krugman 1996, Velupillai 1986, Odum 1988, Holland 1998, Allen 2004, Portugali 1999, 2011, Batty 2007). In urban studies, many applications were influenced by pioneering studies, for example Portugali's work with Haken, and Allen's cooperation with Prigogine. (Portugali 1999, Haken and Portugali 2003, Allen 2003). These early groundbreaking approaches in natural sciences provide reasonably solid ground for the study of self-organization entirely applicable even today (see e.g. Portugali 1999, 2011; Batty 2007, 2010; Allen 2004).

In mature cities, self-organization is a typical dynamic process, emerging in various ways and (across the) scales, from global to regional and local (Caniggia and Maffei 2001). Special cases of local scale self-organization have been documented by e.g. Portugali (1999) and Shane (2005). Within a dynamically stable city, certain pockets of chaotic behavior occasionally emerge. They maintain the overall stability and the logical organisation of the city (Portugali 1999, Shane, 2005).

With sensitive management these enclaves - and the potential, embryonic "fallow" reserve - can promote innovation, serving as unrestricted breeding grounds for cultural activities and space for creative encounters (Shane 2005, Oswald and Baccini 2003).

Here I build on this theory of local, isolated but porous enclaves as a facilitator for urban dynamics and innovation. It is good to note, however, that there are challenges in how local enclaves can be considered to relate to the global system.

3. Characteristics of self-organization in pioneering studies

For clarity of the concept, I next explore the classical, widely applied¹ criteria for self-organization, and expand to the views of more contemporary scholars. These principles form a basis for applying the theory of self-organization to a specific situation in a city. As a necessary prerequisite for self-organization in the real world, the system must be open, complex, and far-from-equilibrium (Prigogine 1978), sustained by a constant flow of energy (Heylighen 2003).

In Eigen's classification, the self-organization follows three principles: the system's ability to utilize energy through the system; its ability to stabilize certain structures at the expense of others (Eigen 1977, p.547); and its ability for self-reproduction and mutation. These last properties are analogical to Haken's *slaving principle* and *multistability*. Eigen also considers a

¹ (see e.g. Collier 2004; Barton 1994; Heylighen 2003)

need for a catalyst force and a feedback mechanism. Furthermore, Varela and colleagues emphasize the importance of interactions between particles, and the higher level pattern formations. Discrete methods can be used to explore whether this is self-organization in a scientific, not allegorical sense: Self-organizing criticality is a concept indicating that the system operates on or near the threshold of instability, implying complex, “edge-of-chaos” behavior. The system evolves to this critical state from bottom up, without external guidance by self-organization (Bak 1990 p.403). The critical systems typically follow power laws which are of the type $N(E) \approx E^{-b}$ (Gutenberg-Richter law). (Bak 1990 p.404) The power law behavior is considered as evidence for self-organizing criticality, and thus self-organization. Power laws have been empirically applied in research on many natural (climatology, earthquake studies) and human (social and economic) systems (Bak 1990, Pelino et al. 2006, Levy 1996). By evaluating the self-organizing criticality the results can be validated: if they follow the power law, the system self-organizes in a measurable, scientific sense.

One of the classical indicators for self-organization is the decreasing of entropy in time (see e.g. Wolfram 1983): the internal order increases as the particles start to self-organize. Applying information theory, as the information in a self-organizing system qualitatively increases, the entropy decreases due to the grouping of information. (Haken and Portugali 2003, Shannon 1948). This is a salient point, since the level of entropy does not necessarily correlate with self-organization - entropy is not an objective measure for internal order (Shalizi et al. 2004). Instead, increase in complexity, defined as “the amount of information needed for optimal statistical prediction” (Shalizi et al. 2004, p.4.), is a relevant characteristic for self-organization implying “phase transitions”, bifurcation points where the system’s state shifts.

An important feature resulting from these characteristics is resilience. Rather than an indicator, I consider it a typical consequence of the system’s self-organization. Cities consist of many complex, adaptive, trans-scalar interlinked (sub)systems, with dynamic interactions, feedback and multiple equilibria of processes. Resilience implies successful self-control within this system of systems. Urban processes are in many senses self-correcting, yet vulnerable, thus requiring small, considered and well-focused steering maneuvers to maintain this dynamic balance of the city (see e.g. Holling, 2001, Pickett et al. 2004, Allen 2004).

As a conclusion, self-organization occurs from continuous inter-scalar feedback in open, complex and far-from-equilibrium systems. Typically, they need a constant flow of energy and myriad interactive agents. Pattern formation follows the coupled bottom-up/top-down processes

and the systems' complexity increases as the self-organization progresses. These systems are resilient yet vulnerable, multistable and in constant flux.

4. Applying the Characteristic: Self-Organizing Urbanity

4.1. Characteristics of self-organization in the city

I propose the five following features as potential indicators of self-organization capacity in urbanity: *Flow, interactors, enriching, internal order, and feedback*. The flow, the system's enriching and the emerging internal order are determining indicators for local self-organization, either referring to the actual self-organization of a mature area as in this paper, or the potential of a certain area for self-organization which should be supported for the viability of the city. These features are discussed further below. *Interactors and feedback* are considered to be more general, necessary conditions for self-organization, whose existence is self-evident in urban systems.

The connection between the local and the global systems is implied in the concept of energy flow through the enclave, and in underlying economic forces behind the transitions in production and the location principles of actors. However, as regards the impact of forces operating simultaneously in the city the study is limited but within the underlying theoretical frame I consider this reduction tolerable.

4.1.1 Flow of energy

Network is a much-used metaphor in urban theories, representing some of the key features of the complex city of today. The constant flow of material, goods, people and information is a necessary condition in the constantly re-forming urban system (see. e.g. Sieverts 1997, Castells 2000, Oswald and Baccini 2003, Shane 2005). One of the most interesting concepts reflecting the high degree of simultaneous connectedness of the cities is the *rhizome* (Deleuze and Guattari 1987). This philosophical schema has often been metaphorically applied in urban studies to describe any flexible network of people or material, taking various forms, adapting to the local situation and providing passages for mobile, nomadic actors (see e.g. Shane 2005). In urban theory, Shane considers the *rhizomic* structure of the city the main combinatory code, accommodating both top-down and bottom-up dynamics, and generating the self-organization of actors in specific self-organizing areas. Constant "flows of energy" are necessary conditions for self-organization in cities. (Shane 2005, Castells 2000, Oswald and Baccini 2003). The frequency of the rhizome is important in maximizing the potential for social and economic

interaction. A high frequency network enables the efficient utilizing of the pool of concentrated information in urban areas. (Handy and Niemeyer 1997).

4.1.2. Internal order

Agents in the urban system can be defined in various ways and refer to myriad types of actors, e.g. individuals,, firms, land-uses, land-cover parcels, vehicles or interacting groups of the former.. For complexity, the agents' individual dissipative decision-making, and a sufficiently large number of actors are necessary.

According to aggregate economies, actors have their own micro-scale location preferences based on competition or synergy, reflecting and reacting to each other's location choices thereby interacting on a local scale, leading to agglomeration, analogous to pattern formation in natural sciences. Actors organize to utilize proximity, to "reduce the friction referring e.g. to lower costs and efforts to attract potential users (Fujita 2007, O'Sullivan 2009) Here I concentrate on self-organizing local-scale interactions between agents and potential pattern formation at the level of a neighborhood.

4.1.3. Enrichment

The urban, complex system typically evolves sporadically via ruptures, or bifurcations - unstable, chaotic phases of several competing states. A more appropriate concept for cities, a *furcative change*, suggests that enslaved orders, such as the prior dominant production modes of society, remain enriching the system (Figure 1) (Portugali 1999). The prediction of the future dominant mode is impossible. . Thus a diversity of options is required, from which innovations will emerge, helping the city to evolve. Specifically in the areas with evidence of ability to adjust to transitions, a diversity of activities is needed for evolution (Jacobs 1984, Hodgson and Knudsen 2011).

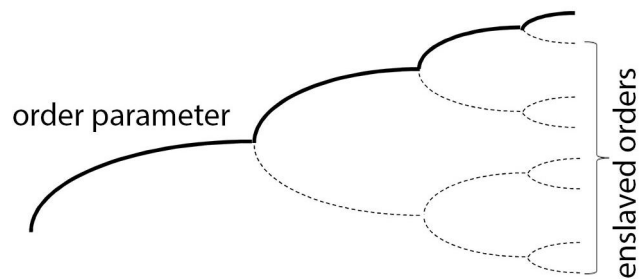


Figure 1. Furcative tree. The enslaved orders remain as the dominant state “enslaves” others in bifurcations. The system becomes more complex over time.

The measurement of unpredictability is rather difficult, but information theory and the concept of increasing complexity provide tools for observing this behavior (Haken and Portugali 2003, Shalizi et al. 2004): The ability of the system to adapt to changing conditions and to maintain its dynamic could refer to balancing between chaos and order, or moving deeper into the “furcative tree”. The complexity of the system - and its unpredictability - increases, referring to the existence of the “critical point” between phases of the system, beyond which entropy production diminishes (Collier 2004, p. 162). In this paper I explore the potential temporal “phase transitions” of activities according to their production modes (Portugali 1999, Castells 2000).

4.2. The case

To connect this theoretical perspective to the reality of urban regions, I explore these characteristics of self-organization in a real urban context: a diverse, local-scale old industrial area Nekala in the city of Tampere, Finland. This area was planned for heavy industry and the processing of agricultural products in the 1930's. Nevertheless, since then the area has undergone a wide range of transformations, from increasing centrality to an expanding diversity of activities. The area seems to have a capability for transformation and autonomously adjusting to the changing environment. Tacit knowledge of such processes raised interest to explore this, and preliminary exploration revealed features indicative of self-organization, such as clusters of many activities (e.g. kitchen fitting stores, renovation shops, interior design shops etc.), with constantly changing emphasizes in time. These local features had not been systematically

studied before, and to be able to apply this knowledge in planning, they needed to be scrutinized using appropriate set of indicators. Nekala provides a useful test bed for examining the indicators derived from the theory –proof of scientific self-organization may be discovered using indicators, applicable on similar areas.

Today, Nekala is among the most important employment areas in Tampere region, one of the largest growth centers in Finland. Its economic viability coupled with self-organization is of great importance even nationally. The spheres of influence of actors vary from local to regional, nationwide and even global scale (Närhi 2009). The main issue seems to be how to enable the actors' diversity and offer *niches* for new actors to enable the continuation of “enriching” in the future.

5. Study design and operation

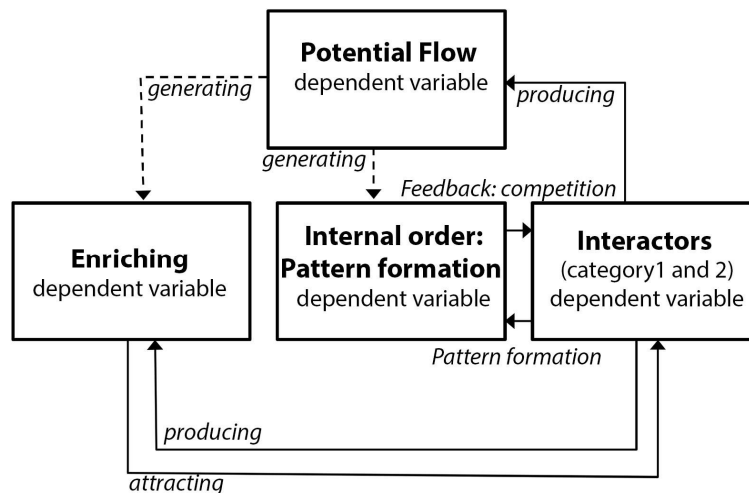


Figure.2. Construction of the study

The study is defined by a set of variables that operate on three scales (Figure 2). These are the system of *potential flows* at the meta-level, *interactors* at the micro-level, and systems of *pattern-formation* and *enriching* at the meso-level. These entities have different inter-scalar, dynamic mechanisms of interactions. High potential flows *generate* the pattern-formation and enriching processes; category one actors' interaction (defined according to the activity type later in the text). In category one the interaction of actors may *form patterns* of internal order, and category two actors (according to the production mode) *produce* enriching of the system. The pattern formation system receives two types of *feedback*: negative from internal order to interactors level as the competition impedes clustering, and positive, as they benefit from

clustering. The enriching mechanism receives the positive feedback from the interactors' level (category two), attracting actors as the potential for variety of choices increases.

5.1 Sampling and data

The variables are urban actors (such as firms, public and other services), with the sample size of the overall number of agents in the area. Statistical data on workplaces from the City of Tampere administration (1971-1989) and central government (2008) on workplaces in the Nekala area are used as material. The data from 2008 are complemented with observations² to scrutinize the real spatial distribution of the activities: These small, non-profit type activities are unlikely to have existed in the area before the two major industries withdrew (1989-2008), leaving them affordable premises in old buildings. Because the (electronic) data after 1986 has not been stored by the City of Tampere administration, the data from 1993 used in evaluating the enriching were collected from a telephone catalog. Compared to other data, the major threat would have been to miss some actors, but actually the number of actors also increased between 1982 and 1993. The data collected by local and central government is considered reliable. The road network data is from the City of Tampere administration. I choose 1971, 1982, 1993 and 2008 for observation to perceive the possible changes in production modes.

6. Methods

6.1 Measuring potential flow: accessibility network analysis

The regional connectedness of the network is important for the potential for social and economic interaction. Since I study the physical activities and their spatial configurations, by analyzing the physical accessibility network specific characteristics can be identified, such as pools of high accessibility that may indicate adequate flow facilitating the self-organization. Good accessibility and saved travel costs are essential for connecting the firm to a larger pool of employees and attracting users.

The basic elements of the trip in traditional measures of accessibility (cumulative opportunities measures, gravity-based, utility-based or space-time accessibility (Handy and Niemeyer 1997)) are the points of departure and destination. They ignore the

² (Närhi 2009)

complexity of a multi-nodal urban environment. More useful is the concept of *relative accessibility*, a space syntax based concept. Computing the *depth* for every street segment -the degree of segments separating it from all the other segments - provide a representation of relative centralities of the network. The resulting accessibility surface provides relative values for accessibility in every location to every other location, revealing the potential for flow (Hillier 2007, Joutsiniemi 2010).

Space syntax investigates relationships between spatial layout and a range of social, economic and environmental phenomena. The main mechanisms that affect the complex spatial configuration and self-organization of urban systems are *integration*, a global hierarchy of depth defined by the configuration of lines representing the circulation of the city, and the *movement economy*, the adaptation of self-organizing activities to this hierarchy. An important implication is the series of spaces between origin and destination. The grid defines the degree of flow passing every location, implying superior potential for certain locations (Hillier 2007). Here I applied the method based on *axial space*, visibility axes following the actual street network, and *depth distance* - sum of the distances from each street segment to all the other segments, providing the mean depth for every segment. First the axial, linear sight-lines are drawn according to the road network. Secondly, the mean depths (md) are calculated for each segment. Finally, the thematic maps are produced to illustrate the relative accessibility of segments in different scales. In this study accessibility was measured on three different scales, loosely following the scales proposed by Joutsiniemi, adjusted to a smaller regional scale: Scales are md 20, 60 and 90 (Figures 3-5), reflecting Hillier's idea that the movement in the city is fractal (Hillier 2007). Since different scales attract different actors, and high relative accessibility implies high potential for self-organization. I assume that multiple scales high accessibility nodes refer to a marked tendency for self-organization by attracting multiple activities (Hillier 2007, Joutsiniemi 2010).

6.2 Interactors, their enrichment and internal order

6.2.1 Data

I use two classifications for the activities: one for the pattern formation tendency of the activities referring to the relations of the activities to their environment, and the other for

enriching of the system, contemplating characteristics of the prevailing production. In category one activities are classified according to the nature of the similarities in their interaction with the neighborhood; these *use types* are *retail, services, business, small industry, and warehouses*. The study focuses on the activity and its relationship to the immediate neighborhood - the classification is fairly simple for better observation of the changes and possible patterns in the system. The second classification of the activities according to their “production mode” characterizes the industry at issue. The *production type* categories are *agrarian, industrial, service, information, and cultural economy* (Castells 2000, Florida 2000).

6.2.2 Measuring internal order

I assume that some of the activities in the area benefit from proximity to each other and form clusters. Activities cluster for various reasons on either the supply or the demand side e.g. to mutually learn how to improve productivity or to optimize their location. Spinoffs, proximity to consumers or lumpy demand also generate agglomerations. (Picone et al. 2009).

Typically, the clustering is measured by comparing the location pattern observed to a random assignment (Picone et al. 2009). In this case, these local factors (the zoning code, geography, and accessibility) are fairly constant, and the pattern formation most probably follows the actors' strategic incentives. Thus in this study these more detailed methods are not applied. Another measurement for clustering tendency is density of firms/employees per hectare (de Propris 2005). Here the diversity of the area can be measured relatively well, and the abstract density without location information, would not represent the spatial configurations of activities and thus the potential pattern formation.

In spatial sciences, the spatial interactions between activities or parcels of land-uses are often implied, especially in approaches using dynamic simulations. Due to the assumed neighborhood effects, many of these urban simulations are based on CA, which accurately reflects local interactions and provides applicable definitions for the “neighborhood”. Naturally proximity is not the sole factor affecting the land use dynamics, but is fairly relevant in agglomeration economies.

Most commonly in these approaches, the entities are defined as cells in an arbitrary grid, whose neighborhood consists of either four or eight adjacent cells. Alternative definitions, such as actual real world parcels or vectors, can be used to overcome certain limitations resulting from the rectangular lattice (Stevens and Dragicevic 2007). Neighborhood can also be extended to adopt effects from more distant cells (Shi and Pang, 2000).

The irregular cell space best reflects many properties of the target area resulting from the fine resolution (Stevens and Dragicevic 2007). The cells are based on the official site division for more accurate representation of the spatial interaction resulting from the morphology and due to the higher resilience of the site to changes over time compared to buildings. The basic entity is a site, with activities merged down to it. The small scale also implies use of immediate neighborhood, since in some cases even a one-step extension to the neighborhood would easily encompass the whole area.

The effective distance for a neighborhood was defined as 24 meters, the traditional block size of the area and a radius of a most competitive advantage for similar uses.

Within this frame, I explored the clustering tendency for each activity separately. I compared the neighborhoods of sites with a certain activity, for example industry (Group 1), to the random allocated neighborhoods (the probability of any site having industrial neighbors) and a site without a certain activity (Group 2), for example the probability of a non-industrial site having industrial neighbors. All the activities on the site (in the “neighboring buildings”) are counted as neighbors except for one (the activity whose neighborhood is contemplated) (Equation 1.).

$$\sum_{i=1}^Z N_i - a_1$$

Equation 1. Calculating the number of type T_i , $i= 1$ to 6, neighbors. N_i is the count of the type T_i activities on the neighboring site, a_1 is the activity whose neighborhood is contemplated.

Two uses, housing and business, are excluded due to their marginal share in the area. In addition, including the neighboring housing area with rather strict regulation would have skewed the results. Yet the business uses seemed also to follow the agglomeration tendency.

6.2.3 Measuring enrichment

Next I studied the adaptability and potential existence of “critical points” in the temporal behavior of activities in the area indicating renewal capacity at the transition phases . I used production type actors, because they do not change over time, but rather adapt to the production mode. I used the method originally developed by Shannon and discussed further by Haken and Portugali (Shannon 1948, Haken and Portugali 2003) to measure the change in information. In this approach the entities of the city - in this case urban activities - are contemplated as

information. Humans perceive the physical city according to the information it embraces in both the Shannonian "objective" and the semantic "subjective" sense (Haken, Portugali 2003). Shannonian information is the amount of information in the system calculated in bits. Referring to the number of possibilities, implying that the pattern contains information about both observed and potential form. "Semantic", contextual information, by contrast, depends heavily on the receiver's cognitive interpretation of urban elements. (Haken and Portugali 2003, Shannon 1948). In cities these two types are closely connected. To define the quantitative information as "bits" the entities need to be categorized according to their common features. (Haken and Portugali 2003).

The relation between Shannonian and semantic information is dynamic and works through circular causality. Entering a new type of entity in the system causes an increase in Shannonian information. Emerging similar cases are grouped by a pattern recognition process. These singular entities become a category and the amount of information again diminishes. This moment of decreasing entropy can be considered a "phase transition"; the semantic information emerges through self-organization (Haken and Portugali 2003).

The classification based on production modes was used to monitor the increasing or decreasing information in the system, and potentially ensuing furcative changes. I calculated the Shannonian information in the sense of absolute values (I) and relative values (i) in order to perceive the total increase of information on the one hand, and the relative increase of information on the other (Equation 2.).

$$I = \sum_{i=1}^N Z_i \log_2 Z_i$$

Equation 2. Shannonian absolute information (I). Z = the number of possibilities.

For calculating the relative values,

as the choice of the indices = j ,

p_j is given by

$$p_j = \frac{N_j}{N}$$

N is the total number of activities, and N_j the number of activities of the same kind according to the selection and recognition process. Equation 3 indicates how the relative information i is given by

$$i = - \sum_{j=1}^N p_j \log_2 p_j$$

Equation 3. Shannonian relative information (i).

i is independent of the total number of activities, but reflects their variety. (Haken and Portugali 2003, p.393; Shannon 1948).

7. The results

7.1 relative accessibility

The results indicate that the target area has relatively high accessibility on all scales (Figures 3-5, red-orange colors).

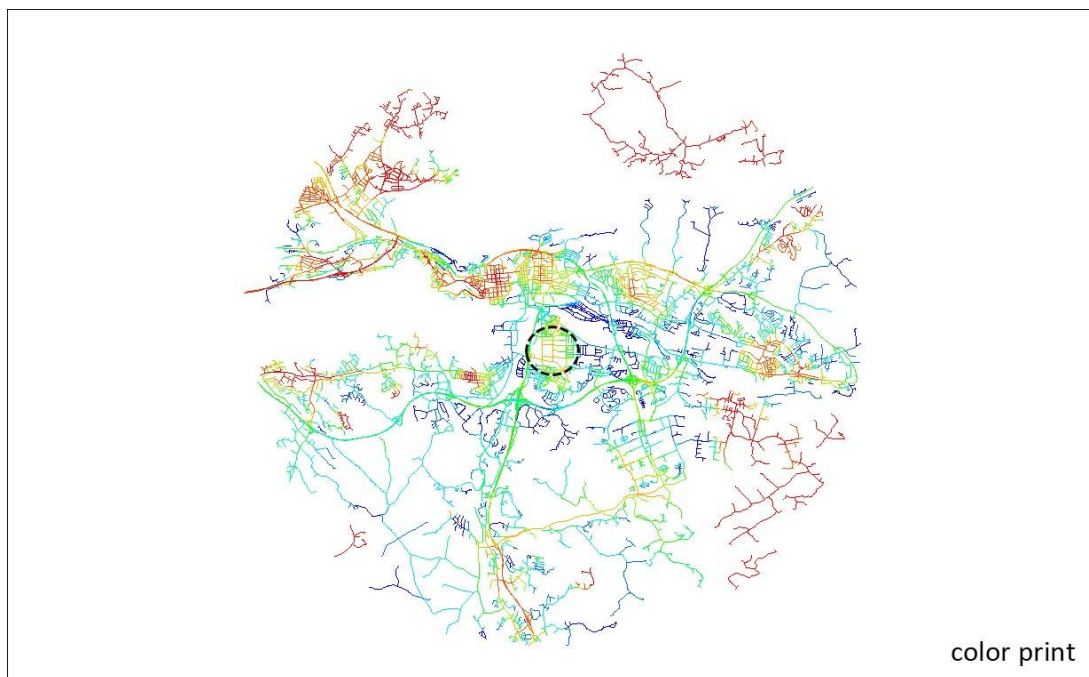


Figure 3. Mean depth 20.

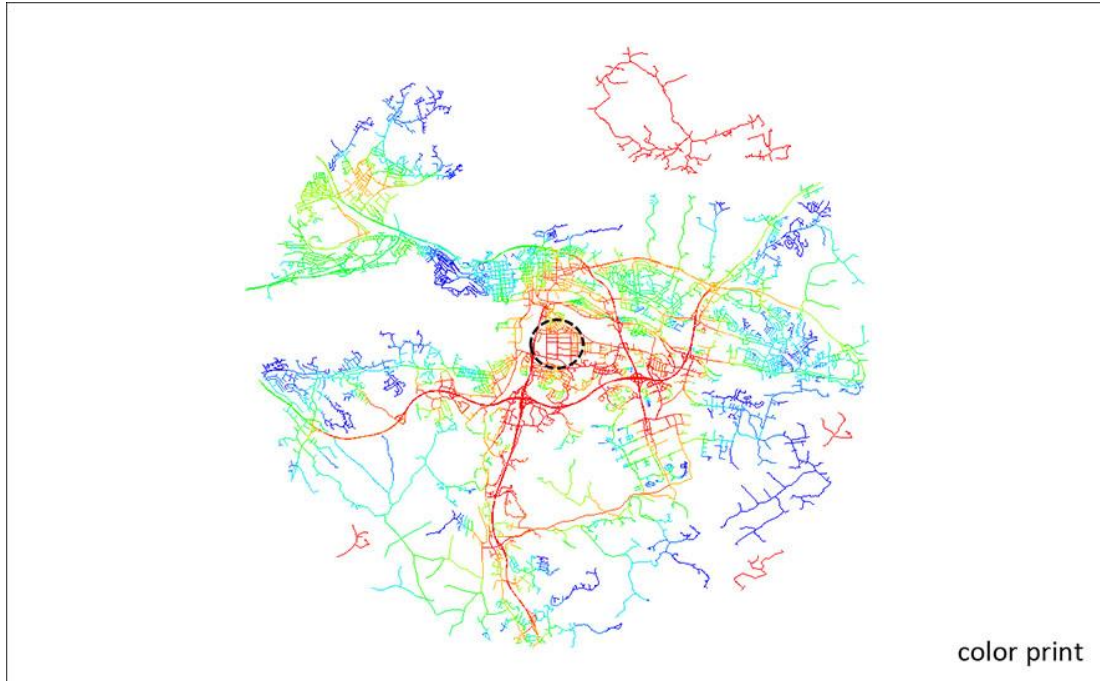


Figure 4. Mean depth 60.

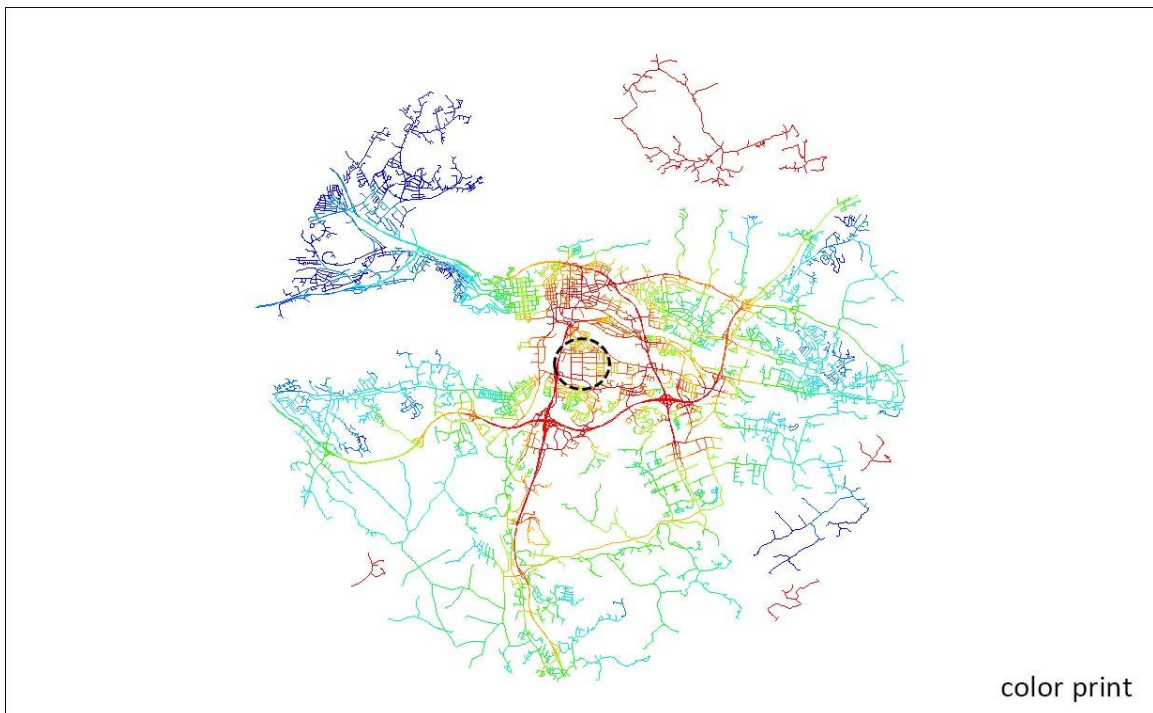


Figure 5. Mean depth 90.

Nekala is the only such area regionally; - in the diverse historical city center, high values in mean depth (md) 20 and 90 occur, but medium scale accessibility is lacking; several other areas achieve two out of three high md values, such as several highway intersections (60 and 90), or

small-scale residential areas (20 and 60). This type of *coinciding centrality* could be considered an indicator for potentially high flows triggering the adaptation and regeneration of the area. Earlier studies indicate correlation between accessibility scales and different types of industry (Joutsiniemi 2010, Hillier 2007). This study reveals a relation between multiple agglomerations of activity types (see below), and coinciding centralities of the network providing sufficient “energy flow” for self-organization.

7.2 Internal order: Pattern formation

Comparison of groups with and without certain activities revealed individual, characteristic distribution for both data series. Group one sites had a significantly greater share of sites with similar neighbors (96%) than the sites without a certain activity (4%) (Figure 6.) and random assignment (66%).

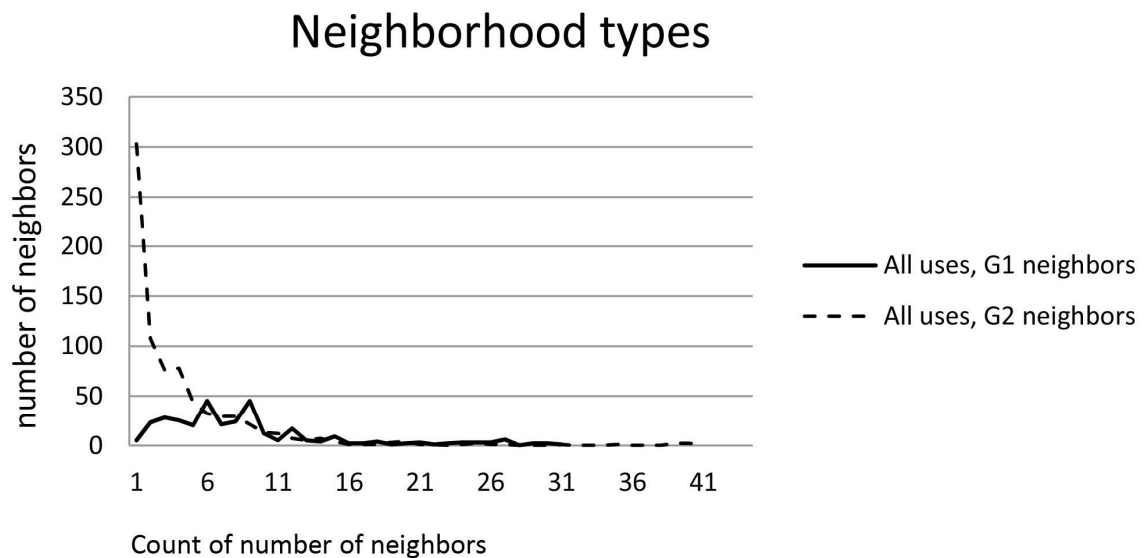


Figure 6. Number of similar neighbors, sites with certain activity (group 1) and sites with “no certain activity” (group 2).

For example, the sites in industrial use had more likely industrial neighbors than the sites without industrial use. Moreover, the share of 0-1 neighbors was greater in sites with no certain activity (G2), while in G1 the greatest share of sites was of those with more similar neighbors within all the activities examined (industry, warehouses, services, retail) and time series, which refers to a high probability of agglomeration and existence of internal order seems evident.. (Figure 7)



Figure 7. Example: Agglomerations of the use “industry” 2008.

7.3 Increasing complexity: longitudinal study of agents

Comparison between the relative shares of production categories indicates a further decrease in already somewhat diminished agrarian production from four to one percent; a decline of traditional industry from 58 to 12 percent, and the service sector first increasing from 35 to 62 percent between 1971 and 1982, but later decreasing to 53 percent by 2008. The emergence of information technology (from zero to eleven percent) and the expansion of the culture industry (from two to 14 percent) take place later, between 1982 and 2008 (Table 2.).

	1971	1982	1993	2008
AGR	6	4	3	3
IND	79	29	42	32
SERV	48	57	92	142
INFOR	0	0	13	30
CULT	3	2	10	37
MISSING				
DATA	0	0	11	24
ALL	136	92	171	268

Table 1. Absolute numbers of activities, 1971-2008.

	1971	1982	1993	2008
AGR	4%	4%	2%	1%
IND	58%	32%	25%	12%
SERV	35%	62%	54%	53%
INFOR	0%	0%	8%	11%
CULT	2%	2%	6%	14%
ALL	100%	100%	94%	91%

Table 2. Percentiles of activities, 1971-2008

7.3.1. Shannonian information

Figure 8 presents the same progress as Shannonian information (I). After the slight decrease from 16 (1971) to 14 (1982), the values increase dramatically from 14 first to 21 (1993) and then to 24 (2008) as the number of activities increases from 136 (92) to 268.

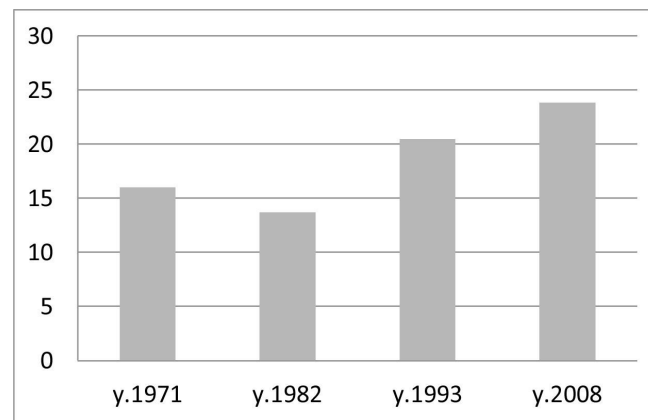


Figure 8. Shannonian information, absolute values (I).

The relative shares of information (i) reveal how introducing new categories affects entropy. From 1971 to 1982, only minor changes occur in the amount of information, from 12.29 to 12.40 slightly increasing the amount of relative information. Interestingly, from 1992 to 2008 the amount of information decreases from 16.08 to 15.80, despite an increase in the number of activity indicating decreasing entropy and self-organization. The major leap from 12.40 to 16.08 takes place between 1982 and 1993; this progress is parallel to the emergence of a new category that of information technology. This method seems to emphasize the increasing of the values

when the first value is zero, ignoring the expansion of the culture industry from three actors to 37 between 1971 and 2008 similar to the growth in information technology (from zero to 30). The method could be criticized for over-emphasizing non-existing values – according to Equation 2, the $\log_2 0$ equals “indefinite”, and thus yields no value. This is a limitation of applying a strictly mathematical method in a fuzzy real world case - delineating categories is not always precise (e.g. “cultural activity” vs. “culture industry”), and availability of data can affect which years can be compared.

The analysis indicates that self-organization starts to occur only between the last two time steps (figure 9). This finding is parallel to what Haken and Portugali suggest – as a new “type” is introduced, the information (i) first increases but soon starts to decrease (Haken and Portugali 2003).

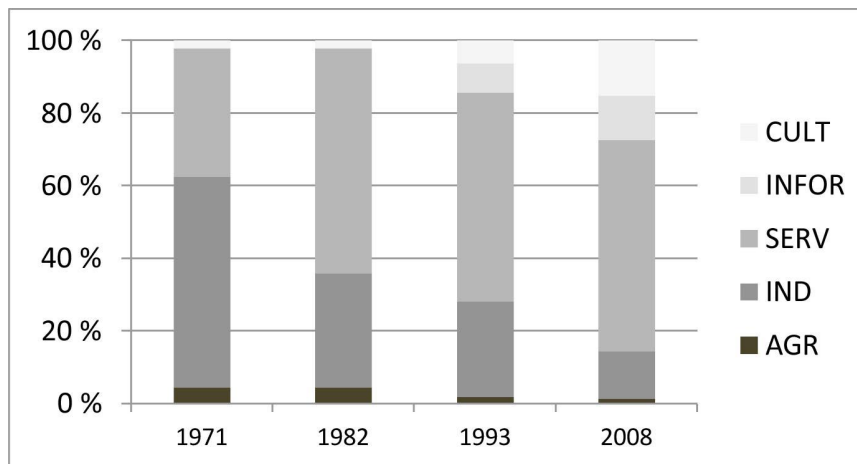


Figure 9. Relative shares of activities by production type.

The results indicate increasing information and decreasing entropy, and a high capability to reflect the global “phase transitions”. In the case of Nekala, the complexity increases in two ways. Network of neighborhood relations expands among similar activities and categories of industries increase: new “species” emerge from transitions of production modes (Figures 1 and 9).

Furcative, critical points seem to exist in the generation of production, referring to “enslaving” of earlier modes. The area is neither redeveloped nor deserted, but adapting to its environment. Perhaps the diversity of activities operates analogically to nature: the greater the variety of species, the more viable the system is (Jacobs 1984, 1992). The area adapts to changes in the environment in a self-organizing manner, apparently enabling the emergence of innovations which accelerate the city evolution.

7.4 Validation

As regards the objectives of this study, a crucial question is whether the method does indeed measure self-organization. The space syntax is considered only to reveal the potential for adequate flow for self-organization. The main interest is in the validation of the internal order and enrichment.

This part was carried out by observing whether resulting data follows certain power law, indicating that the system is close to the critical point, as the organization of entities results from interactions between them. A scatterplot was created on logarithmic scales using the combined data on the neighborhoods of the sites representing the internal order. The plot fitted the least-squares, but only partially. The number of small neighborhoods ($N < 2$) in particular was remarkably low for G1. In addition, in the 2008 data set a couple of extreme values (30-32 neighbors) resulting from the high frequency of activities in the area was also exceptional. These limitations of the method are noted in the literature: often only the tail of the plot follows the rank size distribution, and the extremely high values do not fit into it (Clauset et al 2009). These exceptional values are sometimes considered the most interesting – e.g. under-representation of the sites with the smallest neighborhoods, imply a fairly strong agglomeration tendency. Complementary methods such as goodness-of-fit and likelihood ratio tests could help to overcome these limitations (Clauset et al. 2009). Yet due to the metaphorical nature of the study this type of rough estimation was considered relevant. For comparison, the distributions with $N > 0$ and $N > 1$ were carried out.

The data set G2 fitted the least-squares fairly well: for G2 $c = -1.9613$ and $R^2 (G2) = 0.8899$. For G1 the fit was even better: $c = 2.0083$ and $R^2 (G1) = 0.937$ (Figures 10 and 11).

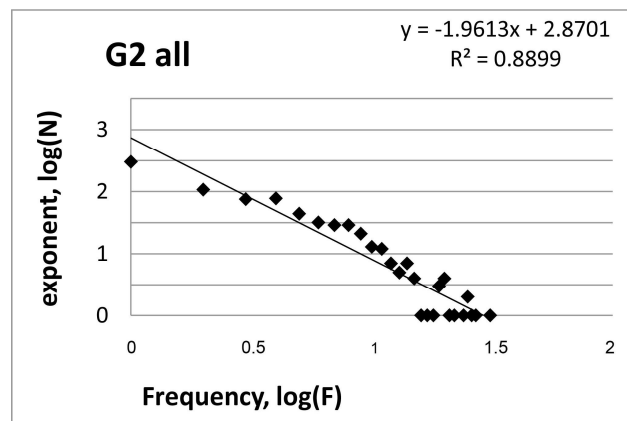


Figure 10. Number of neighborhoods of various sized G2 sites on a double logarithmic scale. Also showing the best-fit line to data.

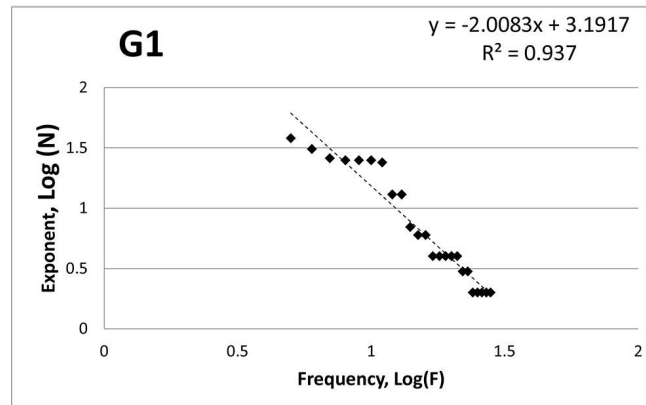


Figure 11. Number of neighborhoods of various sizes for G1 sites on a double logarithmic scale. The data sample follows the rank size distribution. Also shows the best-fit line to data.

The mechanism of enrichment was validated using the same method. Due to the very limited number of observations, these results can only provide guidelines for future studies; although the rank size rule is plausible with absolute values of coefficients between 1.5 and 3 and R^2 between 0.95-1.0. (Figure 12).

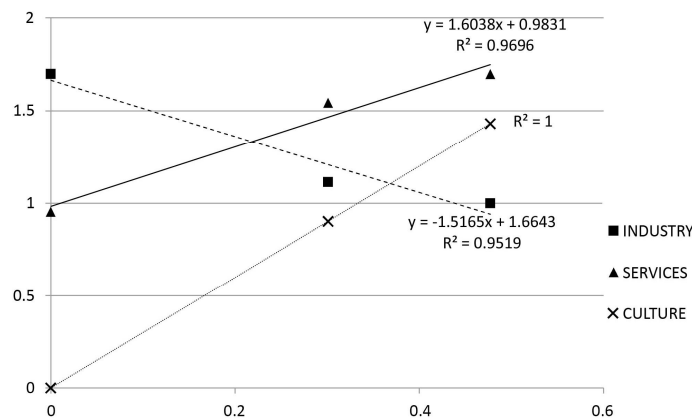


Figure 12. Mechanisms of enrichment on industry, service and culture.

The results of the validation suggest the potential self-organizing criticality, and may refer to self-organization. For accuracy, the observations need more thorough investigation.

From the planning's perspective, border conditions in Nekala seems favorable for self-organization. Building on empiria and theories of self-organization, the indicators discovered could also be applied to reveal potentially self-organizing areas with e.g. adequate coinciding accessibility and perhaps embryonic internal order, but still limited temporal patterns due to

their age. In case such potential is discovered, planning could better support the generative process in these areas.

8. Discussion

Self-organization can be considered one of the most powerful explanations of how complex open systems operate. Within this pre-evolution of unanimous matter order emerges from the system's internal premises. The crucial question is how we could better understand this phenomenon, and integrate such understanding into city management and planning to support these autonomous processes. Here I propose that *internal order*, *enriching* and *flow* are appropriate indicators for self-organization in certain generative urban areas, and a method for discovering and applying these indicators in urban planning. This approach could help to sustain existing work pools such as Nekala and similar areas, and support the emergence of new ones. Naturally humans' ability to plan makes cities crucially different from self-organizing systems in nature: it reflects some aspect of human systems, but does not entirely explain them. The considered use of this metaphor provides a richer interpretation of reality, serving as a lens helping us to focus on issues formerly hidden or obscure.

On a general level, this approach increases our knowledge of self-organizing in cities and may enhance our operational expertise, enhancing planning praxis to support dynamic, adaptive urban processes. Such planning approaches could include, for example, a "dynamic" plan, based on the changing relations between actors instead of static zones or areas. Dynamic simulations provide relevant tools for exploring the outcomes of such plans.

The limitation is that the analysis is based on certain temporal and spatial configurations, which in reality are far more dynamic, emerging from the interplay between regulation and self-organization on many levels, with complex interactions (Reed and Harvey 1992). Yet since any representation of reality is based on decisions, in this case I evaluate only one temporal section of the physical world instead of the myriad underlying processes.

Other implicit location principles besides agglomeration are beyond the scope of this paper. These factors impact agents' behavior, but the results of this study nevertheless indicate a certain tendency to agglomeration between similar activities. These principles should be studied more thoroughly in the future, and a comparative research needs to be replicated elsewhere. Such approaches provide a basis for educational dynamic simulations to learn more about the processes, to be able to make "good guesses about our future cities" (Haken 1980, p.128).

References:

Ahern, J. (2011): "From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world" *Landscape and Urban Planning* 100, pp 341–343.

Alexander C, Ishikawa S, Silverstein M, 1977, *A pattern language* (Oxford University Press, new York)

Alfasi N, Portugali J, 2007, "Planning Rules for a Self-Planned City" *Planning Theory*, **6**(2), pp 164-182.

Allen P, 2004 *Cities and regions as self-organizing systems* (Oxon, Taylor&Francis)

Bak P, 1990, "Self-Organized Criticality" *Physica A* **163** 403-409

Barton S, 1994, "Chaos, self-organization, and psychology" *American Psychologist* **49**(1), 5-14

Batty M, 2007, *Cities and Complexity* (MIT press, Cambridge)

Batty M, Longley P, 1994, *Fractal cities: a geometry of form and function* (Academic press, London)

Batty M, Marshall S, 2009, "The evolution of cities: Geddes, Abercrombie and the new physicalism" *Town Planning Review*, **80** (6). <http://www.complexcity.info/files/2011/06/batty-tpr-2009.pdf>.

Batty M, Marshall S, 2012, "The Origins of Complexity Theory in Cities and Planning" in *Complexity Theories of Cities Have Come of Age*, Eds J Portugali, H Meyer, E Stolk, E Tan (Springer, Berlin Heidelberg) pp 21-45

Caniggia G, Maffei, G L (eds) 2001 *Architectural Composition and Building Typology. Interpreting Basic Building* (Alinea Editrice s.r.l., Firenze)

Castells M, 2000 *The Information Age: Economy, Society and Culture. Volume 1. The Rise of Network Society* (Blackwell Publishing, Oxford)

Collier J, 2004 "Self-Organization, Individuation and Identity" *Revue Internationale de Philosophie* **59** 151-172

Clauset A, Shalizi C R, Newman M E J, 2009, *Power-Law Distributions in Empirical Data* arXiv:0706.1062v2 [physics.data-an]

- Deleuze G, Guattari F, 1987 *A Thousand Plateaus* (Minnesota University Press, Minneapolis)
- Duarte J P, 2011, "Towards a methodology for flexible urban design: designing with urban patterns and shape grammars" *Environment and Planning B: Planning and Design* 38, pp 879 – 902
- Eigen M, 1971 "Self Organization of Matter and the Evolution of Biological Macromolecules" *Die Naturwissenschaften* 58(10) 465-523
- Eigen M, 1977, "The Hypercycle: A Principle of Natural Self-Organization. Part A: Emergence of the Hypercycle" *Die Naturwissenschaften* 64(11) 541-565
- Florida R, 2000 *The Rise of the Creative Class and How It's Transforming Work Leisure, Community And Everyday Life* (Basic Books, New York)
- Fujita M, 2007 "Towards the new economic geography in the brain power society" *Regional Science and Urban Economics* 37 482 – 490
- Handy S L, Niemeier D A, 1997 "Measuring accessibility: an exploration of issues and alternatives" in *Environment and Planning A* 1997 29 1175-1194
- Haken H, 1980 "Synergetics: Are Cooperative Phenomena Governed by Universal Principles?" *Die Naturwissenschaften* 67 121-128
- Haken H, Portugali J, 2003, "The face of the city is its information" *Journal of Environmental Psychology* 23 pp 385–408
- He C, Okada N, Zhang Q, Shi P and Zhang J, 2006, "Modeling urban expansion scenarios by coupling cellular automata model and system dynamic model in Beijing, China" *Applied Geography* 26, pp 323–345
- Hensel M, Achim M, and Weinstock M (eds.), 2004, *Architectural Design vol 74*. (Wiley Academy, West Sussex)
- Heylighen F, 2003, "The Science of Self-organization and Adaptivity", in: *Knowledge Management, Organizational Intelligence and Learning, and Complexity*, in: *The Encyclopedia of Life Support Systems* (Eolss Publishers, Oxford)
<http://pespmc1.vub.ac.be/Papers/EOLSS-Self-Organiz.pdf>.
- Hillier B, 2007, *Space is the machine. A configurational theory of architecture*
<http://discovery.ucl.ac.uk/3881/1/SITM.pdf>

Hodgson G M, Knudsen T, 2011, "Generalized Darwinism and Evolutionary Economics: From Ontology to Theory" *Biological Theory* **6** 326–337

Holland J H, 1998 *Emergence – from chaos to order* (Perseus Books, Cambridge, Massachusetts)

Holling C S, 2001, "Understanding the Complexity of Economic, Ecological, and Social Systems" *Ecosystems* **4** 390-405

Jacobs J, 1992 [1961], *The Death and Life of Great American Cities* (Vintage Books, New York).

Jacobs J, 1984 *Cities and Wealth of Nations Principles of economic life* (Random House, New York)

Joutsiniemi A, 2010 "Becoming Metapolis. A Configurational Approach"
<http://URN.fi/URN:NBN:fi:tty-201102031031>

Kauffman S, 1995 *At home in the Universe. The Search for the Laws of Self-Organization and Complexity* (New York, Oxford University Press)

Keller E F, 2009, "Organisms, Machines, and Thunderstorms: A History of Self-Organization, Part Two. Complexity, Emergence, and Stable Attractors." *Historical Studies in the Natural Sciences* **39**(1) 1-31.

Krugman P, 1996 *The Self-Organizing Economy* (Blackwell, Cambridge)

Levy M, Solomon S, 1996, "Power Laws are Logarithmic Boltzmann Laws" *International Journal of Modern Physics C* **7**(4) 595

Lynn G, 1998, "Blob", in *Greg Lynn. Folds, bodies&blobs. Collected essays.* Eds M Lachowsky J Benzakin (La letter vole, Belgique) pp 157-168

Marshall S, 2009, *Cities, design and evolution.* (Routledge, London/New York)

MVRDV, 1998, *Farmax - excursion on density* (010 publishers, Rotterdam)

Närhi K, 2009, "NEKAPOLIS – tai kaupunginosan tulevaisuus", Master's thesis, School of Architecture, Tampere University of Technology, Tampere.

O'Sullivan A, 2009, *Urban Economics* (McGraw-Hill Irwin, New York)

Odum H T, 1988, "Self-Organization, Transformity, and Information" *Science, New Series*, **242**(4882) 1132-1139

Oswald F, Baccini P, 2003 *Netzstadt – designing the urban* (Birkhäuser, Basel-Boston-Berlin)

Pelino V, Matera A, Colombo T, Giorgi F, 2006, "Validation of precipitation events in a regional climate model simulation using methods from complex systems theory" *Theoretical and Applied Climatology* **84** 213–218

Picone G, Ridley D, Zandbergen P, 2009, "Distance decreases with differentiation: Strategic agglomeration by retailers" *International Journal of Industrial Organization* **27** 463–473

Pickett S T A, Cadenasso M L, Grove J M, 2004, "Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms" *Landscape and Urban Planning* **69** 369–384

Portugali J 1999 *Self-organization and the city* (Springer-Verlag, Berlin Heidelberg NewYork)

Portugali J, Meyer H, Stolk E, Tan E, (eds.) 2012, *Complexity Theories of Cities Have Come of Age: An Overview with Implications to Urban Planning and Design* (Springer, Heidelberg).

Prigogine I, 1978, "Time, Structure and Fluctuations" *Science* **201**(4358) 777-785

Prigogine I, Stengers I, Toffler A, 1984 *Order out of chaos* (Bantam Books, Toronto - New York – London – Sydney)

Pumain D, 2012, "Urban Systems Dynamics, Urban Growth and Scaling laws: The question of Ergodicity" in *Complexity Theories of Cities Have Come of Age*, Eds J Portugali, H Meyer, E Stolk, E Tan (Springer, Berlin Heidelberg) pp 91-103

de Propris L, 2005, "Mapping Local Production Systems in the UK: Methodology and Application" *Regional Studies* **39**(2)197-211

Reed M, Harvey D L, 1992, "The New Science and the Old: Complexity and Realism in the Social Sciences" *Journal for the Theory of Social Behaviour* **22**, pp 356-79

de Roo G, Hillier J and van Wezemael J, (eds), 2012, *Complexity and Planning: Systems, Assemblages and Simulations. New Directions in Planning Theory* (Ashgate, Farnham)

de Roo G, Silva E A, (eds) 2010, *A Planner's Encounter With Complexity. New Directions in Planning Theory* (Ashgate, Farnham)

- Salingaros N, 2000, "Complexity and Urban Coherence" *Journal of Urban Design* 5, pp 291-316.
- Shalizi C R, Shalizi K L, Haslinger R, 2004, "Quantifying Self Organization with Optimal Predictors" *Physical Review Letters* **93**(11), <http://arxiv.org/pdf/nlin/0409024.pdf>
- Shane D G, 2005 *Recombinant Urbanism – Conceptual Modeling in Architecture, Urban Design and City Theory* (John Wiley & Sons ltd, London.)
- Shannon C E, 1948, "A Mathematical Theory of Communication" *The Bell System Technical Journal* **27** (3) 379–423
- Shi W, Pang M Y C, 2000 "Development of Voronoi-based cellular automata—an integrated dynamic model for Geographical Information Systems" *International Journal of Geographical Information Science* **14** (5) 455–474
- Sieverts T, 1997 *Cities without cities* (Spon Press, London)
- Stevens D, Dragicevic S, 2007, "A GIS-based irregular cellular automata model of land-use change" *Environment and Planning B: Planning and Design* **34** 708 – 724
- Tan E, Portugali J, 2012, "The Responsive City Design Game" in *Complexity Theories of Cities Have Come of Age*, Eds J Portugali, H Meyer, E Stolk, E Tan (Springer, Berlin Heidelberg) pp 369-390.
- Varela F G, Maturana H R, Uribe R, 1974, "The Organization of Living Systems, its Characterization and a Model" *Biosystems* **5** 187-196
- Velupillai K, 1986, "From the Fractals of Micro to the Chaos of Macro" *Journal of Economic Dynamics and Control* **10** 269-272
- Webster C, 2010, "Emergence, Spatial Order, Transaction costs and Planning" in *A Planner's Encounter With Complexity*, Eds G de Roo , E A Silva (Ashgate, Farnham) pp 123- 138
- Wolfram S, 1983 "Statistical mechanics of cellular automata" *Reviews of Modern Physics* **55**(3) 601-644
- Wolfram S, 1994 *Cellular Automata and Complexity: Collected Papers* (Addison-Wesley, Reading, Massachusetts)

II

COMPLEX PATTERNS OF SELF-ORGANIZED NEIGHBOURHOODS

by

Partanen, J. & Joutsiniemi A. (2015) in Boelens, L & G. de Roo (eds.):
Spatial Planning in a Complex Unpredictable World of Change:
Towards a proactive co-evolutionary type of planning, InPlanning,
Groningen.

Copyright © InPlanning co-op, 2015

Reproduced with kind permission by InPlanning co-op.

Abstract

Complexity theory has increased our understanding of cities as dynamic, self-organizing systems. However, the planning practice of today often collides with the complex urban realm, and is incapable of steering or even recognizing self-organization. Since many self-organization mechanisms may actually be indispensable to the city, we need a better understanding of them to develop appropriate planning tools. In this paper the complex nature of self-organization in the industrial district of Nekala in the Finnish city of Tampere is studied using isovist analyses for statistical observation to confirm the inner diversity of the spontaneously evolving phenomenon. The conclusion section includes some remarks on accommodating self-organization principles in planning.

Keywords: self-organization, complexity, urban planning, evolution, urban processes

Introduction

A large share of urban planning practice in Europe and in western societies more generally is still concentrated on attempts to control urban development in a top-down manner. This view of the city clashes with the autonomously generating urban realm with myriads of interdependent actors and mechanisms on many scales which are right out of control. The problem is addressed with participatory methods, which, on the one hand, have run into problems of framing and coordination of contradictory desires and, on the other, a lack of a shared vision of viable development positions. Theories of complex systems have recently provided an equivalent and partially competing frame for understanding the city in the light of its intrinsic unpredictability. The emphasis in this is the dynamic, self-organizing, non-equilibrium, trans-scalar nature of cities. It has succeeded in articulating in a credible manner the systemic errors and expectations associated with control, hierarchy and assumed static equilibrium in today's planning.

Within the western planning discourse self-organization and spontaneous development are insufficiently understood, in spite of strong evidence of a dominant way in which many complex systems – including cities – organizes themselves. (Batty 2005, Portugali 1999, Krugman 1996) Planning seems to fail repeatedly in its efforts to control self-organization and this manifests itself in many ways: as the unpredictable re-location of industries and retail; shifts

in economic performance; urban sprawl; surprising traffic behaviour or phenomena such as edge cities and growth on the urban fringe (see e.g. Sieverts 1993; Garreau, 1991; Bettencourt *et al* 2007).

The dynamics described here can be found throughout history from cultural evolution to the progression of modes of production in societies, shifts from agrarian to industrial and more recently to information society are examples of such non-linear, evolutionary progress (Castells 2000). The feature is typical of human (and other open) systems – and crises are inevitable. However, today's planning commonly builds on ambitious end-state rationalism and vague premises of system equilibrium, assuming that it is to some extent possible to reach a permanent steady state. According to complex theories, however, this is impossible. Multiple dynamic equilibria of numerous coexisting and networked social, economic, technical etc. systems dramatically increase the unpredictability of the urban system as a whole in the long run. However, forking development in cities is not random either, but to a great extent related to a phenomenon that we call self-organization. Even though we operate within a strictly circumscribed planning world this is not mere rhetoric.

Despite this, many intrinsically neutral aspects of self-organization are considered - especially in common planning thinking – negative. The focus then is on the malfunctions e.g. traffic jams, sprawling urban structure etc. with very little concern for the fact that some of these unavoidable generic processes and systemic externalities may also be beneficial to the city. For example, regional scale clustering of high-tech industry and more generally the entire agglomeration tendency is a well-known example of urban self-organization with a positive impact. The performance of firms is better when located in proximity to similar actors, and planning should not (and usually does not) prevent it. The clustering tendency has been widely studied on a regional scale (O'Sullivan, 2009; Marshall, 1890; Porter, 1998; Fujita, 2007) but far less in the equally relevant local context.

The aim of the paper is to analyse traces of the complexity phenomenon in local level clustering. The study area is the industrial district of Nekala in the Finnish city of Tampere, which over a period of 40 years has gone through multiple sequential planning phases with multiple planning goals. Therefore, even though the change has come about within the legal planning frame, the overall incremental development is best described as spontaneous.



Figure 1. Aerial of Nekala

The challenge of organizing the complexity is not a novel idea and academic research on planning self-organizing complex settlements is ongoing in multiple arenas. However, research on actual spatial self-organization mechanisms in cities is still rare, hence also our understanding of the diversity and nature of these processes. To build planning tools to support positive self-organization for promoting economic viability and avoiding negative development, we first need to know more about the characteristics and interlinkages of physical self-organization mechanisms currently existing in cities. The loosely controlled nature of special, generative areas with a high capacity for self-organization and a role as facilitators renders important the documentation of the dynamics of self-organizing enclaves and a thorough understanding of their impact on the emergence of neighbourhoods. These enclaves are often old industrial areas, or other decaying areas in transition. Following the natural scientific trail of complexity studies, a quantitative approach was chosen to explore statistical regularities of self-organization in our study area using isovist analyses and scaling of cluster formations.

Nekala area forms a clearly distinguishable enclave with a seemingly large capacity for generative renewal. Former agrarian production and heavy industrial uses in Nekala have gradually been replaced by an increasing variety of activities: Nekala has adapted to the dominant modes of society from simple industrial use to a complex mixture of industrial use, services, information technology and, more recently, cultural uses (Partanen 2015). In contrast to many similar industrial districts primarily planned for heavy industry, the transitions in society never caused a vicious spiral of decay as changing manufacturing jobs decreased or moved from such central areas. Instead, the tendency in Nekala has been towards a constant chain of renewals, filling up the deserted factories and other properties like a car body factory, a slaughterhouse, or a cardboard factory, with small actors representing the emerging mode of production, such as recently a circus school, advertising agency, architect office and several ICT-services and spaces for music production. However, not all the traditional industries have

left – several car repair shops, machinery wholesales and building construction companies (along with a concrete batching plant) are still operational in Nekala. These different uses seem to form varying clusters which most probably also change over time (both in regards of the actor and the location) (Partanen 2015). The diversity of uses and stakeholders in Nekala is most probably reflected in their arrangement of some key interdependencies between actors across industries. Nekala industrial area is one of the most important workplace areas in Tampere region – the second largest urban agglomeration in Finland. The development of the area has followed several planning goals and created a multi-layered industrial ecosystem rather than a well targeted outcome, so it seems likely that some form of self-organization has occurred in Nekala along with its development process. In order to adjust future plans to support such autonomous processes, it is necessary to study the spatial arrangements and potential manifestations of bottom-up processes more closely.

The site plans in Nekala are relatively simple, with only minor variation, hence the expectations for internal complexity are not obvious. The plans have used two generic principles to allocate activities: the permitted usage(s) and predefined maximal *floor area ratios (FAR)*. It is also noteworthy that there is no explicit mechanism in the plan that would directly create any distinguishable sub-cluster formations.

Our strategy was to explore whether greater density correlates with clusters, number of actors and FAR on sites. It was also probable that the plot level restrictions for construction and use played a role in clustering, and the number of permitted uses in the plan in the clusters was compared to ascertain whether the clusters specifically benefitted from less restricted sites. Finally, the effect of age was explored, implying lower quality of facilities and level of rent, on the uses: certain uses might cluster into older, more affordable buildings. The age distribution of all the buildings was compared to the ages of buildings clustering separately for retail, services, warehouses and industry to estimate the effect of age on agglomeration.

The empirical studies presented in this paper are based digital maps and plot structure, workplace data for the period 1971-2007 and the building year records (from 1900 to 1999) all collected and archived by the City of Tampere. The locational analyses were carried out using common desktop GIS software (MapInfo).

Theoretical framework

Self-organization

By self-organization we mean the ability of complex systems to form organized structures without overall control, yet receiving feedback from some systemic level. This is often the case with regulation in cities based on a plethora of rules at multiple levels without a full understanding of their collective outcome. Urban self-organization builds upon the relationships and interactions between local agents (such as firms, individuals), producing a variety of actual dynamic patterns (clusters, networks). Therefore the mechanisms are more evolutionary than planned acts of coordination. Interestingly, as also in natural processes, many of these urban interactions follow certain mathematically measurable principles, such as scaling laws, implying a dynamic interdependency between entities. (Eigen 1977, Kaye 1994, Kello 2010, Bettencourt et al., 2007). These processes of self-organization are neither centrally governed nor random: the actors organize themselves in relation to each other without external guidance (from above).

Self-organization builds upon pioneering studies in mathematics and control theory in the early 20th century. The thinking expanded after the 1960s into biology and physics, and is firmly rooted in the natural sciences (Keller, 2009; Eigen, 1977; Varela et al., 1974; Prigogine, 1978). Formally, self-organization is considered to be an actual mechanism through which patterns emerge from relations among agents and adaptation to a complex system. The emerging patterns may be dynamic, as in biological systems, or static, as, for example, in snowflakes, and occur on the same or higher scalar level (Kaye, 1994). In relation to planning, a concept of self-organization needs an additional remark. Planning, like the majority of human activities aiming to change the course of future development is intentional and the concept of self-organization may seem confusing. We claim that, despite this profound intentionality, the overall development is more or less unpredictable. The intentions of individual actors are micro-scale manoeuvres with only a minor effect on overall development. Even in the case of so-called comprehensive planning ideology the overall development has so many external players that the development is better understood as an emergent, self-organizing whole than as intentionally planned.

In the literature on complex systems several measurable features are associated with self-organization, among them so-called deterministic chaos (implying the temporal irreversibility of processes), and also various cases related to the scaling laws of a system. Scaling laws imply that certain self-organizing patterns emerge repeatedly across the scales¹. They typically occur in systems near critical points or phase transitions, implying a change in the system's state and

¹ Scaling laws express one variable as a nonlinear function of another raised to a power, $F(x) \propto x^\alpha$, $\alpha \neq 0$

reflecting the self-organizing adaptation of agents. (Kello et al., 2010, p.223.). Such scale-dependent characteristics are found, for example, in frequency size statistics and frequency-mass distribution applied e.g. in studies on earthquakes and meteors; allometry in biological systems; fractal drainage networks, occurring in streams and biological branch structures; and time series in river flows, stock markets or the "random walk", to name a few (Kaye, 1994; Kello et al., 2010). Many of these can be mathematically derived to each other (Chen, 2012). Therefore it can safely be assumed the scaling laws are rather universal principles in nature and relevant descriptors regardless of the type of system.

The universality of scaling laws was accepted fairly recently, and it has been much debated whether they are purely coincidental. However, the empirical evidence on scaling is extending across disciplines. It is becoming conceivable that these laws could form a fundamental principle of how all complex, self-organizing systems reach dynamic order via interaction and adaptation, and help integrate distinct scientific disciplines. (Kello et al., 2010, 223; Turcotte et al., 2002). The key characteristic of scaling laws is that they are scale invariant, meaning that an observed property is adaptive on all scales (Kello et al., 2010, 224) and, unlike normal distribution, they succeed in dynamically reflecting regularities and dependencies within the system spatially and temporally transcending scales. These laws reflect the dynamic self-organization of actors in the complex system, causing evolutionary mechanisms to arise (Kello et al., 2010, 223).

From today's planning perspective it is surprising that many processes also found in cities follow rules of this kind and introduce an uncanny idea that certain dynamic self-governing features might also push the development further from the planner's control. In the urban planning perspective perhaps the most challenging feature is trans-scalar dynamics – emergent urban patterns cannot necessarily be predicted even though the agents' interactions are known in detail. In the planning discipline this is often circumvented with a strict built-in hierarchy of plan types (regional plan, general plan, master plan, detail plan). We suggest that some aspects of these patterns can to a certain extent be measured using mathematically discrete methods. Rank size distribution, applied later in this study, is one of these scale-dependent characteristics suggesting a tendency of entities to organize according to their size, typically in an exponential dependency. The rank size rule implies a specific mechanism of self-organization: the entities organize in relation to each other rather than an assumed end state equilibrium – a phenomenon that is difficult to control with a traditional plan due to the vast number and diversity of actors and the inbuilt (unknown) logics of the planning game.

Complexity in planning

European planning systems rely by and large on modernistic ideas of a city as a static entity which, under proper control and regulation, is kept in a state of equilibrium – or at least out of imbalance and away from system states considered flawed. Only recently have theories of complex systems proposed that this imbalance is actually an intrinsic, unavoidable feature of a city. Complexity implies that evolutionary dynamics, manifesting as continuous critical oscillation between stability and instability – with those inbuilt “flaws” – is actually essential for cities to remain resilient and survive. (Batty, 2007; Portugali, 1999; Allen, 2004) Complex urban formations renew themselves through these crises. Furthermore, the observed seemingly steady state of everyday life is in fact not that static, but rather results from myriads of constant changes on micro-level only hidden by the moderate predictability of the immediate future.

In our study area certain traces of a self-organizing tendency and agglomeration of activities seem evident. From the perspective of economic viability we claim that this probably important mechanism should be acknowledged (and encouraged) by planning and therefore better understood. To implement the theoretical framework of complexity and evolution in planning, our aim is to study local clustering and especially the potential impact of factors affecting it (in addition to proximity), namely, *spatial features, co-existence of (multi-)clusters, building age and plan*, and to explore whether potential new patterns emerge from interaction among these factors.

Tracing self-organized clusters

The self-organization of activities is best understood as a trans-scalar phenomenon – as interlinked and networked activities reaching from the neighbourhood corner shop to the global system of cities. Despite the essential fact in any modelling task that many important triggers must be left out, any observed system must be defined in an appropriate manner according to the scale of the phenomenon studied. Thus in the study of self-organization the borders between the chosen systems ought to be porous throughout the scales. Large-scale urban clustering has been widely studied (Marshall, 1890; Porter, 1998; Fujita, 2007), but a smaller observation scale can be even more appropriate, for example, if the primary focus happens to be on the evolutionary, e.g. the informal exchange of information promoting creativity, which is one of the puzzling tasks in our study area as well. Furthermore, today the way this clustering of economic actors enhances knowledge creation, the innovation process and interactive learning is becoming more important than the cost efficiency essential on a larger scale (Malmberg and Maskell, 2002).

In the ideal planning setting, the fundamental logic of actors to constantly seek for more preferable locations is often overlooked. Instead of focusing on the appearance and externally targeted description of district, it is important to distinguish the factors that create the inner conditions of mutual exchange between stakeholders. Such a factor could be agent configuration and the proximity to similar actors in it. For this the wisdom must be sought elsewhere than in planning itself.

Agglomeration economics sheds light on the principles underlying the clustering of activities. The clustering may occur, first, within one industry to share intermediate inputs, labor pool, spillovers (called localization economies). Secondly, various actors may be attracted to a wider city region to benefit from sharing important facilities (e.g. banks), labour pooling and better labour matching in a self-enforcing process (known as urbanization economies), implying that firms attract other firms across industries (O'Sullivan, 2009) and resulting in large diverse cities. Both approaches contemplate the regional, macro-scale dynamics of clustering – actors observe the environment on a regional scale. Another aspect of agglomeration is competition attracting similar firms to locate within geographical proximity of one another to benefit from the same customers. In addition, co-operation becomes significant - arising from mechanisms related to sharing, learning or matching (Duranton and Puga, 2004) analogical to the evolutionary concepts of imitation, mutation and adaptation discussed above. The structure of relations in these mechanisms is not always dependent on geographical proximity alone.

The concept of proximity in an evolutionary context

In evolutionary views concentrating on co-operation facilitating innovations, Boschma and Frenken (2010) define the concept of proximity in a dynamic actor network to be more generally related to knowledge dissemination between similar actors. Thus proximity refers to the linkages between actors not necessarily geographically close to each other. Consequently, five types of proximity become relevant in these networks: institutional, organizational, geographical, social and cognitive proximity, implying similarities in the institutional (laws, regulations) (company's) organizational structure; spatial vicinity, social connections, and similarity of the knowledge base (Balland 2009, Boschma and Frenken 2010). Most probably these types are present in all networks to an extent; however at least one of them is required for innovation facilitation (Balland 2009).

It is likely that in Nekala many of these are present (due to the national and international companies in the area alone). We concentrate in this study on geographical proximity: geographical proximity and the (related) diversity (Boschma and Frenken 2011) is considered to be the most important for the actors in the growth phase (Henderson et al 1995, Neffke et al 2011, Boschma and Frenken 2011); as the actors grow, they are likely to flow to more localized, specialized locations (Duranton and Puga 2001, Holl 2004). There is also certain – yet not fully

documented – proof of similar dynamics in the case area. In mature (perhaps even lock-in) situations – as is the case with many typical decaying industrial areas - geographical proximity plays a less important role, and other network linkages become more relevant (Boschma and Frenken 2011). As regards Nekala, an increasingly diverse breeding ground, we assume that it has an ability to constantly renew itself, allow an outflow of mature firms, attract new actors, and avoid lock-ins. Thus it is justified to propose that geographical proximity (untypically) has remained important in Nekala, along with geographical aspects of (temporal) organizational and social structures benefitting from face to face interaction (Balland 2009), especially as regards the creative industries continuously increasing in Nekala (O'Sullivan 2009).

Micro-scale factors

In physical systems factors of the immediate surroundings of any entity determine the behaviour of that entity to some degree - the actors seek a combination of features and externalities of the site best suited to their preferences. These *micro environmental factors* are also found in the social environment - the character of the area emerges from the diversity of activities and user groups and causes adaptation or resistance to change in the neighbourhood (Andrews, 1971).

It is assumed that physical characteristics – quality and the maintenance level of the environment; topography, site shape and orientation, and spatial characteristics – exert their influence in close proximity to the site. In its most simple form this can be seen in everyday activity, where the spatial characteristics related to the visibility of activities in a space affect the location choice: agents have some preference for activity they can easily see over the unknown, hidden from immediate perception. The so-called isovist approach, which is based on the calculation of the visibility field from the point of observation, provides a discrete method for measuring many aspects of visibility in space, for example the (mean) lengths of the longest views, the diameter or the area of the field of vision, or various other relations between them. Comparing these measurements in various built-up areas reveals the features typical of a certain area, block or building (Turner et al., 2001; Batty and Rana, 2004).

Operating environment defined by hard economic factors forms another set of important information sources for an actor: The property rents and maintenance costs of the property, both related to the age (or condition) of the building, affect how desirable the site is for the actor. Furthermore, their economic performance depends on competition and potential co-operation (based on personal encounters in the space) both with similar and non-similar actors which may cause neighbourhood scale agglomeration of similar actors, or the attractiveness of a more diverse environment may produce simultaneous *multi-clustering* of diverse actors across

industries (Andrew 1971, O'Sullivan 2009, Fujita 2007). In addition to physical characteristics and economic factors, the micro-scale institutional environment - laws, regulations, or planning rules of the site – is also critical for actors' choices of location. In terms of fit between controls and actual processes (and self-organization) much depends on the flexibility of these regulation (Andrews 1971, p.54). Under ordinary circumstances it is assumed that the activity patterns follow the main lines of the regulation, but it is not unusual for the plan to be updated for specific project purposes. In incremental planning ideology these flexible but contradictory adjustments to prevailing planning schemes requiring additional degrees of freedom to host more complicated process are common, but also steer away from the rationale of comprehensive long-term planning ideal.

Malmberg and Maskell (2002) note that observed cluster formations rarely conform to standard industrial classification. Expanding the classification beyond existing groups of firms might also reveal significant yet unrecognized agglomerations. For us the re-classification of the activities according to potential spatial interaction via customer behaviour, competition, co-operation and interaction with the immediate environment in Nekala helped to identify novel types of agglomeration across firm types. New, more specific clustered activities were *retail, services, industry and warehouses*. Therefore, hypothetically, local-scale factors – spatial characteristics, co-existing networks, site plans and the age of the buildings – affect the locations of these activities and produce unplanned, self-organizing patterns. The plans themselves did not provide more than a vague industrial activity definition across the entire area.



Figure 2: *Clusters of industry, 1989.*

In a detailed study the activities in Nekala were explored using time series and the number of similar neighbouring activities was calculated. The clusters with specific activities were compared to sites outside the clusters (e.g. sites with retail and sites with no retail). Based on

this straightforward analysis, clustering seemed to be typical for the area: 96% of actors located as a part of the cluster of similar actors (Figure 2). Whether this was a result of self-organization, the dynamics needed to be compared to a demonstrably generative mechanism, in this case rank size distribution, revealing that self-organization was indeed evident Figure 3. We assume that the reasons for this behaviour were attraction based on co-operation and competition, even though the role of other local factors - the co-existence of clusters, spatial characteristics, building age or site plan - cannot be ignored. In the next phase these findings were analysed further.

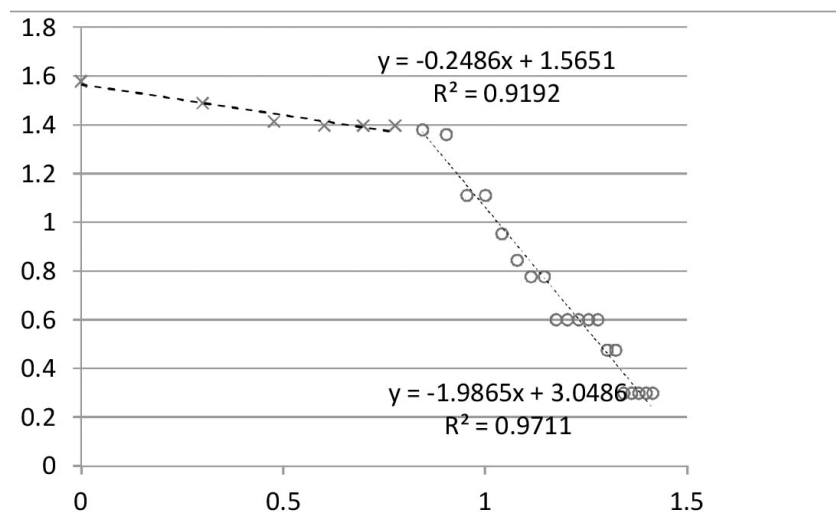


Figure 3: Clustered neighbourhoods ranked on a double logarithmic scale follow the rank size rule.

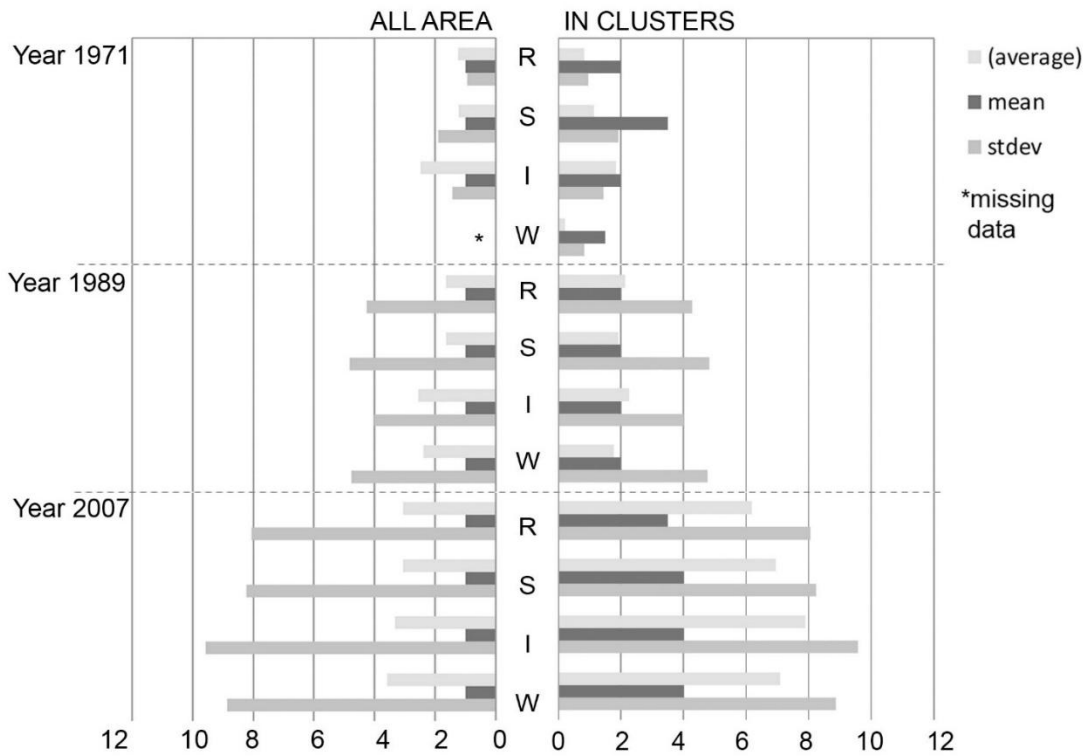
Co-existing activity networks

All clusters occurred simultaneously and none of these dominated the others, and the activities changed over time resulting in constant change and re-formation of the clusters. Therefore it was natural to assume that there was a location-specific mechanism (e.g. attraction or repulsion of clusters, not only similar actors) behind it. This could have been the case, for example, if coexisting/overlapping clusters were remarkably common in the area. Furthermore, perceptible patterns may occur as a result of this potential dynamics. With these aims in mind, the number of neighbours of each activity in clusters was compared statistically to the total number of neighbours of each activity on the adjacent sites. Hypothetically, the resulting variation in mean and standard deviation would indicate the correlation between co-existing activities in these adjacent neighbourhoods and clustering of activities, that is, whether clusters are more likely to emerge on sites with many different actors than on those sites with only a few.

The study revealed that in Nekala many previously unobserved self-organizing processes came to the surface. Certain correlations between the factors, such as agglomeration, overlapping clusters, visibility or plans, were obvious but – typically for complex systems – the causal linkages between the mechanisms and factors would be overly complicated and probably impossible to track. However, examining the mechanisms in detail provides an instructive overview of the convoluted nature of self-organization in Nekala study area.

As regards the coexistence of clusters, it seems that in clusters the diversity of uses is remarkably wider than in general in time series – multi-clusters are fairly common in Nekala. Moreover, in clusters the diversity of activities has recently been growing contrary to the general trend in the area: the number of uses on the site and those adjacent to it has stayed low and exceptionally constant. Since activities in clusters have increased, it seems that there is an attraction mechanism – or gravitation – that causes new actors to locate in these agglomerations, increasing the complexity of the cluster. This mechanism is also dynamic in nature: clusters are not spatially or functionally stable but change, move and transform over time.

Finally, additional differences between clusters and overall area were compared statistically. A summary of these is included in *Figure 4*. In the Nekala study area certain statistical features (means and standard deviations) were fairly similar and predictable over time. The clusters, however, again behaved somewhat differently from the study area as a whole. The relations between the same statistics in clusters seemed to have a specific profile, which changed over time. It is also worth noting that the typical clustering varied over time. Since this is despite the fact that planning principles and methods have not explicitly changed, it is perhaps not unreasonable to assume that the cause is changing economic and social preferences (Figure 4).



R - retail S - services I - industry W - warehouses

Figure 4. Statistical "profiles" of number of neighbours in clusters and all the area.

Characteristics of open space

In order to gain further information on spatial characteristics in cluster formations, the whole area was explored by comparing the visibility areas using isovist analysis. The observation points of isovists were chosen randomly 50 meters apart from each other across the area. The isovists within clusters were then compared to isovists of the area as a whole, outside the clusters and a randomly picked set of areas. The aim was to identify potential profiles within the clusters, suggesting that the characteristics of urban space in this case correlate with the agglomerating phenomenon.

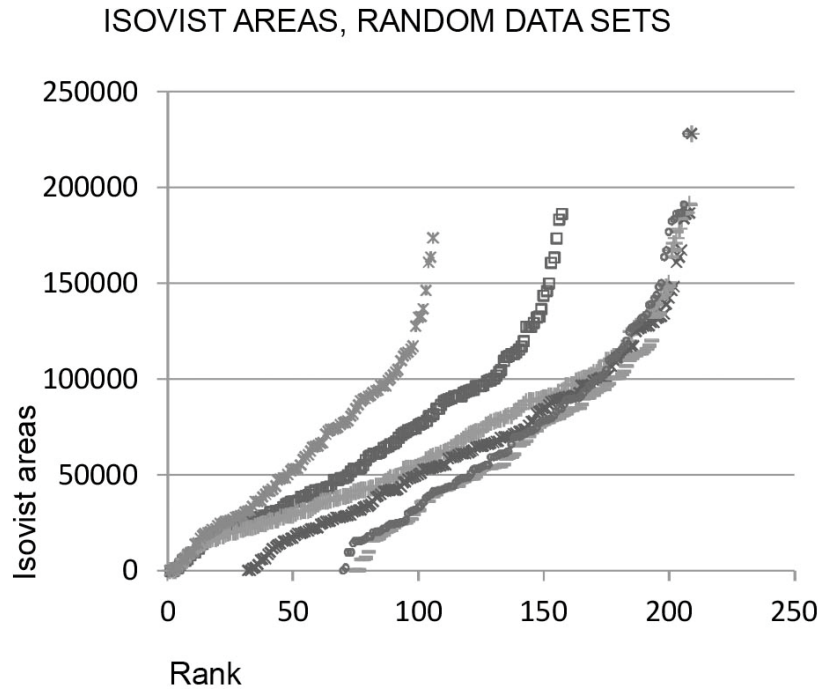


Figure 5. Distribution of ranked isovists, random data

This detailed study of spatial characteristics also revealed some surprising patterns. First of all, as the visibility areas were ranked from smallest to largest separately for all data, random, and data outside clusters, the values for each set seemed to be related to each other. A systematic profile was discerned which in visual examination resembled the logistic curve commonly found in various natural phenomena. (Figures 5) However, the clusters again stood out from the rest of the area. When ranked in groups of small, mid-sized and large, the visibility areas formed distinct, linear distributions with distinctive slopes. (Figure 6) In the literature such transitions are typically found in systems with phase transitions, therefore implying strongly self-organizing system. Again, the locations of isovist areas varied in each case, and the biggest or smallest areas, for example, were not always the same in the comparisons. Therefore it is possible that visibility has some significance in the location decisions of actors; at least the findings suggest that the self-organization mechanism is observed only in clusters. Although it may at first glance seem irrelevant, to us it suggests that it is possible that the main organization principle of our study area is based on spatial characteristics and configuration rather than other normative dimensions of the planning apparatus.

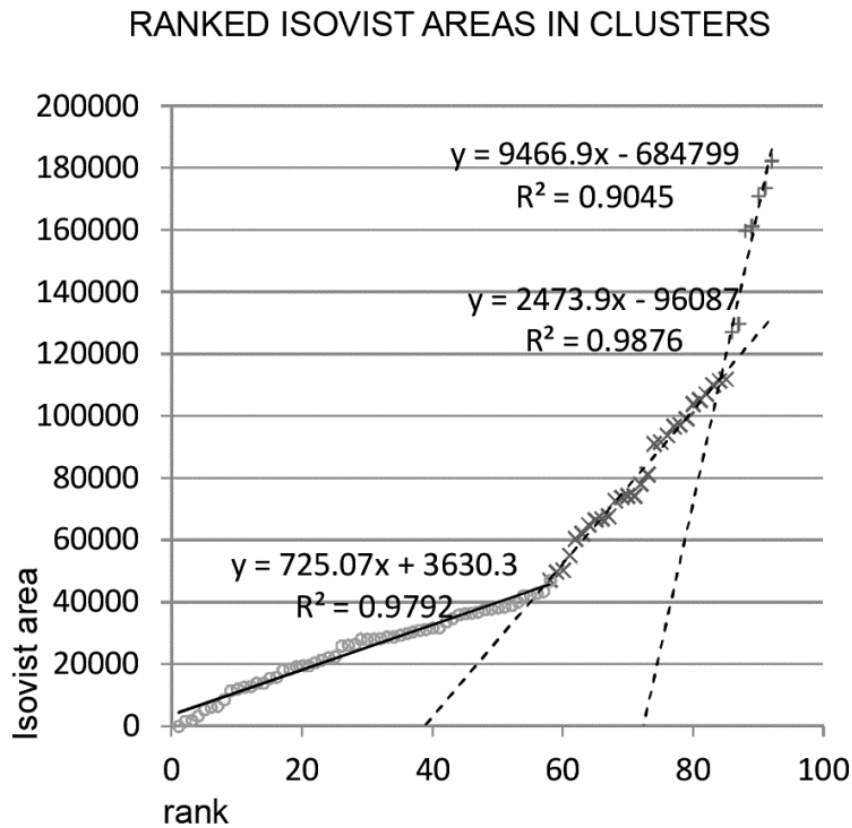


Figure 6. Distribution of ranked isovists in clusters, with “phase transitions” in the system.

The relation between the plan and clusters is fairly obvious: in the clusters the plan generally tolerated more uses (3-4) than the rest of the area – and never fewer uses than two. The result is quite evident and intuitive –the tolerance does not produce clustering, but the clusters emerge following their own self-organizing logic, in a framework of a preferably tolerant plan. Also, it is important to stress that the age of the building or density on the site did not correlate with clustering.

In this study it is not possible to dig much deeper, but it is possible – even probable – that the above factors and mechanisms are interconnected. For example, the overlapping clusters may result from actors seeking certain visibility; a tolerant plan is conducive to cluster formation, but obviously plays no role in spatial hierarchy, or in the actual agglomeration process. After all, the (unplanned) interdependencies of mechanisms are fairly complicated and the plan has only (accidentally) provided an enabling frame for these countless forms of self-organization. It seems that in Nekala it has been enough to let the stakeholders operate under their own premises in the absence of major malfunctions. This alone is a valuable lesson for the planning discipline.

Our further remark on efficient planning practice is that planning is not always (if ever today) a simple, unidirectional process: especially larger projects or somewhat established (but informally emerging) uses may require updating the plan, and form a certain feedback from actors to the planning system. This unspoken policy may also be seen as a relevant way in which the planning institutions with their limited resources respond to the demands of urban complexity. However, due to the vast amount of work required to constantly improve planning procedure, the solution is not the most sustainable. In Nekala, it is likely that the plan has been updated in a more tolerant direction simply by following individual actors' preferences. In an institutional sense the so-called communicative turn never took place, but was by-passed with actor-level degrees of freedom that ensured the mutual benefit.

Discussion

Theories of complex systems provide perhaps the most explanatory paradigm for cities today. The new understanding of complex urban systems emphasizes the trans-scalar, dynamic, non-equilibrium nature, the constant qualitative renewal and evolutionary characteristics of cities. Self-organization is an essential mechanism of how order emerges in complex cities. However, in planning discourse self-organization is currently often used only in a metaphorical way. Its origins in natural science also enable a more discrete measurement and precise study of self-organization in cities in the interests of more considerate planning theory and practice.

Complexity thinking and evolutionary economics provide a perspective for understanding the similarities between the dynamics in city economics and in nature. In complex systems, evolutionary dynamics is essential for systems to remain resilient and survive. Constant shifts between more and less predictable states – too often considered crises – paradoxically sustain continuous urban economic and social processes in a larger perspective. (Batty, 2007; Portugali, 1999; Allen, 2004) This emphasizes the role of planning as an enabling and steering rather than a controlling and regulating device. Supporting the self-organization of individual actors may promote economic performance and benefit the whole "ecosystem" in cities. It is commonly accepted that innovation and creativity play a crucial role in this continuous renewal in cities. They cannot be produced purely by the means of planning or policies, but they can be stimulated by supporting the existing actors' self-organized networks.

Planning of today often clashes with this understanding of self-generating urban phenomenon: self-organization is either not recognized, or considered inferior or simply a flaw in the controlled, stable and predictable urban system. To us it seems important to understand that, despite the prevailing view of self-organization resulting from negative phenomena like sprawl,

dispersed city structure and traffic problems, some forms of self-organization – like the clustering contemplated in this paper – can also be beneficial to the viability of the city, and should not be prevented. Furthermore, as the findings in this paper reveal, these mechanisms can be more complex, hidden and interlinked than planning probably assumes. Therefore their reciprocal influence and beyond is likely to be very complicated and difficult to strictly control.

Conclusions

In this paper Nekala area, the target of this study, was shown to have a very rich system of internal dynamics below its planned surface. It is probable that this particular combination of self-organizing mechanism typical of Nekala is what makes the area unique and viable. We assume that many similar, mature “urban ecosystems” – industrial areas, various centres, cultural hubs – may have developed their own fingerprints over time. It also seems likely that generalized forms of strict regulation would most probably have failed in creating similar dynamics. The results of this study also support this call for tolerance, where the disadvantages of individual actions are controlled in neighbourhood level interaction rather than in the planning principles of the larger district. In Nekala the tolerance of the plan was found to correlate with self-organizing structures, enabling, but hardly producing them.

In this text we have proposed some additional measures that can be used for estimating the performance of a city or a neighbourhood. These include the evaluation of the fractal dimension of the neighbourhood. In practice, a proposed plan can be evaluated against such revealed self-organizing mechanisms or the area's typical profile. In the case of Nekala, typical isovist profiles for clusters could provide such a generative mechanism, and the comparison could reveal whether the implementation of the new plan changes the dynamic spatial profile of the place, and perhaps disrupts the operation of the existing system.

The important message of this study hints towards planning in incremental cycles of small steps: sequential evaluation and re-implementation of improved operations. It also provides an additional option for developing planning practice in the form of discrete methods for evaluating how the system will respond prior to implementation and benefiting the operational procedures actually taken. As suggested, many self-organizing processes cities resemble similar natural processes. These mechanisms refer to the systems' autonomous capacity to seek viable spatial configurations – the maximally effective or beneficial use of space. The opportunity to simulate local self-organizing processes suggests that the role of planning is not only in active interventions aiming at the desired change. Planning also provides information on the

predictable and unpredictable processes upon which the agents and active micro level actors may adapt. These development trends may otherwise have gone unnoticed. For a planner this improved understanding of dynamics offers a novel opportunity to focus only on issues that are likely to be in conflict and avoid the issues that will evolve to specific direction anyhow.

Therefore this view emphasizes the requirements for small manoeuvres aiming at preventing less desirable events and based on scientific knowledge, flexibility, and constant evaluation of system as a fundamental part of this recursive planning procedure, concentrating on observation and steering instead of controlling and regulation. To gain adequate knowledge of the urban system, procedures similar to that described in this study might become necessary, aiming at a more thorough understanding of the identity and unique characteristics of the place. The emphasis should be on calling for flexibility, adaptability and recursive nature in future planning. After all, planning is in vain in processes that emerge and complete themselves without external intervention.

References

- Allen, P. (2004), *Cities and regions as self-organizing systems*, Oxon, Taylor and Francis.
- Antonelli, C. (2003), *The Economics of Innovation, New Technologies and Structural Change*, London, Routledge.
- Andrews, R. B. (1971), *Urban land economics and public policy*, Free Press.
- Bak, P. (1990), "Self-Organized Criticality", *Physica A*, 163, 403-409
- Balland, Pierre-Alexandre. Proximity and the evolution of collaboration networks: evidence from R&D projects within the GNSS industry. No. 0914. Utrecht University, Section of Economic Geography, 2009.
- Batty M. (2007), *Cities and Complexity*, MIT Press, Cambridge.
- Batty, M. and Rana, S. (2004), "The automatic definition and generation of axial lines and axial maps", in *Environment and Planning B*, 31, 615 – 640.
- Batty M, and Marshall S, (2009), "The evolution of cities: Geddes, Abercrombie and the new physicalism". *Town Planning Review*, 80, 551-574.
- Berkes, F., Colding, J. and Folke, C. (eds.) (2003), *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*, Cambridge University Press, Cambridge.
- Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., and West, G. B. (2007). "Growth, innovation, scaling, and the pace of life in cities", *Proceedings of the National Academy of Sciences*, 104, 7301-7306.
- Boschma, R. and Frenken, K. (2011), 'The emerging empirics of evolutionary economic geography', *Journal of Economic Geography*, 11, 295–307.
- Boschma, R. and Frenken, K. (2010): "Spatial evolution of innovation networks proximity perspective" in Ron Boschma and Ron Martin (eds.): *Handbook of evolutionary economics*. Edward Elgar, MA, USA, 120-135.
- Browne, J. (1995), *Charles Darwin: Voyaging*, London, Cape, 385–390.
- Carlino, G. (2005), "The Economic Role of Cities in the 21st Century", *Federal Reserve Bank of Philadelphia Business Review* (Third Quarter 2005), 9-14.
- Castells, M. (2000), *The Information Age: Economy, Society and Culture*. Volume 1. *The Rise of Network Society*, Oxford, Blackwell Publishing.
- Chen, Y. (2012), "Zipf's law, 1/f noise, and fractal hierarchy", *Chaos, Solitons and Fractals* 45, 63–73.
- Comunian, R. (2011), "Rethinking the Creative City: The Role of Complexity, Networks and Interactions in the Urban Creative Economy", *Urban Studies* 48, 1157–1179.

- De Roo G, Hillier J and van Wezemael J, (eds), (2012), *Complexity and Planning: Systems, Assemblages and Simulations. New Directions in Planning Theory*, Farnham, Ashgate.
- Duranton, G., Puga, D. (2001) Nursery cities: Urban diversity, process innovation, and the life cycle of products. *American Economic Review*, 91(5): 1454–1477.
- Duranton, G. and Puga, D. (2004), “Micro-foundations of urban agglomeration economies”, in J. V. Henderson and J. F. Thisse (eds), *Handbook of Regional and Urban Economics* 4, Amsterdam, Elsevier Science, 2063-2117,.
- Eigen, M. (1977), “The Hypercycle: A Principle of Natural Self-Organization. Part A: Emergence of the Hypercycle” *Die Naturwissenschaften*, 64, 541-565.
- Feldman, M. P. (1994), *The Geography of Innovation*, Boston, Kluwer Academic Publishers.
- Fujita, M. (2007), “Towards the new economic geography in the brain power society”, *Regional Science and Urban Economics*, 37, 482 – 490.
- Garreau, J (1991): *Edge cities: Life on the new frontier*. New York, Doubleday.
- Haken, H. (1980), “Synergetics: Are Cooperative Phenomena Governed by Universal Principles?” *Die Naturwissenschaften*, 67, 121-128.
- Hautamäki, A. (2009), “Luova talous ja kulttuuri innovaatiopolitiikan ytimessä”, *Publications of the Finnish Ministry of Education and Culture*, 30 (Helsinki).
- Henderson, V. (1997), "Externalities and industrial development." *Journal of Urban Economics* 42 (3), 449-470.
- Hertel, H. (1966), *Structure, form, movement*. New York, Reinhold.
- Hodgson, G. M. and Knudsen, T. (2011), “Generalized Darwinism and Evolutionary Economics: From Ontology to Theory”. *Biological Theory*, 6, 326–337.
- Holl, A. (2004), “Start-ups and relocations: Manufacturing plant location in Portugal”. *Papers in Regional Science*, 83(4), 649–668.
- Jacobs, J. (1984), *Cities and Wealth of Nations Principles of Economic Life*, New York, Random House.
- Jacobs, J. (1992), *The Death and Life of Great American Cities*, New York, Vintage Book.
- Kaye, B. H. (1994), *A Random Walk through Fractal Dimensions*, Weinheim, Wiley-VCH Verlag.
- Keller, E. F. (2009), “Organisms, Machines, and Thunderstorms: A History of Self-Organization, Part Two. Complexity, Emergence, and Stable Attractors” *Historical Studies in the Natural Sciences*, 39, 1-31.
- Kello, C. T., Brown, G. D. A, Ferrer-i-Cancho, R., Holden, J. G., Linkenkaer-Hansen, K., Rhodes, T., and van Orden, G. C. (2010), “Scaling laws in cognitive sciences” *Trends in cognitive science*, 14, 223–232.
- Krugman, P. (1996), *The Self-Organizing Economy*, Cambridge, Blackwell.

- Malmberg, A. and Maskell, P. (2002), "The elusive concept of localization economies: towards a knowledge-based theory of spatial clustering", *Environment and Planning A*, 34, 429 - 449.
- Marshall, A. (1890). *Principles of Economics*, London, Macmillan.
<http://archive.org/stream/principlesecono00marsgoog#page/n16/mode/2up> (Accessed 29 May 2013).
- Neffke, Frank, et al. "The dynamics of agglomeration externalities along the life cycle of industries."
Regional Studies 45.1 (2011): 49-65
- O'Sullivan, A. (2009), *Urban Economics*, New York, McGraw-Hill Irwin.
- Oswald, F. and Baccini, P. (2003), *Netzstadt – designing the urban*, Basel-Boston-Berlin, Birkhäuser.
- Partanen, J. (2015), "Indicators for Self-Organization Potential in Urban Context", *Environment and Planning B: Planning and Design* 2015, volume 42, pages 951–971
- Porter, M. (1998), *Cluster and the New Economics of Competition* *Harvard Business Review*, November-December 1998, 79-90.
- Portugali, J. (1999), *Self-organization and the city*, Berlin Heidelberg NewYork, Springer-Verlag.
- Prigogine, I. (1978), "Time, Structure and Fluctuations", *Science* 201, 777-785.
- Shane, D. G. (2005), *Recombinant Urbanism – Conceptual Modeling in Architecture, Urban Design and City Theory*, London, John Wiley & Sons Ltd.
- Sieverts, T (2003): *Cities without cities: an interpretation of the Zwischenstadt*. Routledge.
- Turcotte, D. L. and Rundle, J. B. (2002), "Self-organized complexity in the physical, biological, and social sciences" *Proceedings of the National Academy of Sciences of the United States of America*, 99, 2463–2465, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC128561/> (accessed 17 May 2013).
- Turner, A., Doxa, M., O'Sullivan, D., and Penn, A. (2001), "From isovists to visibility graphs: a methodology for the analysis of architectural space", *Environment and Planning B*, 28, 103–121.
- Varela, F., G., Maturana, H., R. and Uribe, R. (1974), "The Organization of Living Systems, its Characterization and a Model", *Biosystems*, 5, 187-196.



**AN URBAN CELLULAR AUTOMATA MODEL
FOR SIMULATING DYNAMIC STATES
ON A LOCAL SCALE**

by

Partanen, J. (2015) in *Entropy* 19(1), 12. doi:10.3390/e19010012.

Published online with supplementary material

(<http://www.mdpi.com/1099-4300/19/1/12/htm>).



© 2016 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Abstract: In complex systems, flexibility and adaptability to changes are crucial to the systems' dynamic stability and evolution. Such resilience requires that the system is able to respond to disturbances by self-organizing, which implies a certain level of entropy within the system. Dynamic states (static, cyclical/periodic, complex, and chaotic) reflect this generative capacity, and correlate with the level of entropy. For planning complex cities, we need to develop methods to guide such autonomous progress in an optimal manner. A classical apparatus, cellular automaton (CA), provides such a tool. Applications of CA help us to study temporal dynamics in self-organizing urban systems. By exploring the dynamic states of the model's dynamics resulting from different border conditions it is possible to discover favorable set(s) of rules conducive to the self-organizing dynamics and enable the system's recovery at the time of crises. Level of entropy is a relevant measurement for evaluation of these dynamic states. The 2-D urban cellular automaton model studied here is based on the microeconomic principle that similar urban activities are attracted to each other, especially in certain self-organizing areas, and that the local dynamics of these enclaves affect the dynamics of the urban region by channeling flows of information, goods and people. The results of the modeling experiment indicate that the border conditions have a major impact on the model's dynamics generating various dynamic states of the system. Most importantly, it seemed that the model could simulate a favorable, complex dynamic state with medium entropy level which may refer to the continuous self-organization of the system. The model provides a tool for exploring and understanding the effects of boundary conditions in the planning process as various scenarios are tested: resulting dynamics of the system can be explored with such "planning rules" prior to decisions, helping to identify planning guidelines that will support the future evolution of these areas.

Keywords: urban models; complexity theory; evolution; cellular automaton; dynamic states; entropy; planning

1. Introduction

Theories of complex adaptive systems provide a foundation for a better understanding of cities: cities are complex as regards their trans-scalarity, non-equilibrium nature and interconnected actors and networks [1,2]. Self-organization is an essential mechanism in the way complex cities organize: Cities are built as a result of bottom-up actions by individual actors within the frame of regulations and laws. Urban self-organization which promotes economic viability and fosters innovation is a dynamic process per se; the new layer of urbanity emerges on

the premises of the existing one recursively, implying that the relations and dynamics become even more important than the entities as such. Hence, the study of the dynamics resulting from such interaction in urban system becomes essential. Theories of complex systems suggest that the systems' constant transitions between more and less predictable, mathematically chaotic phases enable their evolution [3–5]. Similarly, within resilience theory, the capacity of the system to absorb disturbances and settle into another qualitative state in time of crises is essential for the continuity of the system [6]. Both mechanisms are based on self-organization [6,7]. This capacity is at its greatest near the edge of instabilities, in which the entropy is typically between the two extremes [3, 8, 9].

Dynamic models such as CA provide popular tools for studying emergent systems with many interacting parts producing a dynamic, higher level order. In the urban context, modeling such temporal dynamics could help us to pinpoint how changing the conditions for lower level actions (for example rules concerning interaction between actors) impacts the global dynamics (the state of the system and level of complexity). This could lead to a better understanding of which features of urbanity the plan should restrict, leaving the rest of the system intact enabling the necessary self-organization [8]. In mathematics and computation dynamic states (static, dynamic) resulting from variance in the rule sets has been studied widely with one-dimensional CA (e.g., [8, 10-13]), and they also provide a robust framework for evaluating urban modeling.

Since the 1940s, CA has developed from simple theoretical models into an extensive family of relaxed spatial models exploring many economic or societal processes. In recent decades, urban CA applications have expanded, exploring myriads of phenomena, such as urban growth or land use dynamics (e.g., [14-22]). Many of these models operate on a regional scale. Local scale applications are still fairly limited and mainly address social dynamics, see for example Schelling [23] and Portugali [5].

Many studies within the field of agglomeration economics reveal that synergetic or competitive actors form clusters on various scales (e.g., [24-26]). These studies often suggest that the dynamic nature of the location principles is worth supporting, especially within the context of the current innovation economy [27, 28]. These studies concentrate mainly on single industry agglomerations. The research on clustering of several coexisting industries in a single area is limited. Such approaches, however, are necessary given that according to many studies certain special local scale demarcated and self-organizing areas constantly emerge in the city, impacting on urban dynamics on a regional level and with great potential for cultural and economic life in the city [5,29-32]. On complex, resilient trajectory, these areas support the cultural and economic viability of the whole city, hence making it important to explore means of supporting their self-

organization. Dynamic micro-simulations are a useful tool for exploring which factors should be encouraged or restricted to support the successful and continuous dynamics.

Therefore, I ask what kind of dynamic states can be simulated with a 2-D cellular automaton based on real world case of a self-organizing area. As regards the level of entropy, which states are preferable and how to encourage these in planning?

In this paper I first frame the theoretical foundation for the study and scrutinize previous research on the cellular automaton, along with its urban applications. Secondly, I introduce a specific modified CA model for studying dynamic states. The rules of the proposed model are based on empirical data on the agglomeration of similar activities. The model is relaxed by means of the irregular cell space and gradually changing, quantitatively and qualitatively defined transition rules based on probabilities for a better correspondence with reality. With this model, I explore how the changing weights on the transition rules representing various “planning decisions” affect the dynamics in a model representing a self-organizing area with a documented clustering tendency. The aim is to discover sets of rules which would support or impede the self-organization of the area in order to make better planning decisions.

Thirdly, I elaborate the results—static, periodic and complex states—validating them against entropy levels proving that complex state is indeed located between the two extremes as regards the degree of entropy. Finally, I discuss how such a model might assist communication between stakeholders, planners, and designers in the planning processes. Different scenarios can be simulated and evaluated to eliminate only the conditions resulting in undesirable outcomes, leaving enough freedom for the urban evolution.

The performance of the model was explored in the Nekala industrial area and in the Vaasa old garrison area in Finland. The Vaasa project was implemented as a part of the actual planning process. The empirical data of the mechanism are mainly from the mature Nekala area, since the garrison area was only recently released from military use and none but embryonic signs of self-organizing behavior of the activities were discernible.

2. Theoretical Background

2.1. Urban Models

Urban micro simulation has been used since the 1990s to study bottom-up emerging phenomena in cities and regions. These applications are often based on interacting cellular

structures in space (CA), free moving agents (agent based models), networks, or combinations of these. Considering the intrinsic characteristics of complex systems (constantly shifting between dynamically stable and chaotic transition phases) these micro-simulations are not able to predict the future very far (not beyond the qualitative change after tipping points), but their value lies in educational use: with models we can learn about the dynamics of the system we study, and especially how the changing weights for rules impact the outcome. For this the model is run exhaustively, using all potential weights and pinpointing resulting “attractors”—the probabilities of the system’s state shifting to another dynamic state as the weights are changed [33]. (In mathematics, attractors refer to the system’s probabilities to behave in a certain manner persistently, e.g., periodically or in a complex manner. The system is stable while on the attractor, but could be pushed to another one with a substantial effort.) Dynamic urban models operate often on the regional level, simulating large scale phenomena such as land use, population dynamics or economics [15, 17], exploring patterns resulting from various conditions between urban actors [34], or, as in this study, exploring the dynamic states of an urban system [21]. However, relatively rare smaller scale models (see for example [5]) are also used implying that the local dynamics is interlinked with higher level dynamics, considering cities as complex nested system of networks consisting of other sub-network throughout the scales [35].

2.2. *The Scale*

The fractality and trans-scalarity of cities [36,21] and movement [37] imply intrinsic dependencies across the scales, also revealing the role of smaller scale phenomena. As regards the neighborhood interaction, a smaller target scale may support the exploration of features based on informal information sharing [38]; in a qualitative sense, lower scale nodes, such as economic or cultural concentrations, can be of great importance on a regional, national or even global scale [30].

Several urban studies contemplate self-organizing local scale enclaves of such trans-scalar importance [5, 29, 30]. Developing Foucault’s concept, Shane [30] considers a certain type of “islands”, the *heterotopias of illusion* as a dominant element in today’s multi-nodal city. These areas are self-organizing and flexible formations within porous boundaries, with the ability to organize society through flexible and norms generated from bottom-up. Oswald and Baccini [31] introduce the term *urban fallow* for areas emerging from sudden changes in society, such as a transition in modes of production, suggesting that areas form important resources in a city, by forming self-organizing breeding grounds for cultural or economic actors. A certain degree of freedom is required for maintaining and supporting the adaptability dynamic, and diversity of these actors [5, 29-31].

In this study, the scale was adjusted to optimize the observance of the pattern formation—an increase in scale would not have yielded more information due to the surrounding, stable housing areas.

2.3. Clustering

Regional-scale clustering is considered an important location principle in agglomeration economies and has been extensively studied (see e.g., [39, 40, 24, 26]). These studies often explore the location principles of a single activity.

Similar agglomeration mechanisms have also been observed locally, but systematic studies of simultaneous clustering of different activity types within one area are limited. A documented simultaneous agglomeration tendency of several activities revealed less than four percent of activities outside the clusters in all the time series for 1971, 1986 and 2007, while large concentrations of activities were also rare [32]. This study was carried out in Nekala old industrial area in Tampere, Finland. The premises of the model in this paper are based on these results.

2.4. Dynamic Cellular States and Entropy

The dynamics of a city or a simulation plays a crucial role in evaluating the complexity and self-organization. The type of such trajectory can be evaluated against the concept of dynamic states. The concept of a dynamic state is based on the work of Wolfram, Langton and others mostly studying artificial computational systems such as CA [8]. According to this approach, a dynamic system can remain relatively resiliently on a highly organized, predictable (cyclical/periodic) level, or fall into a state of disorder and chaos. The transition between the two implies a certain radical phase transition. The ability to reorganize after this jump is intertwined with the resilience of the system: the system reorganizes itself to form a qualitatively different order on a new steady state [66].

Such autonomous computation requires of the system sufficient capacity for the storage and transmission of information. Information storage involves lowering entropy, while transmission involves raising it. For maximal computing capacity, the system must be both, and this optimal state is near the transition point [8,41]. Actually, many complex systems appear to stay in the vicinity of this threshold analogical to systems on a successful adaptive cycle of resilient systems. Therefore, the systems' level of entropy in a complex dynamic state is by default between the two extremes.

The theory of dynamic states has been applied in the real world [8], but mainly studied with artificial systems: Starting from the 1980s the dynamic states of one-dimensional cellular automata have been studied in detail in the mathematical and computational sciences [10, 11, 12, 42]. Since Wolfram's classic categorization of the dynamic states of CA in the 1980s, several classifications have been proposed, aiming at increasingly precise methods of measurement [43, 44]. Wolfram's classification (Table 1) has been widely applied (see e.g., [12,45]), although more formalized representations have also been proposed [11].

Table 1. *Wolfram's [10] classification of evolution of dynamic cellular states.*

1	Homogeneous State
2	Simple stable or cyclical/periodic structures
3	Chaotic pattern
4	Complex localized structures

Based on a state predicting algorithm, Braga and colleagues [11] propose a more precise classification of CA based on pattern growth (Table 2).

Table 2. *Classification of the evolution of dynamic cellular states by Braga et al. [11].*

1	Patterns disappear after a finite transient
2	All patterns stay limited under iteration of the global transition function
3	At least one pattern grows indefinitely

Since the CA model introduced in this paper is rather relaxed and complex compared to one- or even two-dimensional formal CA, no such algorithm is used here. The approaches by Braga et al. [11] and Wolfram [10] provide a frame for interpreting the results: first, with a more (formally) robust perspective, and secondly, with an analogy to Langton's classes of system states, referring to states near a phase transition (Table 3).

Table 3. Analogies between cellular states and dynamic systems. The periodic and cyclical are used in this paper interchangeably.

CA Dynamics	Dynamic Systems Analogue
A spatially homogeneous state	Limit points
A sequence of simple stable/periodic structures	Limit cycles
Chaotic behavior	Chaotic (strange) attractors
Complicated localized structures	Unspecified

Langton used Shannon’s approach to calculate the entropy of the resulting CA patterns, discovering that complex states appear only with a limited set of intermediate entropy values. Following Langton, Wuenche [13] proposes a method for classifying the resulting dynamics according to the degree of entropy in the system, and another simple classification with reference to this (Table 4).

Table 4. Wuenche’s classification of evolution of dynamic cellular states. Entropy level increases from ordered to complex and chaotic states—complex having intermediate state of entropy.

1	Ordered	Low degree of entropy in system
2	Complex	Intermediate degree of entropy in system
3	Chaotic	High degree of entropy in system

Here, I applied these partly overlapping classifications and re-formulated a two-fold classification of preferable, continuous, *dynamic states* (complex or periodic/cyclical), and of *stagnating states* (infinitely oscillating or completely stagnating states). Langton’s and Wuenche’s concept of entropy provides a measure of the unpredictability implying the dynamics applicable in an analogical manner.

2.5. Modifying CA

Cellular automata are much used in urban studies for their spatial, intrinsically dynamic structure and detailed resolution, and they often outperform other models in representing realistic land use change. Formal CA is based on simple principles: the dynamics depends on the state of the cell (on/off) and the state of neighboring cells (for example, a cell is *on* only if 2–3 of its

neighbors are *on*). Traditional CA is able to produce surprisingly diverse dynamics, including self-replicable structures [46]. However, in an urban context CA needs to be somewhat modified to better correspond to the urban reality. Moreover, the modifications may help to overcome the typical challenges to classical CA, i.e., the limited interaction with the outside world, the lack of feedback from the higher level [47] and the inability of an arbitrary regular grid to represent the heterogeneity of land uses due to the stochastic location of grid borders [34]. According to Santé et al. [48], typical relaxations of CA to enable the accommodation of external factors, trans-scalar feedback, accuracy of land uses, and realistic performance of the model, are irregular cell space, e.g., real world grids [34], voronoi polygons [49], and graphs [50]; various neighborhood configurations, e.g., more complex or adaptive transition rules; and growth constraints or irregular time steps.

The level of modification is a trade-off between realistic representation and preserving the essential features of CA, depending on the purpose of the model. The accuracy requirements vary for pure educational or theoretical models, the models roughly exploring policies in decision-making, and for (short-term) predictive models. The rule of thumb states that dependencies between transition rules and model dynamics need to be easily perceived despite the modification (e.g., [51-53]).

3. The Proposed Model

Here, I study the dynamic states of the model in the pattern formation processes on the neighborhood scale using a modified cellular automaton that operates in GIS environment. I assume that the self-organization of activities occurring in specific areas with high generative capacity enhances the innovations and creativity required in all industries today [27, 28]. Self-organization refers here to individual location choices for activities resulting from their decision-making in a certain regulatory framework adequately supporting their autonomous choices. I assume that a complex dynamic state would be preferable, and reflect the system's adaptability in time: the system is able to renew itself.

Since I explore the actual complexity of the system implying phase transitions, such a process cannot be predicted even with a micro-simulation. Instead the model presented here aims at exploring the shifting points in dynamic states of the model during the simulation. Variety depends on different weight values in the transformation rules representing planning decisions. The aim is to learn from the possible interdependencies between rules/border conditions and the resulting dynamic states what type of attractors emerge within the phase space.

3.1. *The Conceptual Framework*

Figure 1 presents the conceptual framework of the model. The system of interacting urban actors (“agents”, integrated into cells) is represented as variables and their relations. The structure of the model follows this schema. The main dynamics in the case area result from four types of temporal interactions between six types of variables. The variables are a cell (agent) (independent variable (iv)), pattern (dependent variable (dv)), land use (dv), volume (dv), border (intermediate variable) and plan (iv) (Table 5). The directions of interactions in this approach are top-down (plan, border), bottom-up (from agent by land use/volume to pattern), feedback (from pattern to agent), uniform level (between agents). Following the principles of agglomeration economics and empiria, the actors seek favorable locations in the proximity of similar actors in the area. A static border resulting from the plan surrounds the area.

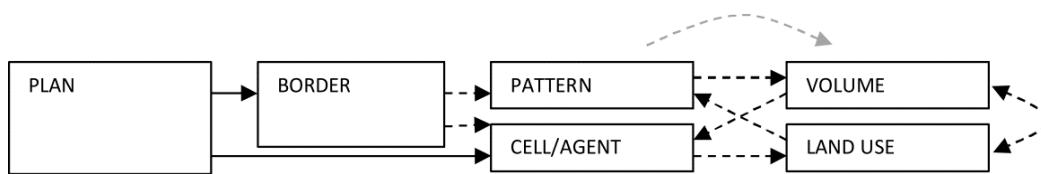


Figure 1. *Conceptual model. Interactions between variables; temporal (broken lines), stable (solid lines). Feedback from pattern to actors is implied in decay of overcrowded clusters—typically of CA, the model does not observe explicitly the global level patterns.*

Table 5. *Relations and directions of interaction between variables (see also Figure 1). In this study, the plan is considered static and unresponsive (the “Plan” column is empty), unlike in some cases in the reality.*

Entity	Site (Cell)	Pattern	Use	Volume	Border	Plan
Site		bottom up	top down	top down		
Pattern			feedback	feedback		
Use		bottom up	interaction	interaction		
Volume		bottom up	interaction	interaction		
Border		top down	top down			
Plan	top down		top down	top down	top down	

The typology of urban actors includes firms, public and other services, grouped into six categories—housing (U1), retail (U2), services (U3), offices (U4), light industry (U5) and warehouses (U6)—following an estimated degree of interaction with the environment (Figure 2). (This classification was used in data processing to group the individual activities instead of using ready-made classifications. For the sake of simplicity, precise numerical values are not coded;

these relations serve as a conceptual mental frame in the modeling experiments, which are based on the tolerance between adjacent activities.) The actor's future type and volume depend on those in the neighborhood. Following the principles of cyclical urban change, the sites transform gradually within the limits of the building efficiency indicated by the plan.

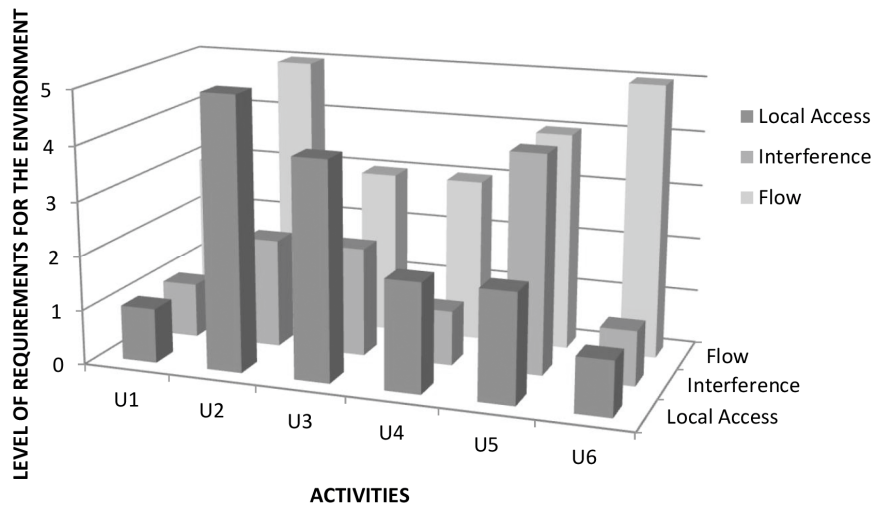


Figure 2. Degree of interaction between activities and their environment for classification of activities: U1, housing; U2, retail; U3, services; U4, offices; U5, light industry; and U6, warehouses. Local Access refers to the local interaction between the site and its environment—how easy it is to access the site, for example, from the street. Interference refers to the level of “disturbance” it tolerates—for example, regarding noise or air quality; and Flow to moving of goods and people to/from the site, implying global accessibility by car, truck etc. The classifications were made on the basis of these assumed relationships. (For example, the requirements for housing regarding disturbance (environmental “interference”) due to noise, smells or heavy traffic differ from those for retail or warehouses. Similarly, some activities need easy access from the street with less privacy, while others benefit from being part of the higher-scale networks, providing constant flows of customers, goods, or material).

The initial state and the input for the model are the actual configuration of activities at the time of data collection for all simulation runs.

3.2. The Model Configurations

3.2.1. Relaxation

The proposed CA was relaxed in terms of the irregular grid, qualitatively (the type of activity) and quantitatively (the floor area of each activity) defined cell spaces, and more complex

transition rules based on probabilities. The rules are modified to overcome the typical limitations of CA and to better reflect real-world micro-scale economic geography while still remaining simple and legible. Several limitations still persist: The model interacts with the outer world by an externally defined growth factor and user interface matrix providing an opportunity to control desired proximities between actors. However, the model's interaction with the outside world during the simulation is lacking. Furthermore, clustering of similar activities until overcrowded imply the feedback from pattern formation to the individual cell's level.

3.2.2. The Neighborhood and Cell States

The cell space of the model follows the legal site division. The neighborhood of each cell contains all parcels within a certain distance of the central cell (Figure 3). The distance of the interaction was set at 24 m, following the traditional block size in the area. One block was considered the optimal distance for pedestrians, implying benefits for similar activities due to competition or synergy. A 24-m buffer around the site was used to define the radius.



Figure 3. Legal site division and existing buildings. Source: City of Tampere, Finland.

In the model the floor area of each activity (U1–U6) was integrated into the property of a cell. The qualitative state of the cell resulted from combining six activities—the number of actors on each site could range from zero to six, depending on the states of the neighbors and the former state of the site itself. The quantitative cell states were defined following the utilization rate, defined as the ratio of the used floor area to the current building right at the site (Equation (1)).

$$R_j = \frac{\sum FA_{j,u}}{(e_j \times A_j)} \quad (1)$$

where R_j is the utilization rate of the site j , simply presenting how many percentages of permitted floor area are built on a specific site at the time of observation. $\sum FA_{i,u}$ is the total floor area for

all uses (U1–U6) on the site j , and e_j is the floor area ratio (ratio of the total floor area of the building to the size of the site) on the site j . A_j is the total area of the site j .

Each cell was unique as regards form, number and type of neighbors, and quantity and quality of activities. The floor area ratio followed the current plan, varying between 0.5 and 1.25. Cells were classified into four categories according to the utilization rate reflecting the share of utilized building right (see Equation (1)), namely empty, nearly-empty, nearly-full and full (Figure 4). The quantitative cell state affected the site's future mode of transformation following the probabilities presented in the Figure 4 for each case. The utilization rate varied at each iteration.

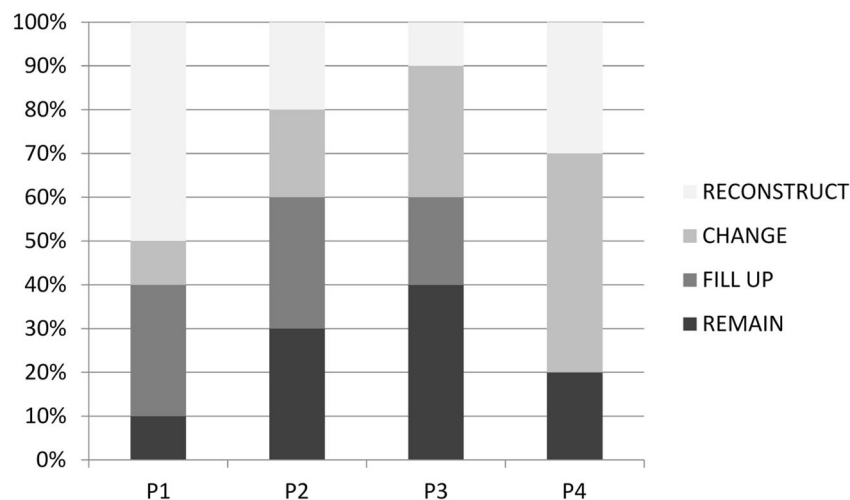


Figure 4. Modes of cell transformation according to their utilization rates. P-1: “empty”, FAR = 0–0.1; P-2: “nearly-empty”, FAR = 0.1–0.3; P-3: “nearly-full”, FAR = 0.3–0.7; P-4: “full”, FAR = 0.7–1. For example, an almost empty cell is likely to be filled more, but also to be reconstructed—at presumably fairly low demolition costs of smaller buildings, whereas nearly full sites might be considered the most resistant to physical changes, but the new additions or uses may occupy these sites easily (see also Table 6).

The plan and the surrounding cells were static, reflecting the resistance to change in the surrounding residential area resulting from the plan, site and building morphology, and fragmented land ownership.

3.2.3. Transformation Rules

The basic mechanism behind the transformation rules was the neighborhood's documented shifting between agglomeration and deglomeration. Similar activities gravitate close to each other, until the clustering causes “overpopulation”, leading to the relocation of some of the activities. For example, a site with a lot of retail and services in its proximity would most probably

change or be filled with these activities. Other activities with less volume in the surroundings (e.g., warehouses) are possible on the site with lower probabilities. The emergence of a random activity on the site is small, yet exists. Basically, the progress produces clusters of certain activities, which disappear as the cluster becomes overpopulated, and the cycle starts again. The process is observed for each activity separately.

First, to define the site's *mode of transformation*, sites were grouped into four categories according to the current cell state according to their utilization rates (P-1 to P-4, (see Figure 4)) indicating the probability of changes. Next, the categories defined the type of change: The site may remain as it is (RM), it may fill up (F) according to the user defined growth rate (GR), activities may change (C) while volume remains the same, or the volume and activities may be reconstructed (RC) (Figure 5). The premises were that, first, new actors filling the vacant sites are likely similar to the neighbors. Second, the sites were built to use the building right efficiently, and, finally, that eventually the buildings would be replaced as the demolition/construction costs became theoretically profitable (Table 6.). Due to lacking data, exact measurements for real world correspondence were limited (no data were available on the actual demolition costs or life cycles of the buildings).

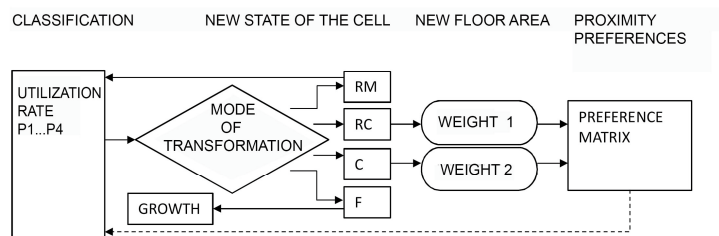


Figure 5. Operational chart of the model.

Table 6. Transformation rule 2: The type of transformation depends on the state of the site.

State of the Site	Most Probable Procedure	The Motive
vacant	build a new building	to use the building right
nearly-empty <10%	demolish (fill up)	to use the building right more effectively: low demolition costs
nearly-full	fill up (change)	to use the building right more effectively: demolition costs above the threshold (It is assumed that there is a threshold value defining the shifts from one mode of transformation to another. E.g., a limit when it becomes more profitable to reconstruct the site, taking into account

		the demolition costs/m ³ and new/old FAR. The demolition costs could be calculated, see e.g., DiPasquale and Wheaton [54], p.85. In this theoretical approach, the classification of the sites is based on estimates.)
full	remain/change/fill/reconstruct, e.g., 0.6/0.3/0.01/0.99 (These values can be changed to fit the circumstances depending on the case at issue.)	certain inertia on the full site; however, once the site is full, it will eventually be developed and reconstructed (no more space for additions). tendency to change if one use starts to dominate the neighborhood = high FA

4. Cases and Data

4.1. The Case of Nekala

The model was built and tested in a case area of the Nekala industrial area in the city of Tampere, Finland. This area of approximately 80 sites was planned for heavy industry and the processing of agricultural products in the late 1930s. Today, the formerly peripheral location has become relatively central due to urban growth, and the area forms a unique enclave within the urban fabric surrounded by mostly residential areas. Nekala has a proven capacity for self-organization, and the ability to adjust itself to the current mode of production, from mainly industrial to a gradually more complex mixture of service, information technology, and cultural industry.

4.2. The Case of Vaasa

The second case study for developing the model further was an old garrison area in the Finnish town of Vaasa, Finland. In this area located within the central area of old Vaasa, the transition from military use had occurred quite recently. The area consisted of different types of gradually filled or historically valuable buildings, large empty sites and buildings beyond repair. A wide range of temporary and permanent actors, such as flea markets, artisans, daycare facilities, leisure activities and storage facilities, had started to settle in to the affordable old buildings: an original and vital bottom-up culture had started to emerge in the area.

In Nekala, several indicators for self-organization potential were discovered in addition to the enclave form: high accessibility, increasing diversity and self-organization of certain actors [32]. In Vaasa, characteristics indicating similar behavior were perceived, but these were less marked than in the more mature Nekala.

In Vaasa, the model was used as a communication tool in a planning process. The resulting implications are discussed below.

4.3. Data

The sample size was the overall number of actors in the area. Statistical data on actors and digital maps were obtained from the City of Tampere and the Town of Vaasa. Numerical spreadsheet data were combined with location information using GIS.

Due to the fragmentation of the plans, data on specific years were unavailable. Some of the actors were multi-functional in the database and classified into several categories: the cell might simultaneously accommodate multiple uses. This reflects the area's diversity, and provides a realistic representation of self-organization.

In Nekala, the actual site division was used, but in the Vaasa case the main target area—a large empty military field—was divided into hypothetical “sites” following the site division of the existing built area to enable the CA performance.

In Nekala, all non-residential sites were active, whereas in Vaasa sites with historically valuable buildings were “protected” and static in the model, with the existing, probably most suitable uses. The surrounding housing area with minor services was also static.

5. Simulation Runs

The first test simulations were run in Nekala with a first, preliminary version of the model controlled by stable parameters in the code defining the relative shares of activities on the sites. These values varied according to the number of uses on the site and the site's current mode of transformation. The resulting pattern formation process was relatively dynamic, but it was difficult to observe how changes in the code affected these patterns.

For the Vaasa case a user interface, *preference matrix* (Table 7) was introduced. Here it was hypothesized that it could be possible to regulate (and “plan”) on the level of the actors' interactions, and leaving the global level largely intact. Such an approach would presumably encourage the existing self-organizing mechanism—small scale clustering. Consequently, weight values on each matrix row—for example U1 (housing)—were applied to each activity pair—for example $U1 \times U1$ (housing next to housing). The larger weights and thus more tolerant allocation logics created more heterogeneous spatial configurations. Heavy weights between similar uses increased the degree of agglomeration of this activity. In this experiment the weight values ranged

from one to 20, and they were iterated exhaustively by trial and error, simulating various planning decisions. For example, with the matrix the “virtual planner” could experiment with how the high tolerance between housing and all other activities, or low tolerance between housing and industrial uses impacted the model’s dynamics, building overall scenarios or “possible worlds” in a bottom-up manner.

Table 7. Preference matrix which serves as a planner’s user interface: the values increase the likelihood of the two activities being located near to each other. Changing the values makes it possible to learn from their impact on the model dynamics.

	U1	U2	U3	U4	U5	U6
U1	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6
U2	μ_7	μ_8	μ_9	μ_{10}		
U3	μ_{11}	μ_{12}	μ_{13}			
U4	μ_{14}	μ_{15}				
U5	μ_{20}					
U6						

μ_1 to $n = 1 \dots 20$.

The aim was to explore potential state transitions in the system. Therefore, formal calibration considering the “ruptures” was not possible. The model was calibrated to fit the conditions using visual parameter test echoing Clarke et al. [18]. The weight values were static during the iterations. The time steps were in this case considered hypothetical, since in Vaasa the area’s transformation was not traceable and even manual calibration was not feasible to adjust the computing time steps to reality.

As a result of a negotiation among stakeholders in the planning process, two sets of rules were chosen for simulation. The amount of new housing in the area became a crucial question in the meetings, along with the diversity of other activities, and the first scenario was to support new housing (highest matrix values between housing, $U1 \times U1$). The second one was based on lower weight for housing, implying more mixed uses. However, the static, preserved sites produced a certain diversity in all cases.

The objective was to observe shifts in dynamics resulting from various weight values for each activity pair. The lengths of the runs ranged from 100 to 500 iterations, but extremely long runs (1,000 to 2,000) were also computed for the potential temporal resilience of the dynamics.

5.1. Performance of the Model

The temporal dynamics and the changes in volumes of activity groups were observed separately for each activity and simulation. The resulting dynamics varied from run to run, depending heavily on the initial matrix values. Different classes of dynamics emerged, and they might occur within a run for different activities simultaneously. For example, the dynamic state of housing might differ from the state of industry with the same initial values. The emerging dynamics were classified into two main categories according the end state, and two sub-categories describing the behavior in more detail (Table 8).

Table 8. *Dynamic states of the model. In an oscillating system less complex than periodic state usually two or three values take turns.*

	Type 1	Type2
static	stagnation	Oscillation
dynamic	cyclical/periodic	complexity

5.1.1. Static States

For the simulations that ended up in a certain end state, two types of static behavior were perceived. In the first case, the system might progress gradually until one use/volume configuration became dominant: The system ended up in a permanent end state. This stagnation might happen simultaneously to one or more activities, and the spatial configuration of sites might vary. In the second case, a dynamic phase in the beginning led to infinite oscillation between only a couple of values on specific sites. The general progress ceased despite these “blinking” (a “blinker” refers to a well-known case in CA dynamics, oscillation, in the famous Game of Life—see more in [46]) cells; the dynamics can likewise be considered static.

These states were the most common findings. They seemed to correlate with unrestricted, high impact from surrounding housing. In that sense the model appeared to have reflected the urban reality well, as politically the location and surrounding land use caused pressure towards housing development. The static state seemed a plausible, yet not desirable, future for the area.

5.1.2. Dynamic States

As the emphasis was shifted in the matrix from interaction between housing and other uses ($U1 \times Un_{(1-6)}$) towards interaction between office/industrial uses ($U4-U5$) (see Figure A1 in Appendix A), the behavior of the model changed. First, the volumes started to gradually increase and decrease over time for all activities, resulting in a certain type of coherent yet unpredictable

pulse emerging from phases of higher and lower utilization rate on the sites. A certain order seemed to emerge within the system, with measurable cycle length. The changes in the rule set (matrix values) have a marked influence over the dynamics of these periods: With certain rule sets (see the optimum configurations in Table 9) the system gravitated towards a periodic, non-uniform state. The period length was in flux, mostly oscillating between 10 and 12 time steps, revealing dynamics far more diverse than before. Some of these cyclical states started with a stochastic phase, soon settling onto predictable periods (see, e.g., Simulations 207, 212; Supplementary material, Figures S3-S8).

Table 9. Optimum rule sets resulting in different dynamic states. The values (1 to 20) represent the relative attraction between those activities. For example, in rule set 1, attraction is fairly equal. For Rule set 2, office/industry is stressed. In rule set 3, in addition to that, the housing is restricted. (Note that the states with rule set 1 and 2 were remarkably resistant to changing matrix values, for the rule set 3 yielding complex dynamics the configuration was unique—only one configuration of matrix values yielded complex dynamics).

	emphasis	matrix configuration*	resulting dynamics
rule set 1. <i>optimum example</i>	all uses: values range from low to moderate (1-8)	6 4 4 4 1 1 4 8 4 2 1 1 8 2 6 4 1 2 8 4 6 4 4 2 6 1 2 4 2 1 1 1 2 1 1 1	stagnating/oscillating dynamics; oscillation increased as the $U1 \times U_{n_{1...6}}$ (attraction between housing and other activities) values decreased
rule set 2. <i>optimum example</i>	U5xU5 (small industry) and U4xU4 (services) are high ($\mu > 10$) other values are moderate (μ 2-8)	2 4 2 4 1 1 4 4 2 2 1 1 2 2 6 4 1 2 2 4 6 10 16 2 1 1 2 8 12 1 1 1 2 1 1 1	continuous, periodic (cyclical) dynamics (for all activities)
rule set 3. <i>unique configuration</i>	U1xU1 (housing) is low ($\mu = 1$), and U4xU4 (services) and U5xU5 (small industry) are high ($\mu > 10$) other values: moderate (μ 2-8)	1 1 2 4 1 1 1 4 4 2 1 1 2 2 6 4 1 2 2 4 6 10 16 2 1 1 2 8 12 1 1 1 2 1 1 1	continuous dynamics: - For housing (U1) complex, - For other uses (U2-6) periodic (cyclical)

With a very particular set of matrix values (Table 9) the model's behavior changed radically again. The uses except housing remained periodic, but the lengths of the cycles and degree of predictability seemed to change slightly for different activities. For example, in some cases retail gravitated to a somewhat mixed state with both periodic and more unpredictable phases. The most remarkable shift towards a higher degree of complexity was perceived for housing. Similarly, to the periodic states, the simulation started with a seemingly stochastic phase, soon starting to gravitate towards a certain cycle often with a length of 10, 11 or 12, or occasionally also any random value (Supplementary material, Figures S3-S8). The period might reoccur from two to as many as 18 times (see e.g., Simulation 190, Figure S9 in Supplementary material). Various cycles might occur during one simulation. Despite these short, constantly emerging and disappearing cycles, the overall dynamics of the system was decidedly unpredictable. This oscillation seemed to continue infinitely even with remarkably long runs (up to 2000 iterations) (see Supplementary material: Complex behavior, Figures S9-S14).

Within many of these simulation runs another new feature emerged, also only with the same complex rule set. While the system balanced between more and less ordered states, a very accurate period of 145 time steps occurred within nearly all runs (see e.g., Simulations 158, 170, 177, 202 in Supplementary material, Figures S11-S14.). Apparently, this period was independent of the state of the system, and was continuous during both the periodic and less predictable states. Perhaps the most interesting feature of this regeneration cycle of 145 time steps was its dynamic stability: in 87% of cases it appeared as the seventeenth cycle, that is, 16 regeneration cycles emerged between two cycles of 145 (for example, the overall volume of the area might have peaked after 27, 12, 10, 34, etc. iterations 16 times before the maxim occurred again after 145 iterations (see Supplementary material, for example Figures S11-S14); then the process resumed, repeatedly). The lengths of the other recurring cycles—for example those of 10 or 12—were all less predictable. The input for the model stayed the same. There is no reference in the literature to this type of CA dynamics where several different nested dynamics co-exist on many levels. This finding may indicate an extremely high level of complexity of the system, but remains to be scrutinized in future studies.

5.2. Validation

These results were visually clearly observable. For validation, I followed the ideas of Langton [8] and Wuenche [13] for entropy measurement of the patterns. The entropy values for the results were calculated for the whole system after simulation. The aim was to discover the differences in overall diversity and predictability.

Six examples of periodic and six of complex behavior were chosen at random from the 60 data sets which passed the visual evaluation test. The entropy for the system was calculated according to Equation (2).

$$\sum_{j=1}^N s_j \log_2 s_j \tag{2}$$

where s_j is the relative share t/t_{all} of the entities; t is the number of a certain regeneration cycle; and t_{all} is the number of different cycles in that run. The resulting entropy values are presented in Table 10. This equation describes the overall entropy of the simulation after the runs are completed, providing an estimated level of complexity in regards of time steps between changes in utilization of building right. (For example, for a periodic run 160, the cycle of 10 occurred 72 times out of a total of 178 different cycles. Hence, for run 160, $s_j = 72:178 = 0.040449$ and consequently, $\log_2 s_j = -1.3058$. Thus $s_j \log_2 s_j = 0.5282$. This calculation was carried out for each cycle (10, 11, 12, 16, 22, etc.) for the total sum, yielding the entropy value of run 160).

Table 10. Degrees of entropy, random samples from complex and periodic/cyclical series, compared to a stochastic set.

periodic/cyclical	R = 159 2.85134	R = 160 2.11139	R = 162 2.20135	R = 163 2.22823	R = 212 2.32039	R = 207 2.02637
complex	R = 202 4.3864	R = 177 4.17142	R = 158 4.82893	R = 170 4.1556	R = 208 4.39262	R = 190 3.81511
(stochastic/hypothetical)	R = 202 5.8579	R = 177 5.7279	R = 158 5.90689	R = 170 5.88264	R = 208 5.72792	R = 190 6.285

The results indicate a clear dispersion between highly ordered, periodic, and more unpredictable, complex states. All the entropy values for periodic states were below 2.86, while for complex states they ranged from 3.80 and 4.90 (Table 8, Figures 6 and 7) (for the graphical representation of the dynamics of these systems, see Supplementary material, Figures S3-S14). Since no chaotic state was perceived in this study, a stochastic set was created for purposes of comparison, indicating the maximum value of entropy in the system. For this set the entropy was calculated in a hypothetical case using the data set resulting in complexity and calculating its entropy assuming all values to be unique, occurring only once. As expected, the degree of entropy for these stochastic comparison groups was high, all of them above 5.70 (Figure 8).

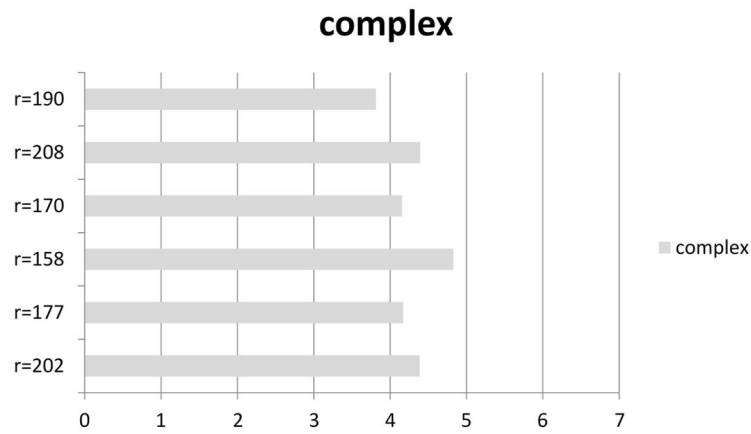


Figure 6. Entropy values (i) for six data sets visually classified as “complex”; $3.8 > i > 4.9$.

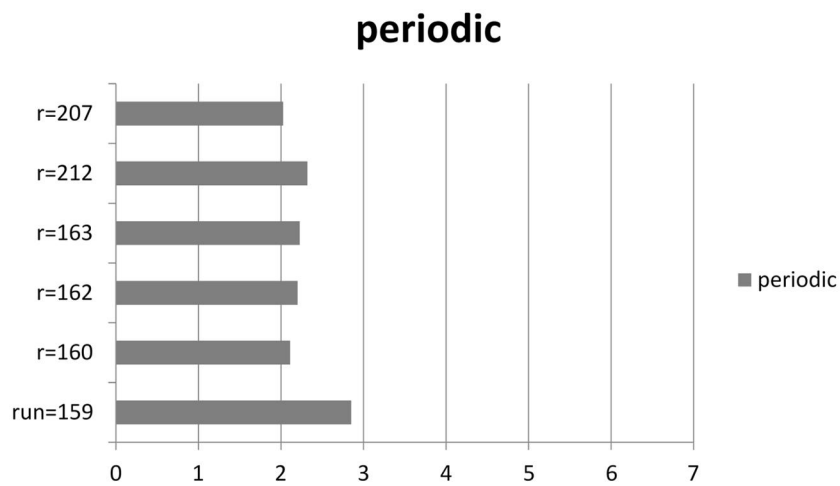


Figure 7. Entropy values (i) for six data sets visually classified as “periodic”; $2.0 > i > 2.85$.

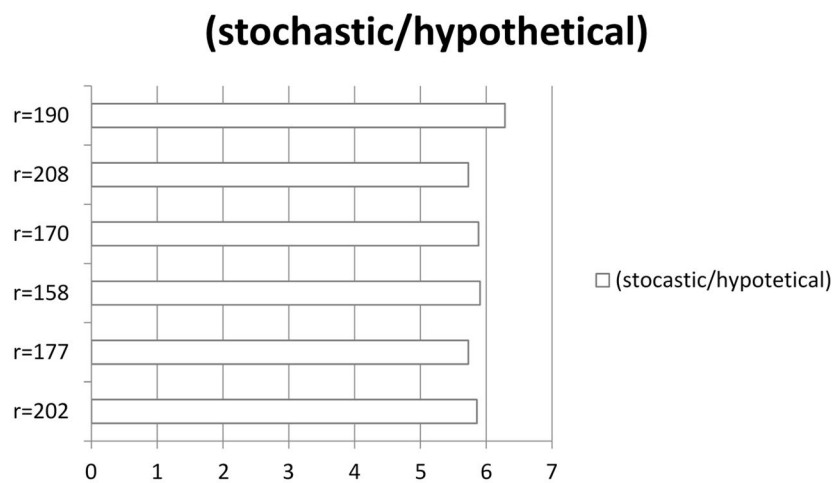


Figure 8. Entropy values (i) for six hypothetical classes with maximal stochasticity; $i > 5.5$.

These results indicate that the periodic state is far more ordered than the complex state, but that the observed complexity was not totally stochastic.

The limitation of this static method of measuring entropy is that it only measures the number of cycles in total and not their temporal frequencies or the potential altering of the periodic and unpredictable phases. For example, in Simulation 190 (Supplementary material, Figure S9), a cycle of 11 forms a period, occurring three times successively between time steps 30 and 32, four times between 63 and 66, and four times again between time steps 51 and 57 implying the relatively high order in these phases. Therefore, this feature needed to be evaluated visually, or by exploring complementary indicators beyond the scope of this study. However, although Equation (2) is static, since it measures the occurrence of the time steps ($t_{n+1} - t_n$) between changes, it results in a fairly good representation of the overall entropy of the dynamics. The static states were not included since no measurable period occurred.

5.3. Discussion

This paper contemplated a local scale relaxed urban CA model. The research proved that such a two-dimensional, irregular CA with integrated volume and activity types is capable of simulating the main classical dynamic states typically studied using 1-D CA: Various static, periodic and complex states. Furthermore, the validation indicates that, following the core literature, entropy levels of complex states were indeed between the two extremes (for stochastic and static), thus pointing out the most preferable dynamics for urban evolution.

In this study the transition of these systems from one dynamic state to another did not occur abruptly. On the contrary, the process seemed rather continuous and gradual: as the stress in the matrix was shifted from relations between housing, retail, and services ($U1-U3 \times U1-U3$) towards office/industrial uses ($U4-U5 \times U4-U5$) (Appendix A Figure A1), the dynamic states also seemed to shift gradually first from static/oscillating states to periodic states with a stochastic phase at the beginning towards more complex dynamics. Only one set of matrix values produced extremely complex behavior (Table 9) referring to high sensitivity to initial conditions.

The results suggest that in order to support the continuous states in this modeling case, housing needed to be restricted, while office and light industrial uses needed to be encouraged. The impact of housing on dynamics is not surprising given the volume of the surrounding housing area. However, the complex dynamics for housing is undoubtedly caused by non-linear processes and hence could hardly be discovered in a planning process without a microsimulation. Interestingly, rather high values were also required for offices $U4 \times U4$ and industry $U5 \times U5$ for

dynamic continuity. No such effect was observed for activities retail and services. It is plausible that the few static sites in the area formed certain kernels (consisting of retail, services, offices and light industry), and supported the emergence of these actors, but it does not explain the high values required for offices and industry. It is possible that such a surprising impact could be explored further using, for example, complex networks, and emphasizing the number of linkages between actors and the general topology of the nets. Since the objective was to use the existing configurations as the initial state for the CA, such complex interconnectedness of these mechanisms was beyond the scope of this study. The results also highlight the fact that complex interactions between scale levels are not linear and may be extremely unpredictable. In this sense the surprising role of offices and light industry was somewhat noticeable, even though in this case their impact on dynamics in reality is not that self-evident.

In addition, the model corresponds with the reality also in that the static states can be considered analogical with a traditional, hierarchical planning process, in which the plan consolidates a certain static position. Implemented in complex cities in a state of flux, this implies a relevant yet burdensome task of constant, incremental updating of plans. Apparently certain level of flexibility is needed.

However, this modeling experiment indicates that total freedom would not be preferable. Even though the total control of the system will most probably lead to stagnation, a certain degree of guidance is necessary for the process to achieve the most desirable outcome, such as high diversity promoting the evolution of the city. In this sense, the results support the intuition: the maneuvers promoting the diversity of activities in the model produced the most dynamic outcomes.

A couple of limitations concerning the relationship between models and reality overall are worthy of note. This model is based on real data and used in a real planning case, and the results appeared intuitively fairly logical. For example, the housing development could indeed become dominant over other uses. However, the model can at its best predict the future only for a short time span since in complex systems, the future is predictable only in a stable state. Hence, applying the complexity framework underlines the intrinsic nature of the world as, first, an evolutionary system with qualitative transitions impossible to predict, and secondly, its chaotic characteristics, especially in the proximity of these transitions. The system might change drastically due to small initial changes, or not react to larger ones and adapt. One relevant option to respond to this dilemma is, as in this paper, to exhaustively study the dynamics emerging from the simulations instead of for example spatial outcomes. Even then, the simulation results might differ from reality, and hence in planning it is necessary to evaluate the implementations constantly in trial-and-error manner.

Furthermore, another limitation follows from the configuration of the model. While modeling we stand on the fine line between simplicity and complicatedness. The more detailed the configuration selected for the sake of accuracy, the more difficult it may become to interpret which rules are responsible for a certain model behavior. Hence, several configurational limitations also emerge for the model presented in this paper. For simplicity, the model is based on certain assumptions of agglomeration and regression tendency of activities. In reality, other mechanisms also impact urban dynamics, such as land/property rent, accessibility, synergy between non-similar activities or other externalities. In addition, despite the relaxations, the feedback from the higher level and the outside world was rather limited. In addition, interaction between activities and their environment was contemplated only conceptually to maintain the model simple (Figure 2). For a solution providing greater accuracy and more relevant feedback, possible future studies could therefore include research on other mechanisms of self-organization, studies on the complex linkages and interdependencies between various interacting actors and networks operating on various scales, and comparative studies in other areas.

However, despite the limitations, the model introduced in this paper could be utilized as a good policy-relevant model, which, in Helen Couclelis' [47] words does not provide instructions for decision-makers on what to do, but instead, on what *not* to do. In city planning, this would mean, first, acknowledging the uncertainty intrinsic in complexity thinking, but secondly, understanding that urban processes, such as the dynamics that drives location decisions of activities, occur bottom up and their guidance requires setting guidelines rather than of imposing controls.

In such an environment, more flexible planning could provide a frame for urban processes, but the potential impact of the frame must be scrutinized—in this endeavor micro simulations are useful, along with other “complexity planning tools” such as measurement based on fractality, scaling or computation [55, 56,,32]. In practice, with micro simulation models it is possible to model the environmental factors affecting actors, and then by altering the virtual “planning rules”, for example permitted proximities or other factors, to learn how the guidelines affect the dynamics. Actual decisions could then be based on these findings in a flexible manner, thus supporting self-organization, resilience, city evolution, and continuity of autonomous socio-cultural processes in the city.

Supplementary Materials: The following are available online at www.mdpi.com/link, Video S1: Complex behavior of the model (housing); Video S2: Periodic behavior of the model (Industrial uses); Video S3: A “blinker” or static/oscillating behavior. Figure S1: Legend for Video S1 and S3 (housing,

volumes); Figure S2: Legend for Video S2 (industrial uses, volumes); Figures S3-S15, Graphical presentation of the model dynamics..

Acknowledgments: The research and data collection were funded by TEKES (the Finnish Funding Agency for Innovation) and Tampere University of Technology Graduate Program. Part of the theoretical work was carried out at the University of Washington, Seattle, USA, funded by the Valle Scholarship, UW Seattle. I would also like to thank Dr. Anssi Joutsiniemi for writing the code for the model, and three anonymous reviewers who helped me to develop the article profoundly.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A.

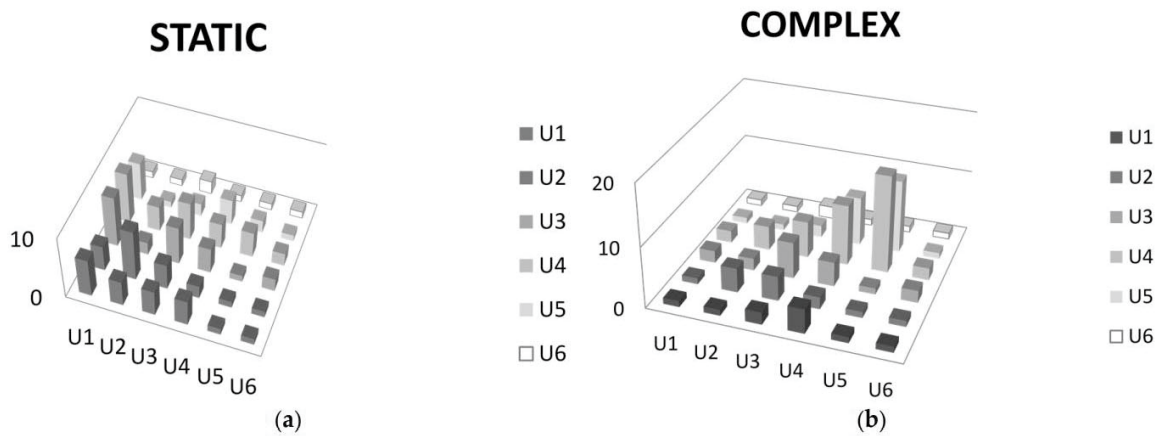


Figure A1. Weights for proximity preferences among activity types resulting in different dynamic states: U1, housing; U2, retail; U3, services; U4, offices; U5, light industry; U6, warehouses. (a) Matrix values for static states; (b) Matrix values for the complex states.

References

1. Haken, H. *Information and Self-Organization: A Macroscopic Approach to Complex Systems*; Springer: Berlin/Heidelberg, Germany, 2010.
2. Holland, J.H. *Emergence—From Chaos to Order*; Perseus Books: Cambridge, MA, USA, 1998.
3. Kauffman, S. *The Origins of Order: Self-Organization and Selection in Evolution*; Oxford University Press: Oxford, UK, 1993.
4. Kauffman, S. *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*; Oxford University Press: Oxford, UK, 1995.
5. Portugali, J. *Self-Organization and the City*; Springer: Berlin/Heidelberg, Germany; New York, NY, USA, 1999.
6. Walker, B.; Salt, D. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*; Island Press: Washington, DC, USA, 2012.
7. Levin, S.A. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* **1998**, *1*, 431–436.
8. Langton, C.G. Studying Artificial Life with Cellular Automata. *Physica D* **1990**, *22*, 120–149.
9. Kugler, P.N.; Turvey, M.T. *Information, Natural Law, and the Self-Assembly of Rhythmic Movement*; Routledge: London, UK, 1987; pp. 52–53.
10. Wolfram, S. Universality and Complexity in Cellular Automata. *Physica D* **1984**, *10*, 1–35.
11. Braga, G.; Cattaneo, G.; Flocchini, P.; Quaranta, V.C. Pattern growth in elementary cellular automata. *Theor. Comput. Sci.* **1995**, *145*, 1–26.
12. Culik, K., II; Yu, S. Undecidability of CA classification schemes. *Complex Syst.* **1988**, *2*, 177–190.
13. Wuenche, A. Classifying Cellular Automata Automatically; finding gliders, filtering, and relating space-time patterns, attractor basins, and the Z parameter. *Complexity* **1999**, *4*, 47–66.
14. Rienow, A.; Goetzke, R. Supporting SLEUTH-Enhancing a cellular automaton with support vector machines for urban growth modeling. *Comput. Environ. Urban Syst.* **2015**, *49*, 66–81.
15. White, R.; Uljee, I.; Engelen, G. Integrated modelling of population, employment and land-use change with a multiple activity-based variable grid cellular automaton. *Int. J. Geogr. Inf. Sci.* **2012**, *26*, 1251–1280.
16. Batty, M.; Xiu, Y.; Sun, Z. Modelling urban dynamics through GIS-based cellular automata. *Comput. Environ. Urban Syst.* **1999**, *23*, 205–233.

17. Caruso, G.; Peeters, D.; Cavailhès, J.; Rounsevell, M. Spatial configurations in a periurban city. A cellular automata-based microeconomic model. *Reg. Sci. Urban Econ.* **2007**, *37*, 542–567.
18. Clarke, K.C.; Hoppen, S.; Gaydos, L. Methods and techniques for rigorous calibration of a cellular automaton model of urban growth. In Proceedings of the Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, NM, USA, 21–25 January 1996; pp. 21–25.
19. Li, X.; Yeh, A.G.-O. Modelling sustainable urban development by the integration of constrained cellular automata and GIS. *Int. J. Geogr. Inf. Sci.* **2000**, *14*, 131–152.
20. Portugali, J.; Benenson, I. Artificial planning experience by means of a heuristic cell-space model: Simulating international migration in the urban process. *Environ. Plan. A* **1995**, *27*, 1647–1665.
21. White, R.; Engelen, G. Cellular automata and fractal urban form: A cellular modelling approach to the evolution of urban land use patterns. *Environ. Plan. A* **1993**, *25*, 1175–1199.
22. White, R.; Engelen, G.; Uljee, I. The use of constrained cellular automata for high-resolution modelling of urban land use dynamics. *Environ. Plan. B* **1997**, *24*, 323–343.
23. Schelling, T.C. Dynamic Models of Segregation. *J. Math. Soc* **1971**, *1*, 143–186.
24. Fujita, M. Towards the new economic geography in the brain power society. *Reg. Sci. Urban Econ.* **2007**, *37*, 482–490.
25. Manson, S.; O’Sullivan, D. Complexity theory in the study of space and place. *Environ. Plan. A* **2006**, *38*, 677–692.
26. Porter, M. Clusters and the New Economics of Competition Source. *Harv. Bus. Rev.* **1998**, *76*, 77–90.
27. Florida, R. *The Rise of the Creative Class and How It's Transforming Work Leisure, Community and Everyday Life*; Basic Books: New York, NY, USA, 2000.
28. Hautamäki, A. *Luova Talous ja Kulttuuri Innovaatiopolitiikan Ytimeissä*; Publications of the Finnish Ministry of Education and Culture: Helsinki, Finland, 2009.
29. Allen, P. *Cities and Regions as Self-Organizing Systems*; Taylor & Francis: City, UK, 2004.
30. Shane, D.G. *Recombinant Urbanism—Conceptual Modeling in Architecture, Urban Design and City Theory*; John Wiley & Sons Ltd.: London, UK, 2005.
31. Oswald, F.; Baccini, P. *Netzstadt—Designing the Urban*; Birkhäuser: Basel, Switzerland; Boston, MA, USA; Berlin, Germany, 2003.
32. Partanen, J. Indicators for self-organization potential in urban context. *Environ. Plan. B* **2015**, *42*, 951–971.
33. DeLanda, M. *Philosophy and Simulation: The emergence of Synthetic Reason*; Bloomsbury Publishing: New York, NY, USA, 2011.

34. Stevens, D.; Dragičević, S. A GIS-based irregular cellular automata model of land-use change. *Environ. Plan. B* **2007**, *34*, 708–724.
35. Reed, M.; Harvey, D.L. The new science and the old: Complexity and realism in the social sciences. *J. Theory Soc. Behav.* **1992**, *22*, 353–380.
36. Batty, M.; Longley, P.A. *Fractal Cities: A Geometry of Form and Function*; Academic Press: New York NY, USA, 1994.
37. Hillier, B. *Space Is the Machine. A Configurational Theory of Architecture*, 2007. Available online: <http://discovery.ucl.ac.uk/3881/1/SITM.pdf> (accessed on 3 June 2014).
38. Malmberg, A.; Maskell, P. The elusive concept of localization economies: Towards a knowledge-based theory of spatial clustering. *Environ. Plan. A* **2002**, *34*, 429–449.
39. O'Sullivan, A. *Urban Economics*; McGraw-Hill Irwin: New York, NY, USA, 2009.
40. Marshall, A. *Principles of Political Economy*; Maxmillan: New York, NY, USA, 1890.
41. Crutchfield, J.P.; Young, K. Computation at the onset of chaos. In *The Santa Fe Institute*; Westview: Boulder, CO, USA, 1988.
42. Kurka, P. Languages, equicontinuity and attractors in cellular automata. *Ergod. Theory Dyn. Syst.* **1997**, *17*, 417–433.
43. Gutowitz, H.A. A hierarchical classification of cellular automata. *Physica D* **1990**, *45*, 136–156.
44. Gilman, R.H. Classes of linear automata. *Ergod. Theory Dyn. Syst.* **1987**, *7*, 105–118.
45. Sunter, K. Classifying circular cellular automata. *Physica D* **1990**, *45*, 386–395.
46. Gardner, M. The fantastic combinations of John Conway's new solitaire game 'Life'. *Sci. Am.* **1970**, *223*, 120–123.
47. Couclelis, H. Modeling frameworks, paradigms, and approaches. In *Geographic Information Systems and Environmental Modeling*; Clarke, K.C., Parks, B.E., Crane, M.P., Eds.; Longman & Co.: New York, NY, USA, 2000; pp. 1–15.
48. Santé, I.; García, A.M.; Miranda, D.; Crecente, R. Cellular automata models for the simulation of real-world urban processes: A review and analysis. *Landsc. Urban Plan.* **2010**, *96*, 108–122.
49. Shi, W.Z.; Pang, M.Y.C. Development of Voronoi-based cellular automaton integrated dynamic model for geographical information systems. *Int. J. Geogr. Inf. Sci.* **2000**, *14*, 455–474.
50. O'Sullivan, D. Exploring spatial process dynamics using irregular cellular automaton models. *Geogr. Anal.* **2001**, *33*, 1–18.
51. Couclelis, H. Cellular worlds: A framework for modeling micro-macro dynamics. *Environ. Plan. A* **1985**, *17*, 585–596.
52. O'Sullivan, D.; Torrens, P.M. *Cellular Models of Urban Systems*; UCL Center for Advanced Spatial Planning, Working Paper Series; USA, 2000.

53. Agarwal, C.; Green, G.M.; Grove, J.M.; Evans, T.P.; Schweik, C.M. *A Review and Assessment of Land-Use Change Models: Dynamics of Space, Time, and Human Choice*; CIPEC Collaborative Report Series; Center for the Study of Institutions, Populations, and Environmental Change, Indiana University and the USDA Forest Service, USA, 2002.
54. DiPasquale, D.; Wheaton, W. *Urban Economics and Real Estate Markets*; Prentice Hall: Upper Saddle River, NJ, USA, 1996.
55. De Roo, G.; Hillier, J.; van Wezemael, J. (Eds.) *Complexity and Planning: Systems, Assemblages and Simulations. New Directions in Planning Theory*; Ashgate: Farnham, UK, 2012.
56. Batty, M.; Marshall, S. Centenary paper: The evolution of cities: Geddes, Abercrombie and the new physicalism. *Town Plan. Rev.* **2009**, *80*, 551–574.



© 2016 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Supplementary material:

Figures S3-14. Graphical presentation of the model dynamics.

In these tables, the time differences between the major shifts in the model (period, time steps on the y -axis) are ranked in chronological order (from the first to the n th (x -axis)) (This means that for each simulation, the number of iterations occurring between the volume maxims was calculated. (That is, the time steps required for the area to gradually fill. After that the progress started over again—see Videos S1–S3.) These values were then presented graphically in order from the first to the last. e.g., in B1, the area filled first after 10 time steps, then 12, 10, 12 and so on.).

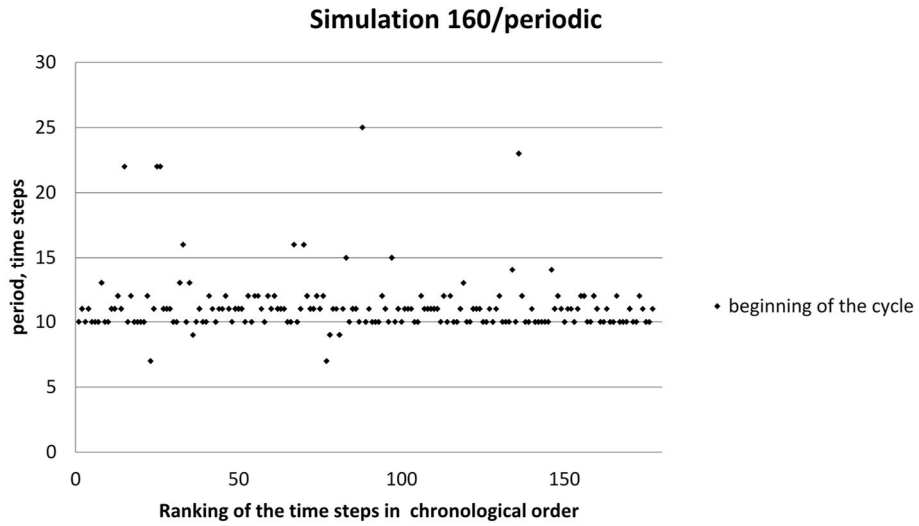


Figure S3. Periodic behavior.

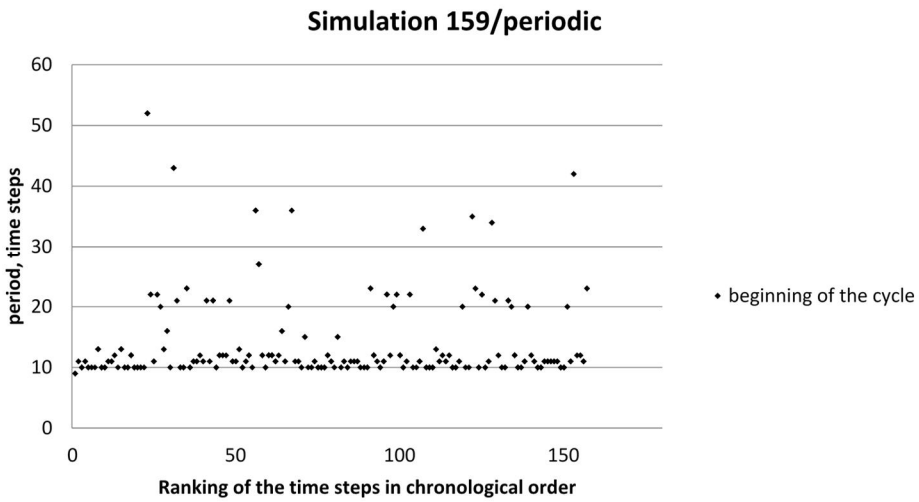


Figure S4. Periodic behavior.

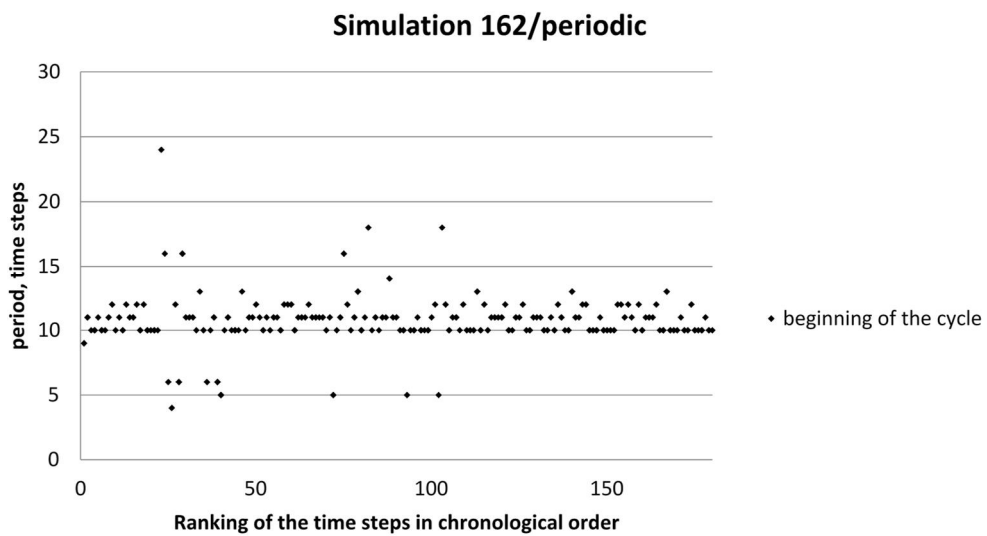


Figure S5. Periodic behavior.

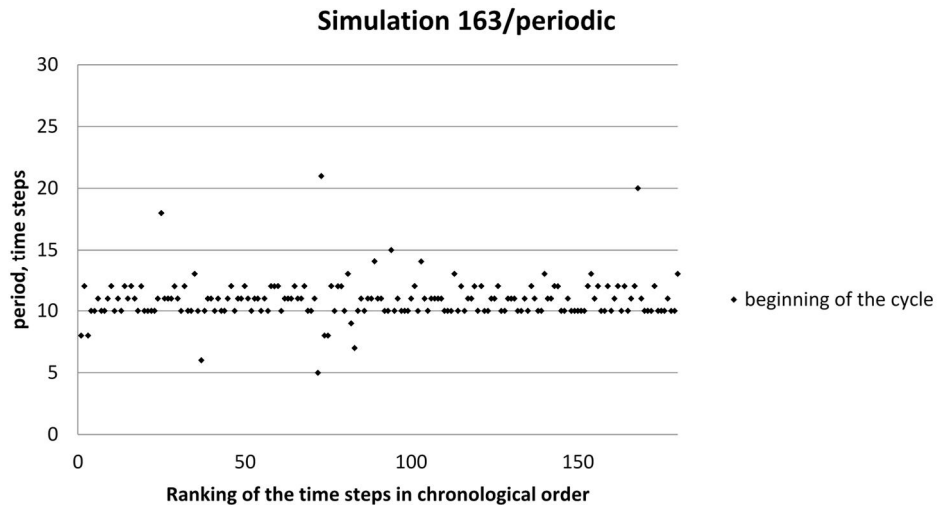


Figure S6. Periodic behavior.

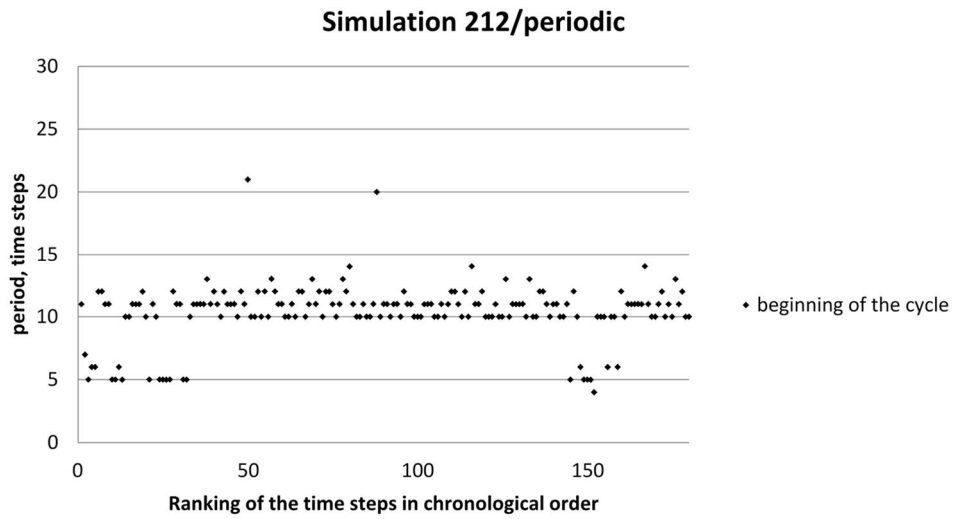


Figure S7. Periodic behavior.

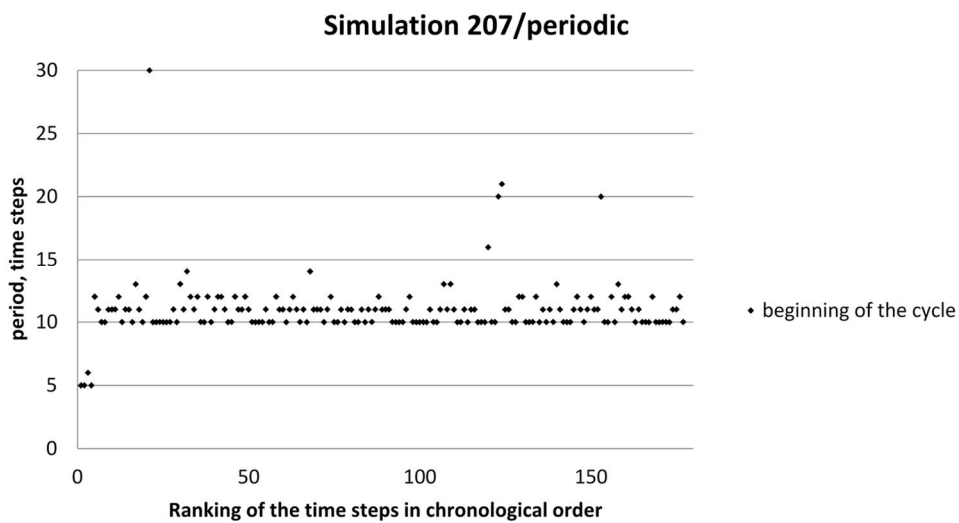


Figure S8. Periodic behavior.

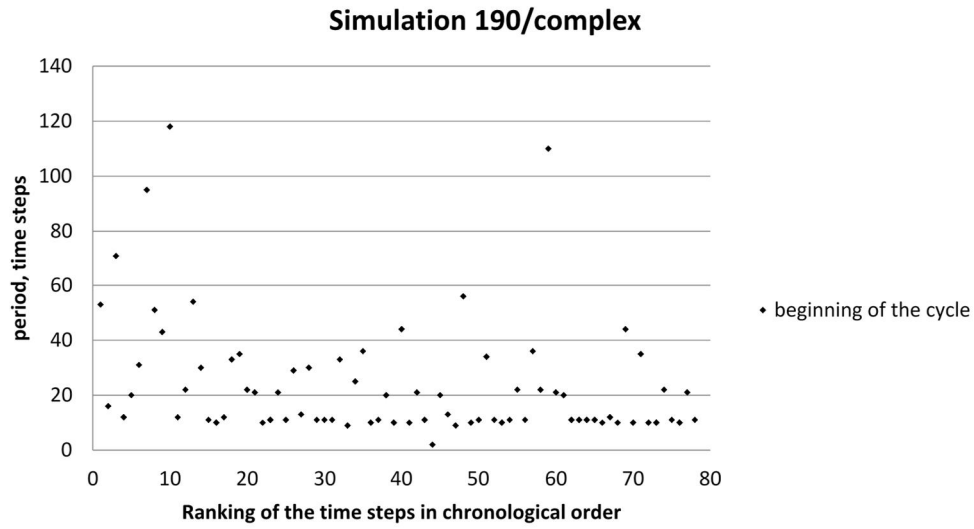


Figure S9. Complex behavior.

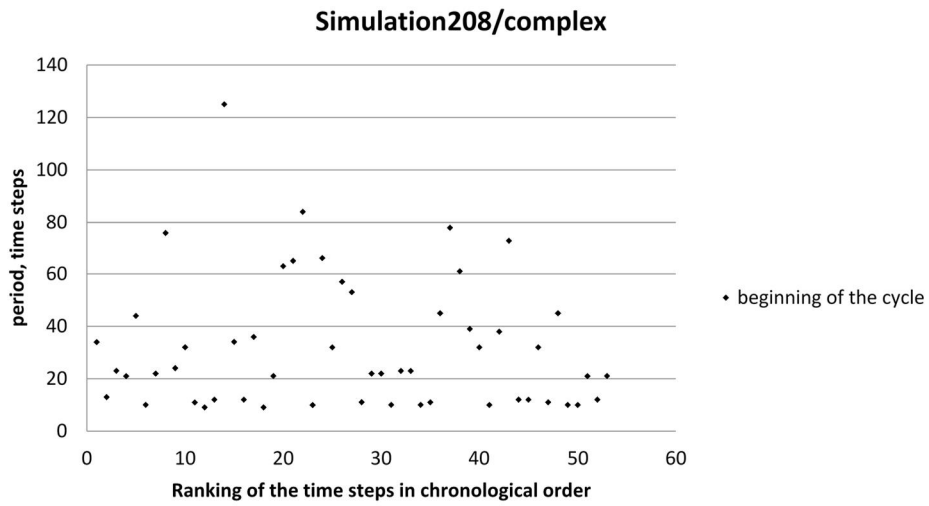


Figure S10. Complex behavior.

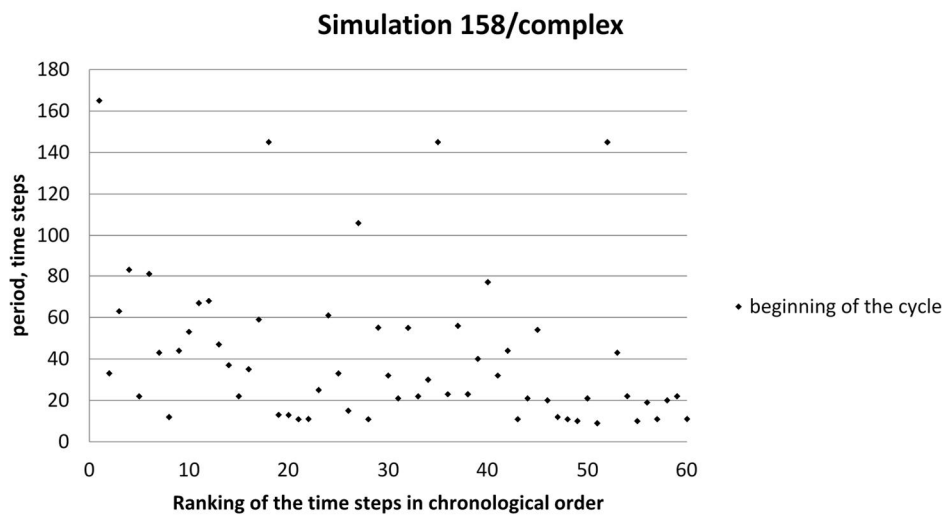


Figure S11. Complex behavior.

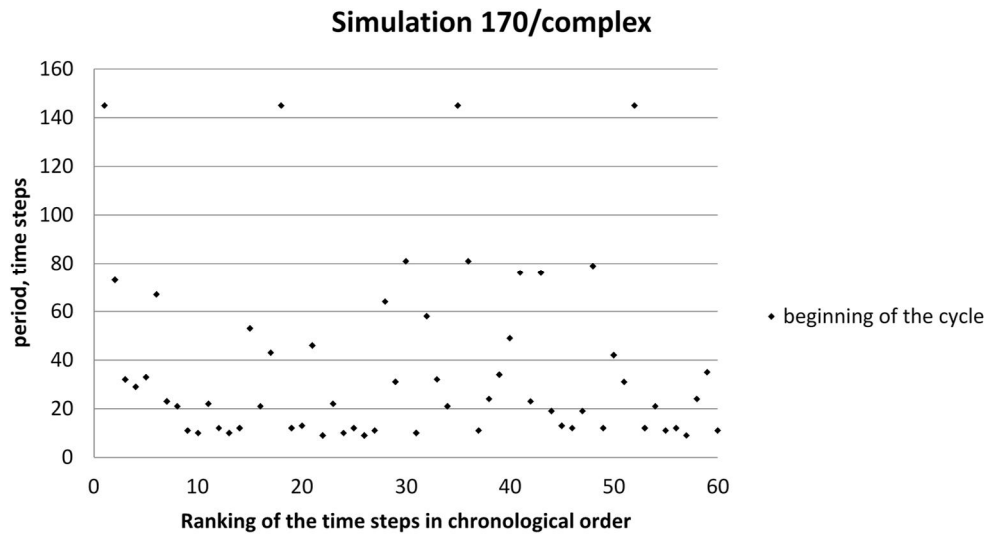


Figure S12. Complex behavior.

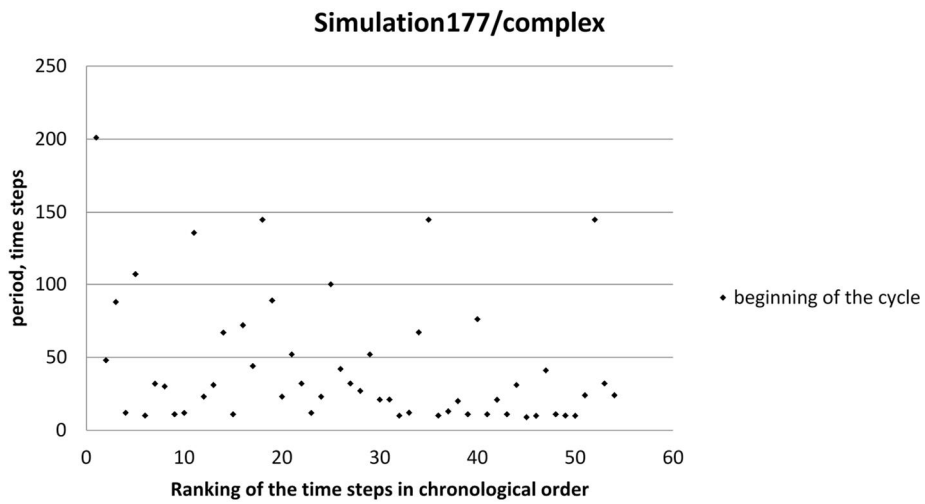


Figure S13. Complex behavior.

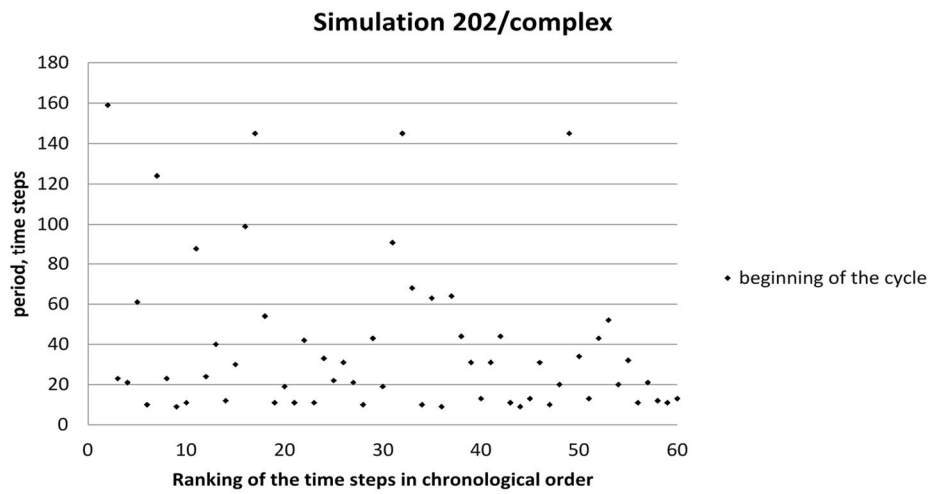


Figure S14. Complex behavior.

IV

LIQUID PLANNING, WIKI-DESIGN – LEARNING FROM THE CASE PISPALA

by

Partanen J. (2016) in *Environment and Planning B: Planning and Design*,
0265813516647965. Published online
(<http://journals.sagepub.com/doi/abs/10.1177/0265813516647965>).

Copyright © 2016 (SAGE Publications)

Reproduced with kind permission by SAGE Publications ltd.

Abstract: As the key aspects of theories of complex systems have been established, the premises for academic research on planning and on planning praxis still necessitates the development of novel planning tools and approaches to address inevitable urban self-organizing transformations. We have accepted that cities emerge from bottom up. However, planning methods simulating this emergence are still limited. Progress has been made in recent decades and many systemic, evolutionary, and computing based planning approaches have been proposed. The work here builds on these premises.

Network theoretical, computational, and democracy discourses have proposed *proxy* or *liquid* approaches as for genuinely democratic forms of decision-making. More importantly, they enable information organization from bottom up in a digital platform. This process actually follows the very principles of self-organization of information in information or cognitive sciences: entropy decreases as the “bits” of information self-organize into coherent classes. These principles are also applicable in bottom-up planning. Hence, and to bring this discourse closer to the planning realm, I compared the conceptualized structures of Liquid Democracy, SIRN cognitive model and prior self-organizing planning proposals in a bottom-up planning experiment in Pispala neighborhood, Tampere, Finland. I evaluated its capacity for self-organization of information and hypothesized that the case provides a frame for a new self-organizing planning method. Based on this evaluation a structure for a digitalized Liquid Planning procedure is suggested and discussed.

Keywords: complexity, planning, self-organization, citizen science, liquid methods

1. Introduction

Complexity thinking provides today an established basis for understanding the dynamic, unpredictable, and dissipative nature of the city. A set of theories termed complex systems originally included variety of approaches - from fractality, dynamic systems and chaos in mathematics, to information theory, self-organization in biology and chemistry, and further to scaling in mathematical statistics - contemplate open and complex systems. These have been increasingly applied in many fields beyond natural sciences: economics, social sciences, psychology and urban dynamics, just to mention a few (Casti 1994, Mitchell 2009, Allen 2004).

So-called complexity as an explanatory model reportedly provides a new viewpoint on urban studies and city planning. A new paradigm for planning praxis echoing such understanding is developing within academia through many proposed applications (deRoo et al. 2012, Portugali et al. 2012). These complexity planning methods can be classified into 1) methods evaluating the preferability of proposed plans or actual urban dynamics including modeling and measuring of dynamic configurations (scaling, fractals) (Batty and Longley 1994, Pumain 2012) and 2) methods producing the actual plan. These include rule based and evolutionary design, advanced systems dynamics thinking, and computational (but not necessarily computer-aided) and self-organizing approaches, which represent perhaps best the bottom-up perspective. In self-organizing planning the rules emerge within a self-organizing process, enslaving the system and defining the future maneuvers. Certain “computation” between entities, such as buildings, is implied against the environment to better adapt to it (Tan and Portugali 2012).

We still need new methods to explore the urban processes and learn how urban actors use the space to understand the preferable relationship between local (self-organizing) maneuvers and global (top-down) planning frames: which aspects of urban dynamics the global plan should restrict to provide enough freedom for optimal progress (de Roo and Silva 2010, de Roo et al. 2012, Portugali et al. 2012, Batty and Hudson-Smith 2013, Batty 2007). Global planning needs to carefully consider self-organization with imperfect knowledge and uncertainty of conditions to facilitate preferable dynamics. The question is how to build such plan. Note that the concept of self-organization is borrowed from natural science and hence value-free. Society needs a value judgement to promote social equality, avoid market failures and environmental disasters. Hence planning should prevent undesirable self-organization, leaving space for positive economic and social processes to emerge. Border conditions meeting these requirements must be defined, and rapidly re-evaluated if -unwanted outcomes emerge.

Liquid democracy is a bottom-up organized direct democratic system which is considered to respond better to the characteristics of today's “liquid”, ever-changing society (Bauman 2000). Rather than electing a representative and granting a mandate to decide on future (unknown) issues, in liquid democracy most issues are decided by referendum or delegating the vote by topic, not person. Delegation is temporary and can be revoked at any time. The system is considered to have many benefits, among them transparency, less concentration of power, involvement, flexibility and consideration of bottom-up features voting for an initiative, not a representative (Boldi et al. 2009, Ford 2002¹). The liquid method implies self-organization of proposals: with no prior agenda, individual contributions are made and grouped by participants into entities. Such information processing implying entropy reduction is typical of human

¹ Online example, <http://blog.liquidfeedback.org/mission/> and <http://trac.adhocracy.de//>.

cognition (Haken and Portugali 1996, 2003), and exemplified for example in SIRN city games (Tan and Portugali in Portugali 2012). The characteristics of these approaches may provide a frame for evaluating the level of self-organization in a planning case.

Recent technological development enables collecting and processing bottom-up data online, requiring fewer technological skills, and revitalizing the old traditions of citizen science. With increasingly powerful devices, open source programs and online communities, laymen can collect and even process environmental data efficiently, encouraging debate and cooperation between professional and amateur science (Silvertown 2009, Devish and Veestraeten 2013, Hand 2010, Sauerman and Franzoni 2015). These methods are also applicable in collecting, analyzing, sharing and evaluating qualitative and quantitative data for planning, once appropriately structured and monitored. Positive experience (Hand 2010) implicitly highlights the cooperative nature of the process and the relevance of professional guidance to guarantee data quality. Citizen science does not replace but complements conventional science.

A bottom-up planning experiment was carried out in the neighborhood of Tampere, Finland to pinpoint the central spatial and functional features of the area from bottom up and encourage the autonomous emergence of essential themes, goals, and rules for planning. The process involved local stakeholders and planning professionals from the University and the City. Professional expertise ensured the project standards regarding legal and other restrictions and produced a variety of analyses, visualizations, and the final report. Themes and proposals appeared to emerge within the process, suggesting certain self-organization of information. Hence I hypothesized that the Pispala case structure could provide premises for a new self-organizing planning approach.

The case apparently exemplified the above mentioned conceptualization of self-organization of information. Hence the Pispala case structure was evaluated against this conceptual frame derived from liquid thinking, self-organizing planning principles, and a human cognition model. Answers to the following questions were sought: What are the conceptual cornerstones in a social/cognitive self-organizing process? To what extent are these present in the case of Pispala, and what would be the basic layout of a digitalized self-organizing planning approach drawn from these conceptualizations and the case? Finally, the paper presents a structure for Liquid Planning and applicable digital bottom-up -tools following the proposed basic structure.

2. Theoretical background

Theories of complex adaptive systems currently form a credible foundation for understanding the trans-scalarity, inter-connectedness and non-equilibrium nature of many open natural and artificial systems (Haken 2010, Holland 1998), including cities. Self-organization resulting from multiple agent interactions is an essential mechanism in the emergence of complex cities. Cities are built from bottom-up as a result of local actions by individuals or larger collectives, agencies, and groups within a top-down frame consisting of laws, regulations and other limitations. Urban self-organization produces many positive outcomes such as cultural or economic clusters and networks fostering innovation but only within a certain frame excluding the factors potentially causing negative externalities (in cities social inequality, lock-in's, market failures, downward spirals), still leaving enough space for the emergence of preferable dynamics.

The key issue is that traditional planning practices have not duly acknowledged urban self-organization, where actors often adapt to what is locally optimal. For example, studies of fractal cities have revealed that actors often seek locations in which they fill urban space very efficiently. (Batty and Longley 1994, Batty and Hudson-Smith 2013 p.19). Portugali (2012) uses the term *local planning* to refer to the variety of individual (building or urban development) projects which eventually produce the actual city, and (re)form it. Often these projects follow the city plan only loosely, or the plan is adjusted according to (larger-scale) projects. Local and global planning coexist and cooperate, and local planning is often “more dominant and effective in the overall urban process than global planning” (Portugali 2012, p. 230). A top-down procedure aims at total control with an illusion of “closing the system” until the urban project is finished. After a local building project, for example, the project is over once the plan has been implemented.

However, in the city, once the plan has been implemented the game is just beginning in the form of myriad bottom-up processes. Local planning is not only a reactive, but a proactive force. Any global city planning opposing this self-organization will fail. Global planning should not disrupt the positive local processes. At its best global planning can reflect the principles of bottom-up organization and let the preferable, fruitful urban evolution proceed by hindering less preferable factors. A global plan is necessary, but its success depends on the success of the interplay between global and local planning. On the one hand, we must make a good global plan for harnessing positive self-organizing processes for a more viable city. On the other, following adaptive planning principles in ecosystem thinking, we must keep the maneuvers small, constantly evaluate the realization of the plan, and react rapidly in case of a negative outcome (Batty and Hudson-Smith 2013, Allen 2004, Kato and Ahern 2008)

Cities are changing in response to the IT revolution: urban areas respond faster to new information, new innovations, to physical changes. The almost ubiquitous use of devices allows us to capture, share, and create information, resulting in countless ways of producing, consuming, thinking, innovating, and entertaining. Clearly cities will be used in more diverse and uncertain ways than before; local planning is gaining more ground in more unpredictable ways. The effects are ambiguous, especially regarding built environment. Simultaneously the people are better able to obtain coherent information on their environment to make decisions ever faster (Lupia and Matsusaka 2004, Batty and Hudson-Smith 2013).

One response to this progress has been the recent development in participation procedures. Novel methods, such as use of the dynamic models in the planning process (Kieser and Marceau 2011), participatory GIS solutions and (role play) games (computerized and live, individual and group games) have recently been introduced (see, for example, Castella et al. 2005, Poplin 2012, Susi et al. 2007). Many open source planning participation tools have been developed within online communities, such as the Google Open Planning Tools group. These applications are gradually bringing bottom-up knowledge production closer to the actual production of spatial plans and design, blurring the distinction between the two. Many of these novel tools have been assigned to the participatory tool box. However, merging the bottom-up features under the concept of participation appears somewhat limited given the dissipative, emergent, non-equilibrium nature of cities: the fact that bottom-up processes produce the city is ignored. Participation is a part of today's planning system which still emphasizes the role of static global planning: the planners are basically separated from the planned, largely ignoring the power of local planning (Portugali 2012). The participation implied in this system is limited to letting people have their say during the (global, top-down) planning process (Portugali 2012). This thinking collides seriously with the basic notion of self-organization of local actions and use of space described above. Although the dissipated nature of society is often recognized in participatory action, participation only adds a new layer to the old rational planning paradigm. To actually renew the paradigm a more thorough reevaluation is required. I consider complexity thinking a promising foundation for this paradigm change in planning.

2.1 Complexity planning approaches

Various solutions for new complex planning praxis have been proposed (see for example de Roo and Silva 2010, de Roo et al. 2012, Portugali et al. 2012) to better respond to the unpredictability of dynamics in actors' locations, increased mobility, individuation and accelerating digitalization characteristic of today's urban reality (Ascher 1994, Castells 1996, Graham 2001). These still mostly academic enterprises take one profound step further from the

participatory addition. The complexity planning evades the idea of overall static control implicit in traditional planning. These methods are bottom-up, dynamic, allow for self-organization and emergent patterns, phase transitions, and recognize the limitations in our ability to control the system. First, they include evaluative methods applying simulations or other methods measuring relational order in systems (such as fractals or scaling) for the constant appraisal of plans or urban dynamics. They help to estimate the desirability of dynamic patterns in the system. Secondly, productive methods are related to the actual production of a spatial functional city, such as rule based and evolutionary design (implying that entities with chosen local rules concerning their relations produce designs); computational and self-organizing approaches (adaptation of entities produces the rules). Each of these approaches serves a significant purpose from evaluating an existing city or plan to producing actual spaces or designs (for further evaluation).

I concentrate on self-organizing planning, for it presumably best reflects how the actual local processes function behind the (re)formation of the complex corporeal city: they build the “plan” from bottom up within a dynamic interplay between actors (see e.g. Alexander 1977, Alfasi and Portugali 2007, Duarte 2011, Lynn 1998, Novak 2001). In self-organizing approaches the spatial configuration or plan/design emerges within a process based on dynamic, autonomous and adaptive “computation” and relationships between urban entities, defining for example tolerable proximity, use or volume of adjacent buildings. Individual (both professional and local) planners produce urban environment during a collective process from which the rules and patterns emerge (Tan and Portugali 2012; Webster 2010, Salingaros 2000).

Within this theoretical frame my aim here is to propose a novel self-organizing planning approach applying digital networks in information processing. For this purpose, I next explore the potential of a digital social network through the concept of Liquid Democracy for providing the self-organizing planning frame. Furthermore, citizen science is introduced as this concept provides tools for collecting and organizing data in cooperation with professional planners. Finally, a self-organizing SIRN-model of human cognition is elaborated, as a model of information processing within human systems, presumably also bottom-up planning. These provide a conceptual framework for evaluating the self-organization of information in the planning case.

2.2 Liquid democracy

The notion of *liquid democracy* follows the ideas of Zygmunt Baumann introduced in his book *Liquid Modern* (2000). Baumann hypothesizes that society has transformed into a “light society”, assuming that elastic emergent networks in a state of constant flux have replaced the rigid social structure; a “citizen” member of society has become a “person” with changing preferences and identity constantly reflected in others, with no predefined frame, and burdened with the demand to define one in a non-stop self-reflecting process (Bauman 2000). In this liquid, constantly transforming networked society representative democracy responding to the needs of the rigid society of “solid modernity” with predefined, fixed classes or groups is no longer an appropriate solution. Increasing digitalization is likely to liquidize the society even more, but may also provide solutions for novel type of social organization.

Liquid democracy is a proposed bottom-up democratic alternative to representational democracy. It is claimed to have more capacity to consider the characteristics of today’s society. Liquid democracy is a direct democracy approach. In the simple form of direct democracy people vote directly on issues without a delegate, resulting in a fairly cumbersome system (Clarke and Foweraker, 2001). Direct democracy methods are considered to create more efficient government and a healthier relationship between money and power (Lupia and Matsusaka, 2004). Liquid democracy is lighter and more efficient than pure direct democracy, but more flexible than representative democracy: instead of voting for a representative for four years and giving the candidate a mandate to decide on future unknown issues with no option to revoke the vote, in liquid democracy most issues are decided by direct referendum or delegating the vote by topic, not person. Delegations are transitory and can be revoked at any time. Liquid democracy has several advantages: transparency, less concentration of power, involvement and true participation, flexibility and consideration of bottom-up features and voting for an initiative, not a representative (Boldi et al. 2009; 2011, Ford 2002). The downsides may include difficult traceability of the online system for common users and the complexity of the structure, and group thinking, which can be overcome by value-laden steering, having multiple groups and outside expertise, and by avoiding isolation of groups (Janis 1972).

2.3. Citizen science –methods

Citizen science is a process involving ordinary people collecting and processing data as a part of scientific inquiry, including observation, measurement, and computation of phenomena. Citizen science projects are expanding mainly in ecology and the environmental sciences, but their roots

go back centuries (Silvertown 2009). Today technological innovations may revitalize the tradition of citizen science: new tools and applications demand fewer skills and guarantee certain standards for the data (Silvertown 2009, Devish and Veestraeten 2013). Technology has transformed citizen science from monotonous tasks such as species counting to sharing, uploading and mapping data, and recently enabling even computation and visualization of the results in real time, for analyzing and representing the data. During this process the relationship between citizen scientists and professionals is shifting from dependence towards debate (Bonney 2014, Newman et al. 2012). Citizen science projects assisting “real” science have yielded promising results with efficient data processing (Hand 2010).

It has even been suggested that technological progress will increase the independence of citizen science, with the assistance of virtual experimentation with the data. GIS-based visualization, augmented reality tools or simulation models may enable citizen science to adopt certain theory building and validation mechanisms, resulting in a “co-production” of science (Newman et al. 2012). Despite the benefits of these tools, they should be adopted cautiously; the quality of results is precarious, and professional steering is needed (Gura 2013). However, guides and tools are available for planning, testing and evaluating projects, likewise data management and quality control plans to overcome these problems (see for example citizenscience.org) (Bonney 2014).

Devish and Veestraeten (2013) propose that dynamic simulations may be applied as citizen science tools for validating “results”. However the inherent complexity, chaotic nature and path dependence of reality limits the validation of simulations themselves, making them educational tools to learn how the prior decisions affect the outcome. (Zelner 2008, Zelner et al 2012). Thus using any readymade simulation may be challenging and need prior professional modifications to improve performance of the model.

Recent ICT development, such as page ranking methods and algorithms, existing online life in social networks, the family of crowd sourcing and other bottom-up planning support system tools, and ongoing visualization/virtual cities projects (Yamakawa et al. 2007, Batty 2007) provide methods suitable for liquid democracy thinking in spatial planning. Along with the “citizen science” applications, they enable dynamic, often real-time combination, production and reorganization of data. For instance Boldi and colleagues (2009; 2011), and Yamakawa et al. (2007) have discussed potential computation structures for proxy voting systems. A two-step liquid operational method has been developed in a trial program LiquidFeedback². First, problem statements and potential directions are formulated in open discussion. Propositions and

² An independent open source project published under MIT license by the Public Software Group of Berlin, Germany (<http://liquidfeedback.org/>).

claims are grouped by the people themselves according to their perceived similarities. Open discussion and formulation of issues produce problem statement(s), and potential directions for solutions in a self-organizing manner. Then comes the actual proxy vote on solutions.

Distributed data collection and (professionally guided) processing methods have considerable potential in planning, recognizing existing city features and self-organizing processes to be considered in defining the planning rules. Liquid and citizen science approaches fit well with complexity thinking as inherently self-organizing, trans-scalar methods: multiple agents producing and arranging data, with observable patterns on the higher scale, within a framework of given rules for this self-organizing process involving lay and professional planners. In planning, the requirements proposed for the citizen science project by Silvertown (2009) become even more necessary: a well-designed method, explicit assumptions, and a “hypothesis” should be formulated. This study aims to build such a frame.

2.4. Self-organization and cognition

An important mechanism in this process is grouping or self-organization of information. Through this essential cognitive procedure humans perceive the city - not only in terms of what is observed, but also in terms of potential patterns, giving entities simultaneously a contextual, relative meaning by grouping. (Haken and Portugali 2003). To perceive the city, information needs to be self-organized. New entities are perceived, information is grouped (as a new “class”) decreasing entropy, which enables giving it a semantic meaning (Shannon 1948, Haken and Portugali 2003). This self-organization takes place in a multi-level process called SIRN (synergetic inter-representation networks) (Haken and Portugali 2003; Portugali 2012). In SIRN, an “order parameter” emerges from interactions between internal and external representations. This cognitive process consists of three sub-processes: Intrapersonal, interpersonal, and combinations of these in the context of a collective “reservoir”, such as the city. One of the competing interpretations enslaves the cognitive system, manifest as human action and decisions (Haken and Portugali 1996, Portugali 2012).

I propose that the above liquid process also follows the basic principles of self-organization of information and decreasing of entropy fundamental in SIRN: the “problem statements” and individual claims first emerge and self-organize in intra- and interpersonal processes. Once coherent entities (themes, rules or “plans”) emerge, they develop in the framework of these “reservoirs”.

2.5 Conceptualizing self-organization

All these approaches follow a basic structure which is common to self-organizing systems: 1) *entropy*: introduction of new elements/entities; 2) *self-organization* of information: emergence of a new “group” with a meaning and 3) *stability*: establishing the class (Table 1). They also imply a certain self-regulating feed-back loop – the resulting class enslaves the system, which impacts the future classifications, or the emergence of a new class, and so on.

		1. Entropy	2. Self-organization	3. Stability
	S-O of information, conceptual	<i>New entity type</i>	<i>Emergence of a class</i>	<i>Stability and enslaving</i>
	Levels in SIRN model	<i>Intrapersonal</i>	<i>Interpersonal</i>	<i>Reservoir</i>
Self-organizing planning		<i>Single maneuvers</i>	<i>Group of entities</i>	<i>Emergence of a rule</i>
Liquid democracy -model		<i>Single proposals</i>	<i>Grouping of similar themes</i>	<i>Established themes, voting</i>

Table 1. *Conceptualization of self-organization of information in social processes.*

Next, to bring this conceptualization closer to the realm of planning, a bottom-up planning experiment is introduced and evaluated based on the above classification, aiming at proposing a Liquid Planning structure, along with suitable, digital bottom-up citizen science tools.

3. *The case of Pispala*

The project was administered by Tampere City Planning, and financed by the European Structural Fund (ESF). The consultants were Tampere University of Technology architectural team (design of the process, GIS analyses, data gathering and mapping, visualization and interpretation), and a social planner, a moderator responsible for design and chairing of large collective meetings, and a local coordinator responsible for general information dissemination. For this case study, the material, such as meeting minutes, maps, (GIS) analyses, group meeting reports, and presentations produced during the process by Tampere University of Technology (TUT) specialists and the participating groups was analyzed from the perspective of information processing.

3.1 The case characteristics

Pispala is a topographically and architecturally unique neighborhood in Tampere near the city center (Figure 1). Since the 1890s it has grown independently just outside the former municipal border of Tampere around the old village of Pispala, with major expansion in the 1920s along with burgeoning local industry. Yet the population was very diverse. The neighborhood grew in a very self-organizing manner, with very limited building or other regulations. Border conditions were mostly limited to available and affordable techniques and materials and the peculiar topography, a moraine ridge with steep slopes. The process resulted in unique building codes and morphology, and autonomous infrastructure organization such as water supply, along with a myriad of small workplaces, factories and shops, but also a rather unruly reputation implying resistance against authorities.

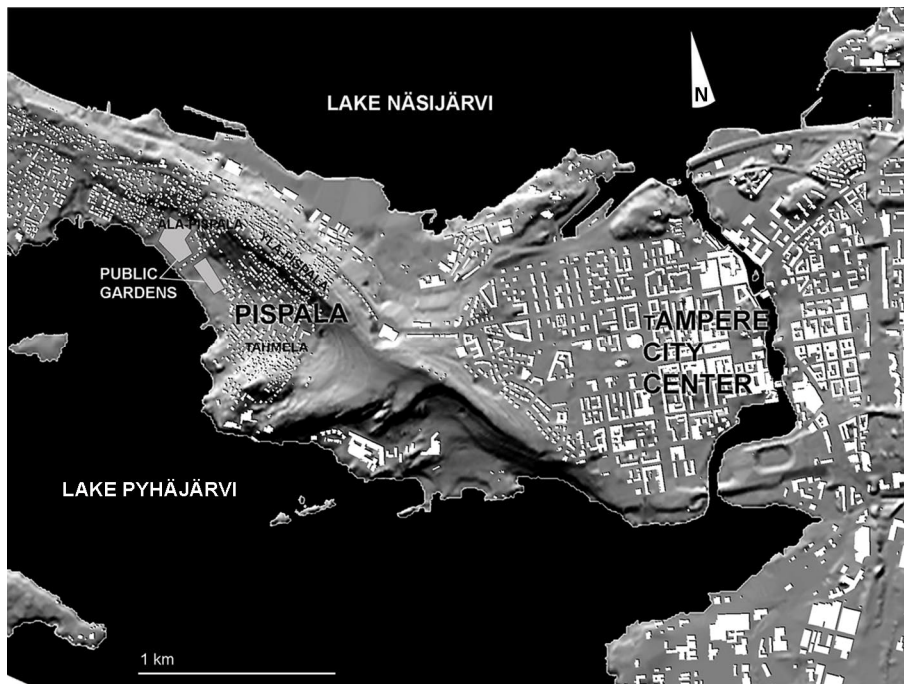


Figure 1. Location, topography and morphology of the Pispala neighborhood.

In 1937 Pispala merged with the city of Tampere, but the attempts to regulate the area with strict municipal plans proposing drastic demolition and modernization were unsuccessful, thereby preserving much of the built heritage and population diversity. Despite the growing attractiveness of the neighborhood due to its unique identity, atmosphere and topography, the area gentrified only partially, and the original bottom-up organization largely remained. Today over 30 political, cultural, economic, and other associations operate in the area with a

population of approximately 3,500 (PRH 2013, City of Tampere 2013) (Figure 2.). Yet in recent decades the increasing attraction of the area along with the old plan and fairly free interpretations of regulations have caused housing volumes to increase, with incongruous contemporary architecture and (ill-considered) demolition of built heritage. At the same time, several issues, such as more recent limitations on demolition, restrict the utilization of building rights, and the city's growing interest in building up the traditional allotment garden area by the shore, which is one of the very few public open spaces in an otherwise extremely dense built structure, give rise to widespread resistance. These circumstances have caused a lot of tension between different groups and seemingly permanent mistrust in the city planning authorities.

Against this fairly complicated background, the area forms a suitable yet challenging laboratory for a bottom-up planning experiment.

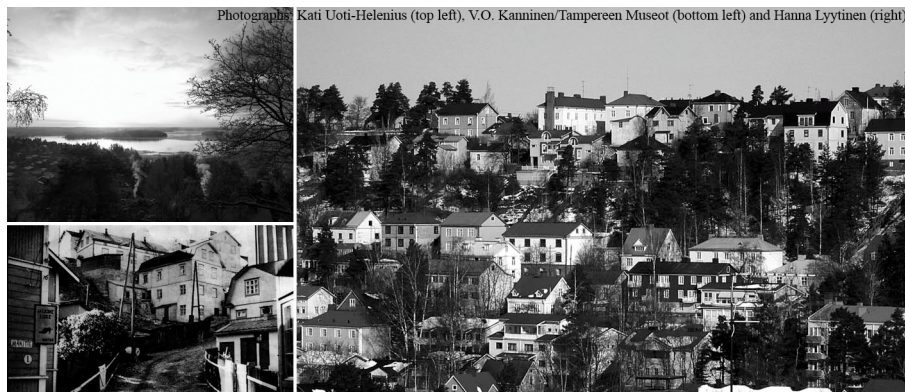


Figure 2. Characteristics of built environment in Pispala: historical layers, topography and scattered, self-organized dense settlement structure result in typical spatial appearance of the area.

3.2 The planning experiment

3.2.1 The structure of the project “KaOs” (KaupunginOsat – city districts)

The design of the KaOs project followed the basic design described in Figure 3.

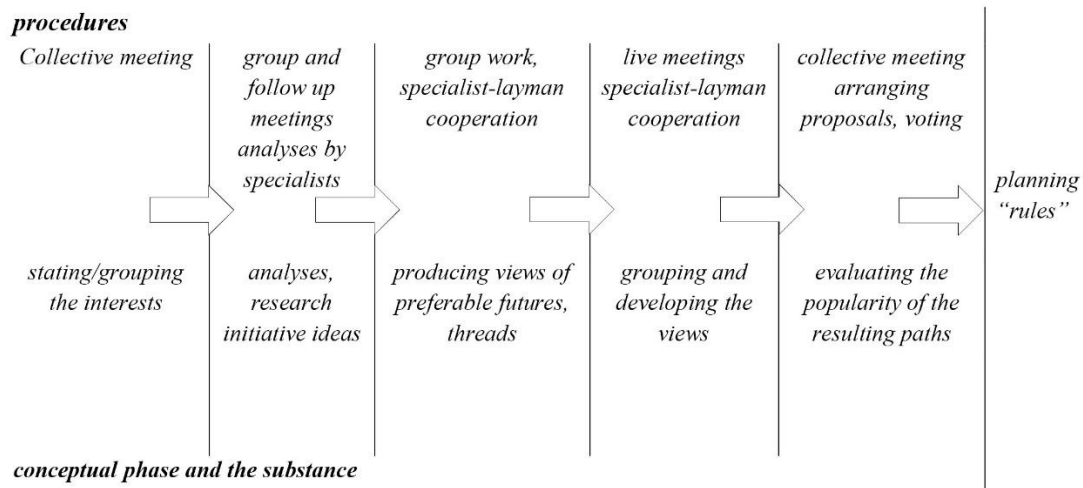


Figure 3. Structure and sequential results of the KaOs project .

Opening: The conference

The process started with a large open conference aiming at mapping the most crucial problems and other issues, grouping these into entities, and forming interest groups around the emerging themes. No prior solutions or proposals were offered.

Each participant presented a brief overview of her personal interests in the area and wrote down the main point using one sentence. These notes were collected on the wall, and arranged into groups according to emerging themes by the presenters. Anybody was free to move anyone else's note, if able on request to explain why. Finally, the notes formed seven categories. Next, people were invited to join the group(s) best representing their interests. The groups elaborated the main challenges in the area from the perspective of the chosen theme, and concluded with tentative directions for future work. Finally, the groups presented their interpretation of the main challenges and the means to start working on the problem.

The groups consisted of citizens, firms, and many specialists. Most importantly, experts from the City of Tampere administration (different sectors, such as planning, parks and recreation, and real estate) were encouraged to participate actively in the groups throughout the process. The city administration was committed to this core principle of the project plan from the very beginning. These "city experts" were equal to other group members for freer discussion within the group. Researchers from the universities in Tampere were voluntarily involved as participants. The conference was significant in laying foundations for future work, and the grouped statements formed unique, unconventional themes. The project timeline is presented in Figure 4.

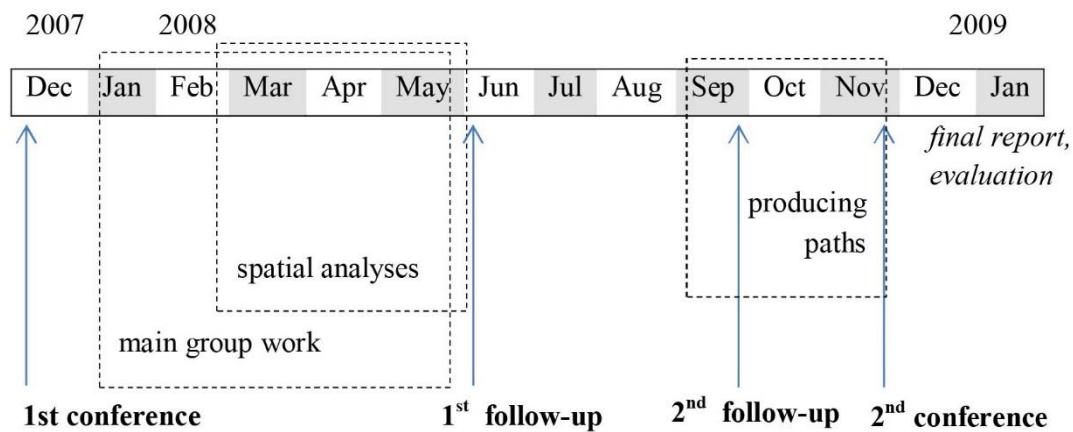


Figure 4. The project timeline.

Groupwork

Next, the groups started to work independently. Their bottom-up emerging methods ranged from traditional meetings to city walks, lectures, and spontaneous inquiries. Groups were assisted by consultant architects from TUT producing and collecting spatial planning material (GIS analyses of the area, combining spatial information and local knowledge produced by the groups). General help was provided by local the coordinator. This phase formed the core of the process, producing environmental knowledge for future steps.

In two follow-up meetings the ongoing work was shared among the groups, the TUT specialists and the Tampere planning office and the next steps were planned. These meeting provided an overview of the process state, and enabled open discussion across the groups and specialists.

Designing paths

The working groups were invited to a meeting to collaborate on the structured paths for the future. The TUT architects then collected the saturated claims emerging from the material produced with and by the local people. Claims concerned what should/not be done, for example “no special use [such as residential only] is defined for sites - housing and other activities are equally supported in the area”, “existing building right remains, voluntary renovation may increase the legal building right (sqm) on the site”, “in renovation, wind/solar energy will be obligatory/allowed/restricted”, “outer fringe of the allotment garden may be built on”, or “no building on the traditional garden area”.

Each person was asked to choose the claims they agreed with, either existing ones (original or modified), or their own proposals. The participants used 210 claims in total to articulate their visions. In more than half (115) of these statements new or altered claims were used. The TUT experts grouped the claims in cooperation with the participating laymen, first, according to the emerging subject. These categories were housing, built environment, [allotment] gardens and the shore area, parks and [urban] woodlands, traffic, and services and workplaces (Figure 5). The claims were distributed as follows: housing (59), gardens (26), parks (49), traffic (44) and work (28).

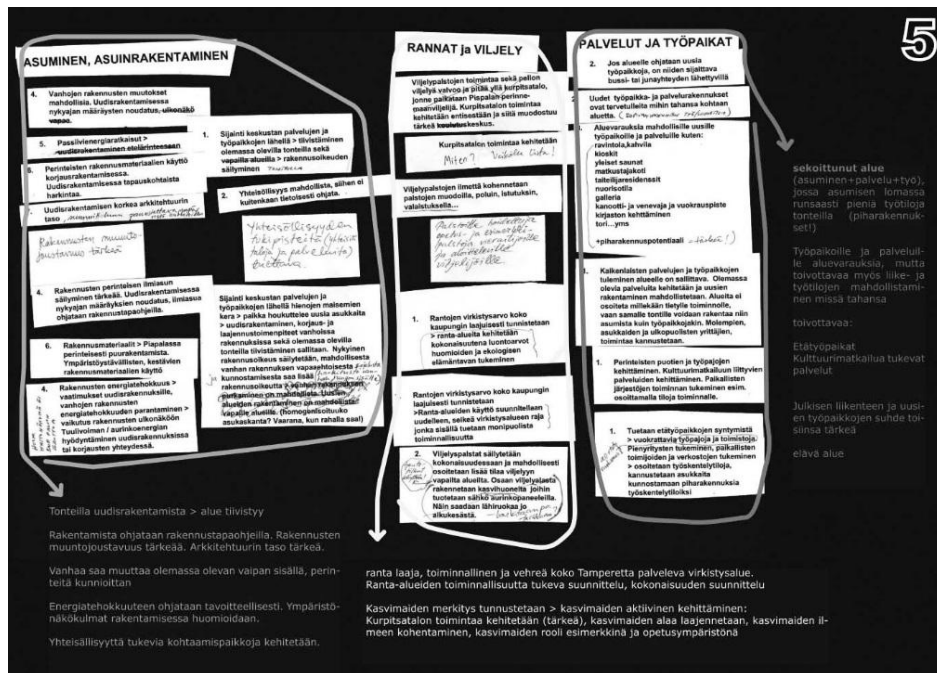


Figure 5. Example of the material from the path creating process. First round of grouping of statements, emerging themes housing and built structure (left), coastline and allotment gardening (middle), and services and workplaces (right).

Secondly, proposals were classified according to the level of manoeuvres, for example in building conservation “protecting the valuable old buildings [following the evaluation of Tampere city museums]”, “allowing small changes and additions” or “all new architectural layers are welcome in the continuous urban process” (Figure 5). The resulting draft versions were discussed with Tampere city planners and other specialists from the municipal sectors for acceptable, realistic directions. The material was put together by TUT, and served as the basis for the final phase of the project. This phase was essential in structuring the variety of results produced in groups, to be able to discuss the future directions in a constructive manner, yet avoiding predefined solutions.

The final conference and the workshop

The second large conference aimed at elaborating the final versions of the paths and discovering the preferred directions for future development of the area, and proposing maneuvers enabling this. Each group chose a combination of features in the framework of the existing material. During the process some of the initial proposals were developed further or combined by regrouping proposals considered similar. The resulting paths were then presented by the groups and discussed in public. Preferred options then formed a loose frame for the future path with weights (Figure 6).

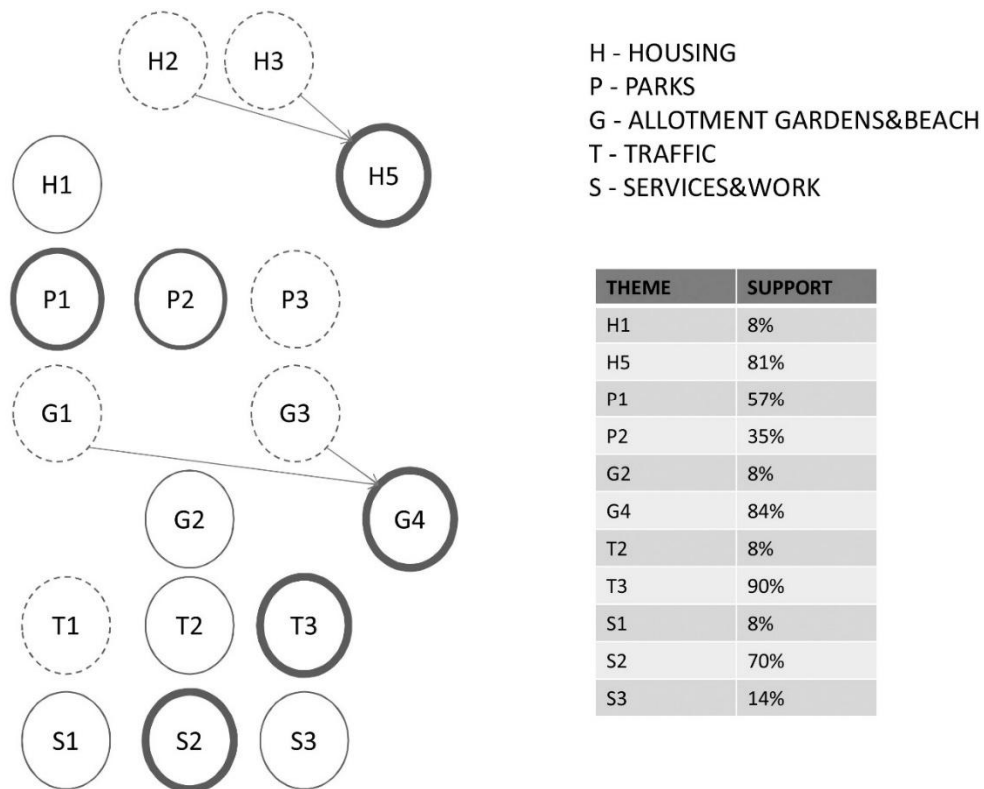


Figure 6. Final phase of the process with the resulting weights of the proposals.

The final material was collected and visualized (photomontages, maps) by the consultant architects, and published online. The meeting was important not only due to the knowledge processed, but also in making visible the surprisingly wide spectrum of views.

The material produced in the groups was mostly in narrative form. To represent the findings spatially, the information was mapped and visualized by the TUT architects. It seems probable that the (artistic) quality and decisions concerning content and visual style of maps, photomontage, and schemes had an important role in communication, emphasizing the future atmosphere of the space and ignoring precise architectural and technical details (examples of

visual material in Figures 8. and 9. in the appendix).The first meeting attracted over 120 participants. In follow-up meetings there were over 60, and in the final meeting over 80 participants, of whom 37 were active in the final workshop. During the group work approximately 50 people were active and others followed the process via email lists or internet.

The formal questionnaire was completed by 39 people, and indicated that the participants were mostly residents (29) and property owners (29); to a lesser extent representatives of public associations (12) and local entrepreneurs (only two). Approximately 10 Tampere city employees worked with the groups. Ages ranged from 36 to 60 (18), or over 60 (12). Young people and families with children were underrepresented. Genders were fairly equally distributed (women14/men19).

3.2.2 Top-down vs. bottom-up

To evaluate the self-organization of the Pispala experiment, the top-down (predefined and emergent) and bottom-up features of the process needed first to be distinguished. Both are necessary for facilitating self-organization in any system. Although the Pispala process basically operated from bottom up, certain predefined top-down rules were crucial. They considered the basic structure of the project, personnel, form and frequency of public meetings, the group working format, broad questions to be elaborated (interests, existing features and proposals for future), and the target area. An essential rule required the presence of a specialist in each group, who provided advice on the relevant laws, regulations and other border conditions to avoid wasting efforts (such as emergence of un-lawful suggestions). The rest of the process - methods, informal meetings and communication, composition of groups and their interest groups, and most importantly, content of work, focuses and interests – was organized from bottom up. From the information organization perspective the emergent content of analyses and proposals were in a crucial role yielding core rules within the project in a self-organizing manner.

Comparison of the project structure to the above evaluation frame of self-organization of information (Table 2.) showed that it followed the basic threefold progress perceived in many self-organizing systems. This was evident especially in group formation and proposal phase, and to an extent in the analyses despite the more prominent role of specialists in producing GIS-analyses and visualization of maps. The emerging themes enslaved the interests (forming groups) and focus on analyses; analyses outcomes steered the planning problem statements, and the grouped statements formed a stabilized setting for voting (and potential planning rules). Hence the basic structure seems applicable for self-organizing Liquid Planning although the role of specialists needs consideration in a digital process.

		1. Entropy	2. Self-organization	3. Stability
	S-O of information, conceptual	<i>New entity type</i>	<i>Emergence of a class</i>	<i>Stability and enslaving</i>
	Levels in SORN model	<i>Intrapersonal</i>	<i>Interpersonal</i>	<i>Reservoir</i>
Self-organizing planning		<i>Single maneuvers</i>	<i>Group of entities</i>	<i>Emergence of a rule</i>
Liquid democracy model		<i>Single proposals</i>	<i>Grouping of similar themes</i>	<i>Established themes - voting</i>
	group formation	<i>individual statements</i>	<i>combining statements – emergence of a group</i>	<i>final group with defined (common) interests</i>
	analyses	<i>collecting data</i>	<i>emergence of planning problems</i>	<i>reports, thematic maps</i>
	planning proposals	<i>individual maneuver proposals</i>	<i>grouping proposals into themes</i>	<i>final set of rules, voting</i>

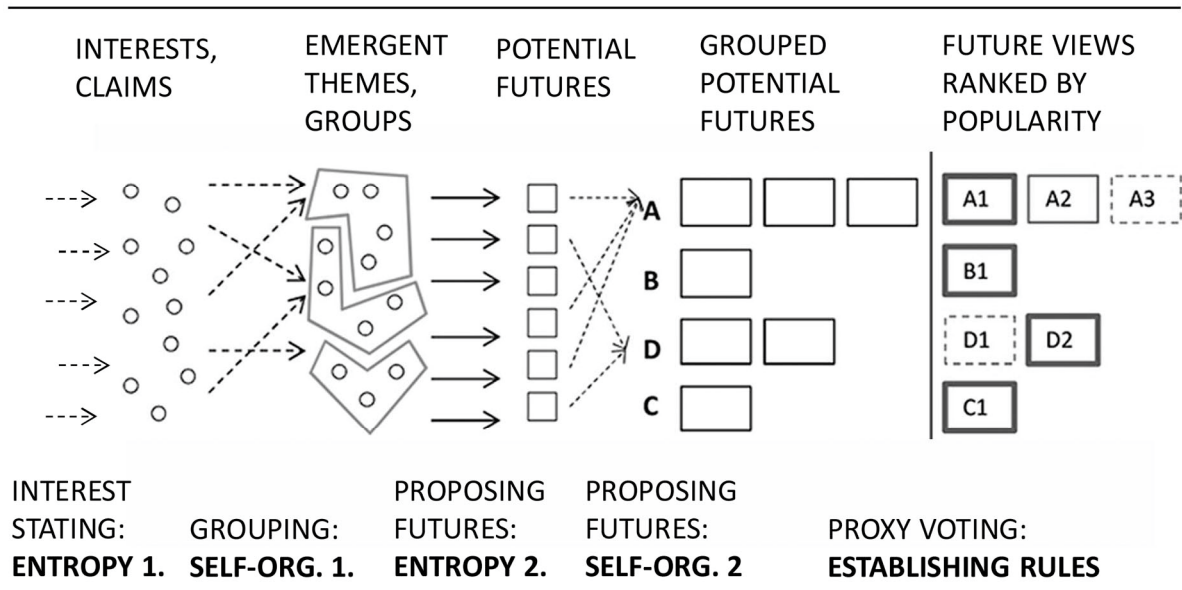
Table 2. Comparison of self-organizing processes and the Pispala case structure. The self-organization of information is a common principle.

4. Liquid planning

In light of this evaluation and conceptual premises, I propose the following structure for a liquid spatial planning process (Figure 7.). First, stating the interests (“entropy creation” 1); secondly, grouping of the interests (self-organization 1 - emergent themes); third, proposing potential/preferable futures (“entropy creation” 2); fourth, grouping and combining of these (self-organization 2 – emergent, grouped proposals); and finally, proxy voting on the popularity of each of the future views (establishing the rules). The analyses would be carried out in groups by local actors (representing economic actors, individuals, organizations) under the guidance of

specialists (for example municipal city or traffic planners), who participate throughout the process, or hired consultants.

PRODUCTS



PROCESSES

Figure 7: *Conceptualization of the liquid process.*

The process would start by formulating statement(s) describing the current problem. The initiative, a loose frame for the work, may be provided by the City (an ongoing (planning) project), or emerge bottom-up. In this case, informing the city planners at an early stage and including them throughout the process would be essential for a mandate for the project. The digital, moderated “shared space” would consist of an online forum, in which registered volunteers could freely and concisely articulate their main interests. Initially, each could propose one crucial aspect of the case with no restrictions on the subject. Next, numerous diverse claims would be grouped by the users and the specialists according to perceived similarities between them. The web design should enable a) creating and reading the claims b) grouping and re-grouping them using hashtags or similar proven methods (Crooks et al. 2013), and c) reviewing the overall structure. Interest groups would emerge through saturation within the process. Members of one group could contribute to any number of groups while each specialist would attend in specific group.

Next, the groups would formulate their main concerns and aims regarding the proposed interests (testable “hypotheses”), producing a coherent problem statement, and a loose work plan. The thematic nature of the groups would encourage choosing the most appropriate citizen science technology for the cooperative “research” with specialists, monitoring how people use the

space, mapping important places, traffic jams, DIY urbanism, vandalism or street art while they move – or use existing online data. Any (online) freeware could be used (such as GoogleMaps, MyStreet), while basic tools could be linked to the service. Groups could also select “analogical” methods (live group meetings or city games, or city walks.). The data could be verified and complemented with standard analyses by the city professionals. The tools, methods and material produced could be shared and debated online during the process.

The procedure would follow the concept of synchronic design introduced by Marc Angélil (2004). Instead of aiming at (unrealistic) dualistic, causal progress from analyses to design, synchronic design solutions emerge in a hermeneutic-heuristic cycle shifting between intuitive production (of space) and conscious analyses (Angélil 2004). The concept resembles the actual design process. Analyses produce embryonic ideas, which prompt more questions, and are tested again, producing more advanced ideas, allowing potential and preferable future views to emerge.

In the next phase, these emerging ideas would again be formulated as short statements concerning the spatial city, and combined according to agreed similarities (for example “green spaces” and “urban gardening”; “pedestrian accessibility” and “sports facilities”). This process would be analogical with the online project Wikipedia: anyone could combine proposed future views to form an “article”, and the resulting new proposals could be split, re-combined, or the manoeuvre could be cancelled. Again, the process should produce structured ideas classified by subject (such as building conservation and history, light traffic solutions, green urban space, economic and business spaces), and, due to a divergence of views, also according to the level of manoeuvres (for example title “traffic modes and accessibility” may range from “mixed street space for pedestrians and cars”, “cars have priority, yet new bike lane needed” to “must stay as it is”). This procedure would enable the utilization of existing analyses and saturation of similarities in views, but also a structured way to point out differences between solutions. Ultimately these could be evaluated using new citizen science tools, 3D visualization (CommunityViz, Esri CityEngine or GeoWeb 3D); or augmented reality (VuFrame, GoogleSketchUp), in cooperation with planning professionals in groups. Customized simulations could also be used, such as collaborative model building techniques (Zelner et al. 2012) in which participants learn about operation and structure of the model to for example propose modifications to existing open-source urban models (Sleuth, UrbanSims). This phase would produce visualized wiki-style articles, perhaps interlinked to an earlier phase or other material such as dynamic maps and visualizations, or to each other.

At this point the system would be frozen, and a proxy voting procedure on proposed scenarios could be carried out. Anyone could vote for a solution, or delegate the vote to someone they

trust, perhaps applying next generation more advanced social networks (Boldi et al. 2009, 2011). Eventually a selection of various future visions would emerge, with weights indicating their preferability.

5. Discussion

Planning praxis responsive to the needs of complex cities is in progress. Here I introduced a liquid planning method based on self-organization, and claimed that it could provide such a new “complexity planning” method producing the necessary planning rules from bottom up. A general conceptual frame for many self-organizing processes – entropy, self-organization, stabilization – was derived from generative approaches in self-organizing human systems. Against this frame, a planning experiment in Pispala was evaluated to estimate whether it did indeed follow these phases and could be used as a basis for self-organizing “liquid planning”. Apparently, the Pispala process managed to capture self-organizing patterns emerging from agent interaction essential in defining the smart planning rules, following the proposed principles of self-organization through decreasing of entropy and emerging order enslaving the system. It hence appeared that the structure of the Pispala experiment could be considered a feasible model for an online liquid planning method applying recent technological tools. Presumably, in digital version several positive features of the Pispala case could be better supported and some challenging issues more easily resolved: The physical limitations made the live project fairly time consuming and expensive (spaces, material, personnel). The project had fixed deadlines, while liquid planning would enable a more synchronic design process. The analyses and design tools were limited - an online application could enable more diverse use of these, and division of the tasks among people (thereby reducing the dependence on material produced elsewhere). An online application could also encourage the non-active groups to join in: families with small children due to more flexible schedules, and young people with greater interest in online activities (Poplin 2012), enabling “lighter” participation by only following the process. A proxy voting system might involve more people, or even offer tools for estimating hypothetical votes calculated on the basis of the social networks of non-active members (Boldi et al. 2009).

Notwithstanding the benefits, limitations of the LP are obvious: The Pispala project was valued especially due to live personal encounters, which would naturally be lost online. Potential live meetings in liquid planning raise the issue of those participating only virtually being excluded. Furthermore, the initial process would probably be time and energy consuming for planners, but could eventually save time during the planning, produce better adjusted, lighter, and more

precise plans with only essential rules, and reduce the need for massive updates of the plans in the future. This requires a shift in how the planner's role is understood: for an appropriate global plan, her perhaps most demanding task would be to conceptualize and convert the results into planning rules, whether these are relationships between entities, emerging "basic blocks", or more static frames for action. In addition, if the project emerges spontaneously, a mandate (via qualification and registration) is needed from the city to ensure the resources and availability of the specialists/planners. It is also noteworthy that the population of the case area, Pispala, is relatively well educated and active. Thus the method must be tested in other neighborhoods or cities - it may not be universally applicable. Essentially, the role of the city planner remains largely unresolved at this stage of the project: Despite the fairly equal role of the city planner and other potential hired experts in the process the city planners' professional skills are necessary for moderating and guiding the process, producing material, and visualization. Spatial planning processes obviously entail responsibilities, skills and knowledge beyond the scope of the average "citizen planner" (ethical issues concerning the "common good", urban design skills, and an understanding of urban processes, information about current and future projects, personal/professional networks), and also non-sharable data, in Finland, for example, detailed census.

Along with increasing operational skills, people's emotional engagement usually increases (Stebbins 2007). Furthermore, planning is crucially often closely related to perhaps more serious or emotional concerns (such as property values and the quality of everyday space) than citizen science in general. Thus in planning the explication of the prior assumptions becomes even more important (Silvertown 2009). These threats must be carefully studied with a future prototype liquid planning case. In the Pispala experiment, the TUT team had a fairly prominent role in the representation and meta-level steering of the process, yet a surprising amount of expertise emerged within the groups (local architects, researchers). The actual online trial version should be tested to evaluate the level of expertise and guidance needed, and whether manipulation in the system becomes an issue. Another open question emerged during the Pispala case: what would be the role of the material produced in a decision-making process? This issue remains open, and should be addressed future in the in the context of city planning procedure:the implication is that the quality of the work might not be adequate for planning. Moreover, to identify further opportunities and problems of the procedure, future research aims first to thoroughly explore the potential open source tools applicable in a liquid process. Secondly, a proto-model needs to be built for a genuine liquid planning experiment. This work is in progress.

In a complex city we need to build better global plans which do not disrupt the desired self-organizing urban processes emerging from local level, and build flexible global guidelines

which may help the city system to adapt to sudden changes. The liquid process could provide a means to pinpoint fundamental features of urban life to create planning rules for such a global adaptive plan but, understandably, does not provide an universal solution. It might help to set the border conditions along with other complexity planning methods including, for example, studies on self-organizing mechanisms and triggers affecting preferable urban dynamics regarding economic, cultural and social processes. The potential impact of these rules on city progress could then be explored using simulations and modeling to rule out undesirable development. The effects of the implemented plans could also be evaluated using the appropriate evaluation methods mentioned above to guide urban processes towards desirable goals and directions, in an adaptive circular process.

A possibility exists that the LP process could become continuous - a certain “local planning democracy”, co-operating with the city and disseminating information on ongoing local planning, hopefully providing a smoother way to adapt to unavoidable shifts and ruptures in urban dynamics.

Literature:

Alexander C, Ishikawa S, Silverstein M, Jacobson M, Fiksdahl-King I and Angel S, 1977, *A pattern language* (Center for Environmental Structure Series, Berkeley, California)

Alfasi N and Portugali J, 2007, “Planning Rules for a Self-Planned City” *Planning Theory* **2** 164-182

Allen P, 2004 *Cities and Regions as Self-organizing Systems* (Taylor and Francis, Abingdon, Oxon)

- Angéilil M, 2004, "*Inchoate: An Experiment in Architectural Education*" (Actar, Barcelona)
- Ascher F, 1994, "Métapolis: Changes in Urban Scale and Shape in France" *Mitten am rand. Auf dem Weg von der Vorstadt über die Zwischenstadt zur regionalen Stadtlandschaft* (Verlag Müller, Wuppertal) 24-37
- Batty M, 2007, "Planning Support Systems: Progress, Predictions and Speculations on the Shape of Things to Come" *UCL working papers series*, Paper 122
- Batty M and Hudson-Smith A, 2012 "Discussions on Systemic Architecture: The Liquid City" in *Systemic Architecture: Operating Manual for the Self-Organising City* Eds M Poletto and C Pasquero (Routledge, London) pp 18-20
- Batty M and Longley P A, 1994 "*Fractal cities: a geometry of form and function*" (Academic Press)
- Bauman Z, 2000, *Liquid Modernity* (Cambridge, Polity Press)
- Boldi P, Bonchi F, Castillo C, and Vigna S, 2009 "Voting in social networks". Conference proceedings on Information and Knowledge Management (CIKM)
- Boldi P, Bonchi F, Castillo C, and Vigna S (2011) "Viscous Democracy for Social Networks" *Communications of the ACM* **54**, 129-137
- Bonney R, Shirk J L, Phillips T B, Wiggins A, Ballard H L, Miller-Rushing A J and Parrish J K "Next steps for citizen science." *Science* **343** 1436-1437
- Castella J C, Trung, T N and Boissau S, 2005 "Participatory simulation of land-use changes in the northern mountains of Vietnam: the combined use of an agent-based model, a role-playing game, and a geographic information system" *Ecology and Society* **1** 27
- Castells M, 1996, *The Rise of the Network Society* (Blackwell, Oxford)
- Casti J L, 1994, *Complexification: Explaining a Paradoxical World Through the Science of Surprise* (Harper Collins, New York)
- City of Tampere (2013): Tampereen Väesto 31.12.2013. PublicationB11/2013. http://www.tampere.fi/material/attachments/v/6H1cI9mEm/Tampereen_vaesto_31.12.2012.pdf. Accessed on 4.12.2013
- Clarke P A B and Foweraker J, 2001, *Encyclopedia of Democratic Thought* (Routledge, London)

Crooks A, Croitoru A, Stefanidis A and Radzikowski J, 2013 “#Earthquake: Twitter as a Distributed Sensor System” *Transactions in GIS* **17**(1) 124–147

Devish O and Veestraeten D, 2013 “From Sharing to Experimenting: How Mobile Technologies Are Helping Ordinary Citizens Regain Their Positions as Scientists” *Journal of Urban Technology* **20** 2, 63–76

Duarte J P, 2011, “Towards a methodology for flexible urban design: designing with urban patterns and shape grammars” *Environment and Planning B: Planning and Design* **38**, 879 – 902

Ford B, 2002, “Delegative democracy” (manuscript) <http://www.bford.info/deleg/deleg.pdf>. Accessed 5.11.2013

Graham S and Marvin S, 2001, *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition* (Routledge, London)

Haken H, 2010, *Information and Self-Organization: A Macroscopic Approach to Complex Systems* (Springer, Berlin Heidelberg)

Haken H and Portugali J, 1996 “Synergetics, Inter-representation networks and cognitive maps” in *The construction of cognitive maps* Ed J Portugali (Kluwer Academic Publishers, Dordrecht) pp 45–67

Haken H and Portugali J, 2003, “The face of the city is its information” *Journal of Environmental Psychology* **23** 385–408

Hand E, 2010, “Citizen science: People power” *Nature* **466** 685-687

Janis I L, 1972, *Victims of Groupthink: a Psychological Study of Foreign-Policy Decisions and Fiascoes* (Houghton Mifflin, Boston)

Holland J H, 1998, *Emergence – from chaos to order* (Perseus Books, Cambridge, Massachusetts)

Kato S and Ahern J, 2008, “‘ Learning by doing’: adaptive planning as a strategy to address uncertainty in planning” *Journal of Environmental Planning and Management* **51** 543-559

Kieser M and Marceau D J, 2011 “Simulating a Land Development Planning Process through Agent-Based Modeling” in *Multi-Agent Systems - Modeling, Control, Programming, Simulations and Applications* Ed F Alkhateeb, E Al Maghayreh and I Abu Doush pp 416-450

Lupia A and Matusaka J G, 2004 “Direct Democracy: New Approaches to Old Questions” *Annual Review of Political Science* **7** 463–82

Lynn G, 1998, “Blob”, in *Greg Lynn. Folds, bodies&blobs. Collected essays.* Eds M Lachowsky and J Benzakin (La letter vole, Belgigue) pp 157-168

Mitchell M, 2009, *Complexity: A guided tour* (Oxford University Press, New York)

PRH, no date, National Board of Patents and Registration of Finland online register http://yhdistysrekisteri.prh.fi/nimihaku.htx?kieli=1&lajittelu=1&hakuraja=1&nimi=Pispala*&ni_re=CHECKED&ni_vi=CHECKED&ni_ai=CHECKED&ni_pu=CHECKED&kielikoodi=FI&kotipaikka=Tampere&sb_haku=Hae&reknro=&dnro= Accessed 29.10.2014

Newman G, Wiggins A, Crall A, Graham E, Newman S and Crowston K, 2012 “The future of citizen science: emerging technologies and shifting paradigms” *Frontiers in Ecology and the Environment* **10** 298-304

Novak M, 2001, ”Liquid~. Trans~. Invisible~: The Ascent of Speciation of the Digital in Architectur. A Story” in *Digital Real. Blobmeister: First Built Projects* Eds P Schmal (Birkhäuser, Basel) pp 214-247

Partanen J and Pylvänen R, 2009, Pispalan kehityskuva – loppuraportti (TUT School of Architecture, Tampere) <http://www.tampere.fi/material/attachments/p/5q0pY4cWM/pispalankehityskuva.pdf> Accessed 29.10.2014

Poplin, A 2012 “Playful public participation in urban planning: A case study for online serious games” *Computers, Environment and Urban Systems* **36** 195–206

Portugali J, Meyer H, Stolk E and Tan E (eds), 2012, *Complexity Theories of Cities Have Come of Age: An Overview with Implications to Urban Planning and Design* (Springer, Heidelberg).

Pumain D, 2012, “Urban systems dynamics, urban growth and scaling laws: The question of ergodicity” in *Complexity Theories of Cities Have Come of Age* Ed Portugali J, H Meyer, E Stolk and E Tan (Springer, Heidelberg) 91-103

de Roo G, and Silva E A (eds), 2010), *A Planner's Encounter With Complexity (New Directions in Planning Theory)* (Ashgate, Farnham)

de Roo G, Hillier J and Van Wezemael J (eds), 2012, *Complexity and Planning: Systems, Assemblages and Simulations (New Directions in Planning Theory)* (Ashgate, Farnham)

Salingaros N, 2000 "Complexity and Urban Coherence" *Journal of Urban Design* **5**, 291-316

Silvertown J, 2009, *Trends in ecology and evolution* **24**(9) 467–471

Stebbins R A, 2007, *Serious leisure: A perspective for our time* (Transaction Publishers, New Jersey)

Susi T, Johannesson M and Backlund P, 2007 "Serious Games: An Overview" *University of Skövde, School of Humanities and Informatics, Technical Report* (Skövde Publisher)

Yamakawa H, Yoshida M and Tsuchiya M , 2007 "Toward delegated democracy: Vote by yourself, or trust your network" *International Journal of Human and Social Sciences* **1**(6) 290-294

Zellner M L, 2008 "Embracing Complexity and Uncertainty: The Potential of Agent-Based Modeling for Environmental Planning and Policy" *Planning Theory and Practice* **9**(4) 437- 457

Zellner M, Lyons L, Hoch C J, Weizeorick J, Kunda C and Milz D C, 2012 "Modeling, learning, and Planning together: An Application of Participatory Agent-based Modeling to Environmental Planning" *URISA Journal* **1** 77-92.

Internet sources:

LiquidFeedBack project: <http://liquidfeedback.org/> Accessed 29.10.2014

Adhocracy: <http://trac.adhocracy.de/> Accessed 29.10.2014

Open Planning -Group: <https://groups.google.com/forum/#!forum/ospt-ecosystem> Accessed 29.10.2014

APPENDIX

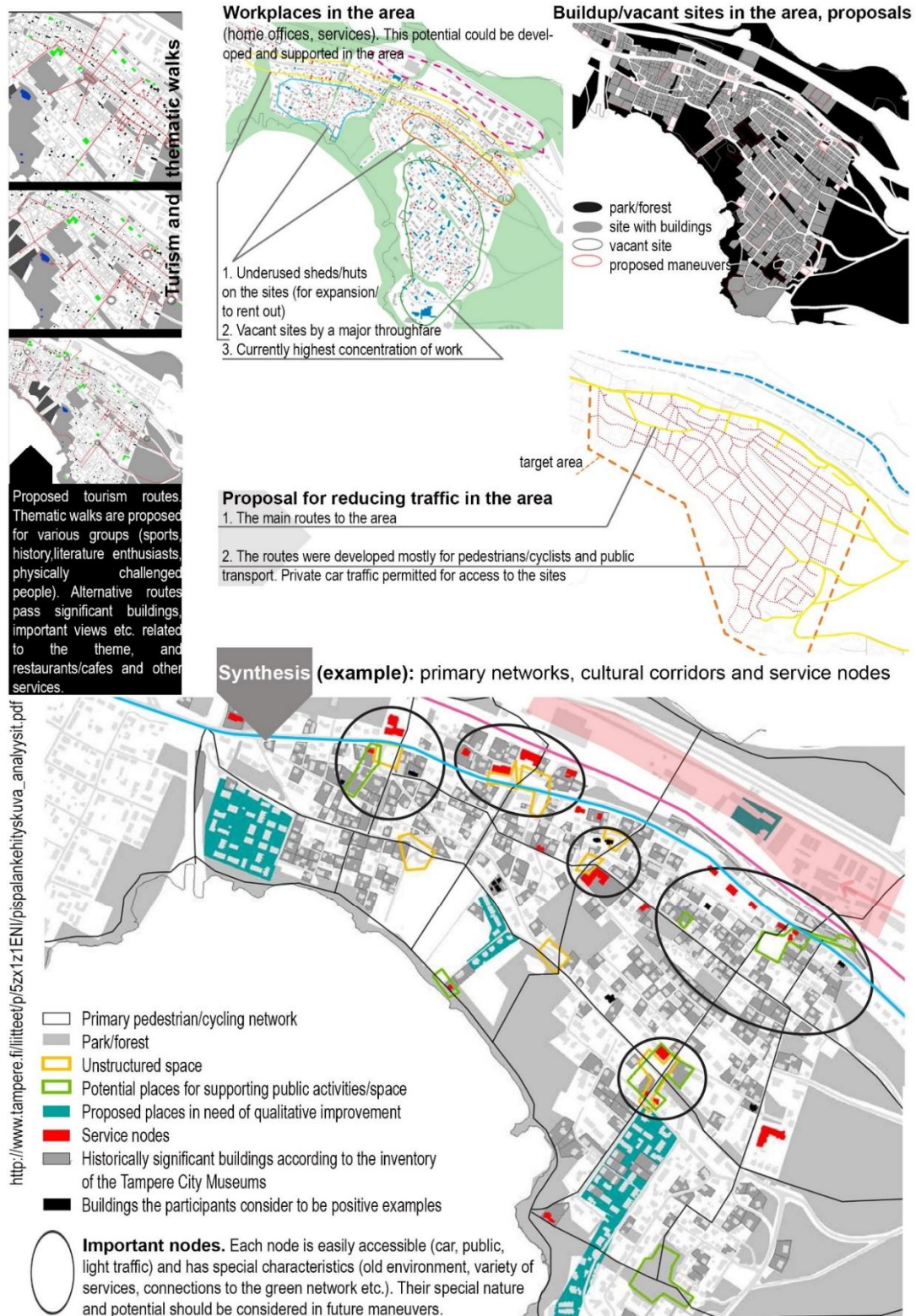


Figure 8. Examples of analyses produced by the TUT team.



Figure 9. Examples of visualizations produced by the TUT team.

Tampereen teknillinen yliopisto
PL 527
33101 Tampere

Tampere University of Technology
P.O.B. 527
FI-33101 Tampere, Finland

ISBN 978-952-15-4050-9

ISSN 1459-2045