Behavioural Urbanism using Multi-Agent Systems

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Contents

Introduction

Presentation of the subject

Forms come into being, survive through varying periods of time, until they decline and collapse. Then their materials are reorganised and new forms emerge. All the forms that exist around us have come into being from complex processes of energy and material flows in fluctuating patterns. As the climate and the earth have been constantly changing, all life has emerged and evolved in response to those changes.

Mankind is no exception. In the same way that all natural forms evolve, the forms produced by human culture come into being, evolve by augmenting their complexity, mature, persist through time, reach a critical threshold where complexity of flows and systems is maximised, become unstable and finally collapse and get reorganised into new forms. Cities, maybe most complex human creations, follow the exact same rules, as they are complex systems that allow for flows of energy, material and information. “Like any emergent system, the city is a pattern in time”[1], that has a lifespan and exists as part of the environment of numerous other equally complex systems. Human culture is “a means of transmitting information down through time”[2]. In other words, culture is a way to encode and transmit the necessary knowledge in order to sustain complexity for the survival and the development of the species. This explains the strong correlation between cultural and biological evolution.

Understanding cities necessitates unfolding the relations and exchanges between the various systems of nature and human civilisation. This study begins by tracing and studying those flows of energy, materials and information across temporal and dimensional scales. A city is a collection of various complex systems of flows that affect one another and are affected by their environment. Those flows, that are primarily made through the various infrastructures of the city, constitute its metabolism.

However, the correlations, dependences and exchanges that are developed do not form linear relationships, but rather complex interconnected dynamic links that cannot be studied nor understood with the linear reductionistic mathematical thought that has dominated the scientific studies of the last centuries. The collection, processing, sorting, and using of the enormous data contained in these processes, as well as the understanding of the non-linear emergent behaviours involved is a problem of “organised complexity”[3]. Addressing the issue of complexity is a question that has set off a huge amount of research from a variety of fields such as mathematics, sciences, art, or biology.

One of the algorithms which operates on the principle of complexity “for free” as Stuart Kauffman puts it, and consequently allows the understanding and dealing with complex systems is multi agent systems. The idea of these systems is that with a group of very simple discreet elements that interact with a set of equally simple and basic rules, larger entities, patterns, and regularities arise, which do not belong to the initial properties of the system. The use of multi-agent systems as a generative strategy in urbanism is mostly still in an experimental phase, but the results of this yet short-lived but rapidly incubating research are already very promising. The implementation of autonomous agents with decentralised local interactions that self-organise in generating emergent collective behaviour, assists in developing a flexible, customised and non-linear architecture that is “grown” bottom-up rather than imposed, but can include also elements of top down design, to regulate its results.

1.JOHNSON Steven, 2001, « Emergence, The connected lives of ants, brains, cities and software », New York, page 104

2. WEINSTOCK Michael, 2010, « The Architecture of Emergence », London, Wiley, page 9

3. JACOBS Jane, 1961, « The Death and Life of Great American Cities», New York, Vintage Books

This essay focuses on the use multi-agent systems in order to study those complex processes and flows that happen in today's urban environments, and see how this method can propose new sustainable solutions of urban design, a practice often called as "emergent urbanism".

Primary starting inquiry

-How can the question of complexity of the urban environment be approached?

-How to understand metabolic processes of cities? How do the flows of materials, people and information make emerge new spatial and temporal forms?

-How can we study emergent forms?

-How can multi-agent systems be implemented in urban study and design?

-What new does it bring to design?

-What is the process and how does it work?

-Advantages, disadvantages challenges, difficulties

-Questions that arise from the use of randomness in design, and the arbitrariness of the process

-How to answer real abstract architectural questions with such an approach? How to decide on the parameters, the rules and the details of the system?

-How does the role of the architect change?

-Multi-agent systems do not necessarily exhibit emergent behaviour nor auto-organisation. How can these properties be recognised and stimulated? Which conditions are necessary for their apparition?

-How can we measure the efficiency of a MAS?

-Emergence and auto-organisation can fluctuate from very positive to utterly destructive phenomena. For example an ant colony, everyday city traffic and a tornado are all emergent phenomena. However impressive they might be, undoubtedly their usefulness for people is not the same. How can the positive or negative effects of emergence be recognised in less obvious cases, such as emergent architectural design?

-How can we arrive to an urban design that has the positive effects of both the bottom-up and the top-down methodologies.

Investigation of the field/scope/sphere of knowledge

This part is made up of two chapters. The first one is about the concept of complexity and multi-agent systems as a model for studying. It investigates notions such as complexity, emergence, self-organisation, multi-agent systems and swarm intelligence. The second part speaks of the city studied as a complex system, and it makes a brief overview of the bipolar top-down/bottom-up design.

Forming of the thesis statement (Formulation de la problématique)

Multi-agent systems allow addressing the complexity of the city using a bottom-up approach with implemented external (top-down) rules that allow for a more optimal organisation of the whole. The purpose of this essay is to examine how this abstract mathematical model can contribute to the study and understanding of urban dynamics, processes and flows. It investigates how it can help proposing solutions to problems and making predictions for the future taking into consideration temporal, spatial and functional dimensions of the modern urban environments. It aims to see the city as a dynamic growing system in constant evolution, profoundly interconnected with its environment, a system made of systems, that has a powerful metabolism, placing the emphasis on the interactions and connectivity of the flows, and question how generative design through multi-agent systems can change the way we study this environment.

It also aims to explore the theory and philosophy behind the multi-agent systems practice, question its characteristics (workflow, way of deciding variables, validation, and so on), summarise its advantages and reveal its disadvantages.

Methods and body

Multi-agent systems allow addressing the complexity of the city using a bottom-up approach with implemented external (top-down) rules that allow for a more optimal organisation of the whole. The purpose of this essay is to examine how this abstract mathematical model can contribute to the study and understanding of urban dynamics, processes and flows. It investigates how it can help proposing solutions to problems and making predictions for the future taking into consideration temporal, spatial and functional dimensions of the modern urban environments. It aims to see the city as a dynamic growing system in constant evolution, profoundly interconnected with its environment, a system made of systems, that has a powerful metabolism, placing the emphasis on the interactions and connectivity of the flows, and question how generative design through multi-agent systems can change the way we study this environment.

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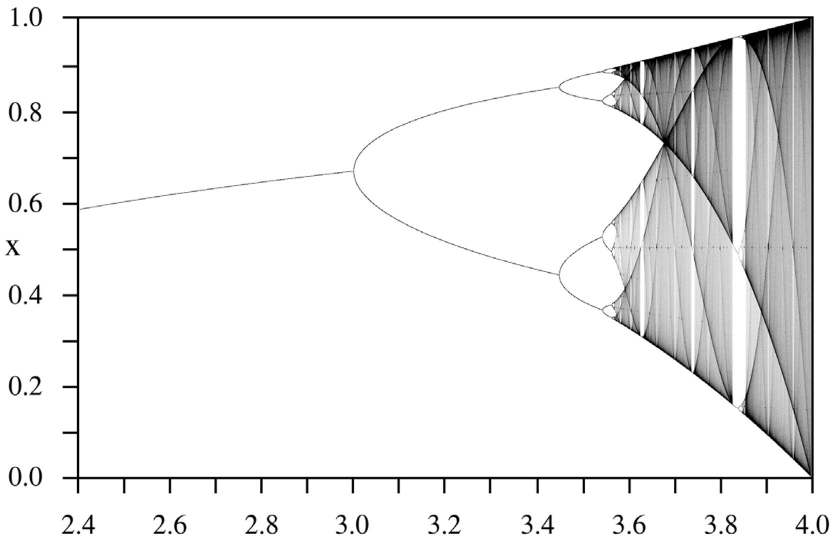
1. Complexity and Emergence

1.1 Reductionism and Holism

Science and physics have developed from the Newtonian paradigm of mechanics which assumes that every phenomenon observed can be reduced to a collection of particles whose behaviour is governed by the deterministic laws of nature. In other words, every aspect of the world can be explained by isolating and studying their individual, constituent parts and their interactions. This approach is called reductionism, and it was widely accepted that it is holding the key to understanding the universe's laws until the late 19th century.

At the dawn of the 20th century, Henri Poincaré, a French mathematician started to speculate why a perfect prediction of the universe advocated by the reductionistic worldview might not be possible. He was a pioneer of modern dynamical systems theory and the first one to introduce the notion of chaos: seemingly random behaviour with sensitive dependence on initial conditions. He proved that chaos can arise even from a deterministic equation after a few iterations, regardless of how accurate the initial values of the system are, because there can never be a "perfectly accurate" measurement as there always exists a more precise number with more decimal digits. What this shows is that prediction is impossible even in principle, since we can never know the precise value of an initial condition. This is a conclusion, that along with quantum mechanics, helped wipe out the 19th century view of the clockwork Newtonian universe that is following a predictable path. His theories were the basis for an entirely new worldview to emerge, a holistic worldview embracing the complexity and un predictability observed in the universe.

$$x_{n+1} = rx_n(1 - x_n)$$



Logistic orbit map. A simple a simple deterministic equation that when iterated can display chaotic behaviour after a certain threshold

By the middle of the 20th century scientists had realised that although the reductionist world-view is enormously useful for explaining many intricate aspects of the world, it appears to be incomplete, and it is but a part of a larger "mechanism" that results in complexity[1]. Observing the lower levels of nature does not always give us insight into why they give rise to the behaviours of the highest organisational levels. To provide the explanations to the unanswered questions of the reductionist view, a holistic way of looking at systems is needed, which will allow to examine the issues of complexity and emergence.

However, in this theory there is order, otherwise called "universality" in chaos: even if chaotic systems are not predictable in detail, there's a broad set of chaotic systems that have predictable universal properties.[2] This quality is of paramount importance when studying complex systems.

1. Cohen, J. and Stewart, I., The collapse of chaos : discovering simplicity in a complex world. New York: Viking, 1994.

2. MITCHELL Melanie, Lecture: Universality in Chaos, Santa Fe Institute, seen on May 2016 at the webpage https://www.complexityexplorer.org/courses/27-introduction-to-complexity-summer-2015/segments/2975

1.2 What is complexity?

Complexity has turned out to be a notion very difficult to define. The large number of definitions that have been offered all fall short in one respect or another, and they are either only applicable to a very restricted domain, such as computer algorithms or genomes, or so vague as to be almost meaningless.

Seth Lloyd in his book "Measures of complexity, a non exhaustive list" gives around 42 different definitions and ways of measuring complexity.

Bruce Edmonds (1997)[1] explores the different definitions of complexity, and the problems of each one of them, concluding that complexity is a subjective quantity as it depends from the point of view of the analysis, the context of the system, the language that is used to model the system, the sale in which the system is being studied and many other parameters. He states:

"The nearest I have come to the definition of complexity is

Complexity is that property of a model which makes it difficult to formulate its overall behaviour in a given language/framework, even when given reasonably complete information about its atomic components and their inter-relations.

The word complexity derives from the latin word "complexus" compound of com- ("together") and plecto ("I weave, braid"), which signifies an entwined and twisted together aggregate of parts.[2]Oxford Dictionary defines something as "complex" if it is "made of (usually several) closely connected parts"[3]

In the definition of the word we can see the basic duality of the term, as it refers to parts which are at the same time distinct and connected. Intuitively then, a system would be more complex if more parts could be more distinguished, and if more connections between them existed. The aspects of distinction and connection determine two dimensions characterising complexity. Connection corresponds to order, while distinction corresponds to disorder or chaos. For complexity to appear, both aspects have to coexist. Perfect order does not generate complexity as it can be described by traditional deterministic laws with very little initial information and it exhibits symmetry. Nor does perfect disorder, as it also generates a statistical homogeneity, that is a result of its complete randomness.[4]

According to Bruce Edmonds, the definition of complexity as midpoint between order and disorder depends also on the scale at which we study a system: what seems complex in one scale, may seem ordered or disordered at a different scale. To illustrate this, Heylighen F. gives the example of a pattern of cracks in dried mud. "When we zoom out, and look at the mud plain as a whole, though, we may see just a flat, homogeneous surface. When we zoom in and look at the different clay particles forming the mud, we see a completely disordered array. The paradox can be elucidated by noting that scale is just another dimension characterising space or time (Havel, 1995)" [5]

In a system composed of different elements, in an effort to define its complexity we can say that it increases as both the aspects of connection between the elements and distinction of the type of

1. http://bruce.edmonds.name, seen on April 2016
2. http://www.wordsense.eu/complexus/, seen on April 2016
3. http://www.oxforddictionaries.com/definition/english/complex, seen on April 2016
4. Heylighen F., 1996, http://pespmc1.vub.ac.be/complexi.html, seen on April 2016
5. Heylighen F., 1996, http://pespmc1.vub.ac.be/complexi.html, seen on April 2016

those elements (differentiation) increase in several dimensions. However, distinction and connection are in general not given, objective properties. They depend upon what is distinguished by the observer, and in realistically complex systems determining what to distinguish is far from obvious.

1.3 Emergence

Emergence is a phenomenon that is all around us, it can be found in most natural phenomena and social processes, and it is an integral part of the formation of life as we know it. Colonies of pheromone dropping ants, the swarming movement of a flock of birds, the shape of weather phenomena and a traffic jam from the interaction of cars, are some common examples of emergence.

Swarming is an emergent behaviour that arises from simple interactions among the birds of a flock (figure from http://becausebirds.com)

The results of emergence can fluctuate from very positive to utterly destructive phenomena. An ant colony, everyday city traffic and a tornado are all emergent phenomena. However impressive they might be, undoubtedly their usefulness for people is not the same.

Definition

We use this term in philosophy, mathematics, biology, science and art to describe the phenomenon where global behaviour (for example larger entities, patterns, or regularities) arises through interactions among smaller or simpler entities that themselves do not exhibit such properties.[1] [2]

From those interactions arises a from of global intelligence that is called swarm intelligence.

Historic Overview

Emergence is not a new topic. It has been around since at least the time of Aristotle who refers to emergent phenomena in his book “Metaphysics” in the 4th century BC.[3]

Conceptual constructs that operate on the principle of emergence are numerous in the western thought as well. For example in 1843 John Stuart Mill, an English philosopher, one of the most influential thinkers in the history of liberalism, writes in his book “On the Composition of Causes” about “The chemical combination of two substances produces, as is well known, a third substance with properties different from those of either of the two substances separately, or of both

1. DE WOLF Tom, Holdout Tom, 2005 , « Emergence Versus Self-Organisation: Different Concepts but Promising When Combined », Department of Computer Science, Kuleuven

2. https://en.wikipedia.org/wiki/Emergence, seen on February 2016

3. Aristotle, Metaphysics, Book H 1045a 8–10

of them taken together"[4]

In 1875 John Lewes, another english philosopher who coined the term "emergent", introduces emergence in the context of dynamical systems:

"(...) although each effect is the resultant of its components, we cannot always trace the steps of the process, so as to see in the product the mode of operation of each factor. In the latter case, I propose to call the effect an emergent. It arises out of the combined agencies, but in a form which does not display the agents in action (…)"[5]

The concept of emergence is tightly woven with the complexity theory, and it has very diverse scientific and mathematical roots: physics, cybernetics, evolutionary biology, artificial intelligence etc. Its study is related with complex adaptive systems, nonlinear dynamical systems and Chaos theory, far-from-equilibrium thermodynamics and many other scientific fields.

Emergence can even in some cases be "chaotic", in which case it can appear unexpectedly, and it has certain characteristics tightly woven with the chaos theory, such as sensitive dependence on initial conditions, a white noise power spectrum, a trajectory in the phase space that does not intersect itself, occupies non-zero but finite volume, and it has a fractal structure.[6]

Characteristics [7]

- *Micro-Macro effect*. The global behaviour of a system is a result of the interactions between the individual entities of the system

- *Radical Novelty*. The global behaviour is novel, and as such it is not explicitly represented in the individual behaviours of the parts of the system. In other words, "the whole is greater than the mere sum of its parts".[8] Therefore emergence cannot be studied by taking a system apart and looking at its parts (=reductionism), it has to be studied by looking at the system as a whole.

- *Coherence*. There is a logical and consistent correlation of parts, which results in a whole that tends to maintain a sense of identity over time.

- *Interacting parts*. Emergence arises from the interactions between the parts, and from the feedback that derives from those interactions.

- *Dynamical character*. Time is a vital parameter, as emergence becomes possible in some point in time, and is not a static phenomenon, but one that changes dynamically.

- *Decentralised control*.There is no central control, only local mechanisms that can be controlled. The whole is not directly controllable.

- *Robustness and flexibility*. Emergent behaviour is relatively insensitive to perturbations or errors, as it can absorb changes and remain unaffected by the failure of individual parts. Increased perturbation will have effects on the system, but even then its decline will be gradual.

4. Mill, John Stuart (1843), "On the Composition of Causes", A System of Logic, Ratiocinative and Inductive (1872 ed.), London: John W. Parker and Son, p. 371

5. Lewes, G. H. (1875), Problems of Life and Mind (First Series) 2, London: Trübner, ISBN 1-4255-5578-0

6. Parunak, H. V. D. and Vanderbok, R. S., "Managing Emergent Behavior in Distributed Control Systems," presented at ISA- Tech '97, Instrument Society of America, Anaheim, CA, 1997.

7. DE WOLF Tom, Holdout Tom, 2005 , « Emergence Versus Self-Organisation: Different Concepts but Promising When Combined », Department of Computer Science, Kuleuven

8. Odell, J.: Agents and complex systems. JOT 1 (2002) 35–45

- *Two-way link*. We observe a “bidirectional link between the macro-level and the micro-level. From the micro-level to the macro- level, the parts give rise to an emergent structure. In the other direction, the emergent structure influences its parts.” [9]

Another essential characteristic of emergence is that its hierarchical relationship between the macro-level and the micro-level has in fact a multi-level nature. There is not a single “microscopic level” that produces the “macroscopic” order but a series of scales of emergent wholes. One emergent whole at one level is merely a component of an emergent system at the next higher level, and so on. “There is not just one global hierarchy of non-linear organisation, but a multitude of inextricably entwined sub-organisations and subsystems.”[10] Those systems are composed of multiple interconnected elements, whose causation is iterative so what is an effect at one scale may also be a cause at a higher scale.[11] [12]

However not all systems with multiple interactive elements can exhibit emergent behaviour. If the conditions are not favourable, a complex system does not produce hierarchies of interconnected parts. What is more, the properties of the emergent can vary according to multiple parameters of the system. Steven Johnson in his book “Emergence, The connected lives of ants, brains, cities and software”[13] based of the observation of emergent systems in nature such as the colonies of ants, talks of five fundamental principles, five important conditions for the generation of emergence, every designer of “a system where macro intelligence and adaptability derive from local knowledge” should follow.

- *More is different*. The statistical nature of the interaction of parts demands that there is a critical number of parts to interact. “Ten ants roaming across the desert floor will not be able to accurately judge the overall need for foragers or nest-builders, but two thousand will do the job admirably”[14]

- *Ignorance is useful*. The simplicity of each part is important for the emergent whole. It’s better to build a densely interconnected system with simple elements, rather than using few “smarter” parts that have an overall understanding of the system. In fact the latter can cause problems and not allow emergent behaviour to be exhibited.

- *Encourage random encounters*. Decentralised systems rely on random encounters among their parts. Thanks to their large number, those random encounters will statistically lead to the emergence of the global behaviour. Without this randomness, the system is not adaptable and it cannot become more intelligent and robust.

- *Look for patterns in the signs*. The individual parts of the system interact using a finite (and usually quite ristricted) number of patterns and signs. With their propagation, information circulates throughout the system.

- *Pay attention to your neighbours*. “Local information can lead to global wisdom” through a process of interaction and the feedback that must come from it. Feedback can be positive or negative. Positive feedback re-enforces or activates a behaviour, so that it may solicit other individuals to follow it. Negative feedback on the other hand controls or inhibits a behaviour

9. DE WOLF Tom, Holdout Tom, 2005 , « Emergence Versus Self-Organisation: Different Concepts but Promising When Combined », Department of Computer Science, Kuleuven, page 5

10. HEYLIGHEN Francis, 1989, «Self-organisation, Emergence and the architecture of complexity », in: Proceedings of the 1st European Conference on System Science, (AFCET, Paris), p. 23-32.

11. CORNING Peter, 2002, « The Re-Emergence of “Emergence”: A vulnerable concept in search of a theory », pages 8-30.

12. http://ngm.nationalgeographic.com/2007/07/swarms/miller-text, seen on April 2016

13. JOHNSON Steven, 2001, « Emergence, The connected lives of ants, brains, cities and software » ,pages 77-79

14. JOHNSON Steven, 2001, « Emergence, The connected lives of ants, brains, cities and software », page 78

in order to avoid that all individuals converge to the same behaviour and a state of equilibrium is reached.

1.4 Self organisation

Historic Overview

In the beginning how the Heav'ns and Earth
Rose out of Chaos

a dark
Illimitable Ocean without bound,
Without dimension, where length breadth, and height,
And time and place are lost; where eldest Night
And Chaos, Ancestors of Nature, hold
Eternal anarchie,

darkness fled
Light shone, and order from disorder sprung

Anon out of the earth a fabric huge
Rose like an exhalation

Paradise Lost (1667), John Milton (1608-1674)

In his poem, John Milton provides a poetic description of the Creation. In these extracts it is clear that at the beginning there was a homogenous state devoid of any order or positional information, and he states that self-organisation raised spontaneously from this state. He implies that the development of order from complete disorder is an intrinsic and indispensable process of the creation.[1]

The term self-organisation was coined by W. Ross Ashby an English psychiatrist and cybernetician. In "Principles of self-organizing dynamic systems" published in the Journal of General Psychology in 1947 he states that "any deterministic dynamic system will automatically evolve towards a state of equilibrium that can be described in terms of an attractor in a basin of surrounding states. Once there, the further evolution of the system is constrained to remain in the attractor" [2]

After its introduction, self-organisation was studied primarily in physics, computer science and systems theory. It has several application in those fields, as well as in economics and ecology. In the 1980's the study of self-organisation was categorised as part of the "sciences of complexity".

The study of self-organisation seeks the general rules about the growth and evolution of the structure of a system, what forms it can take, and how its behaviour can be predicted. In order to model self-organisation, one of the most common ways is the use of multi-agent systems.

1. BOURGINE Paul, LESNE Annick, 2010 « Morphogenesis: Origins of Patterns and Shapes », Springer (translation form French of "Morphogenése", 2006, Editions Belin, France)

2. Ashby, W. R. (1947). "Principles of the Self-Organizing Dynamic System". The Journal of General Psychology 37,

Definition

Self-organization is a dynamical and adaptive process in decentralised systems where some form of overall order or coordination arises, that leads to the formation of a spatial, temporal or functional structure that can be maintained without external control.[3] [4]

How does this structure come into existence?

An explanation is given by Simon (1962).[5] His theory is based on a variation-and-selection process that unfolds as follows. Elements are combined and connected creating a variety of assemblies. From the large number of assemblies produced, only the most stable will survive, and they will function as "building blocks" to be re-combined into higher level assemblies.

The evolving system can be seen as a problem-solver that is generating possible solutions (variations) to the question posed by its environment: "how to be optimally adaptive?". The less optimal the adaptation, the more unstable the system becomes, and the more variations it has to undergo before reaching a new equilibrium. Like all good problem-solvers know, blindly trying out possibilities hoping to accidentally stumble upon the optimal solution is not the best tactic. The chances are enhanced by establishing intermediate steps, i.e. "relatively easy-to-find problem states or configurations, which are no final solutions but which are somehow closer to the goal than the configuration you started with."[6] However here there is never a final solution. Every "goal" of the process can be seen as a subgoal of the next.

A remark that should be made here concerns the binary between deterministic and non-deterministic systems. There are two ways the this variation process can run: it can ether systematically search through all the states according to a given rule (in a deterministic way), or just randomly try out states (in a non-deterministic way). In the first case you can predict which states will be the next one studies, but you still cannot tell if those states will be the solution, because the "solution" is an emergent property. Therefore any process of variation and search although it is not necessarily random, it is always "blind" and thus non-deterministic, regardless of wether the process that creates it has or has not deterministic elements.

Characteristics[7]

From studies of self-organising biological systems, it becomes evident that a critical factor for self organisation is the spontaneous appearance of multiple distinct organisational levels, and the interactions and feedback loops among them. Their evolution proceeds from small simple components that are assembled together, to larger structures that exhibit emergent behaviour, which then, in turn, self-assemble into more complex structures. Self-organisation is characterised by the apparition of 3d structures, redundancy and differentiation, hierarchy and modularity.[8] More specifically:

- *Increase in order*. The increase of the organisation is in essence an increase in its order which allows it to form a type of structure. What is of interest here is the apparition of multiple scales of organisation that remain correlated. The behaviour of the system is restricted and

3. https://en.wikipedia.org/wiki/Self-organization

4. DE WOLF Tom, Holdout Tom, 2005 , « Emergence Versus Self-Organisation: Different Concepts but Promising When Combined », Department of Computer Science, Kuleuven

5. HEYLIGHEN Francis, 1989, «Self-organisation, Emergence and the architecture of complexity », in: Proceedings of the 1st European Conference on System Science, (AFCET, Paris), p. 23-32.

6. HEYLIGHEN Francis, 1989, «Self-organisation, Emergence and the architecture of complexity », in: Proceedings of the 1st European Conference on System Science, (AFCET, Paris), p. 23-32.

7. DE WOLF Tom, Holdout Tom, 2005 , « Emergence Versus Self-Organisation: Different Concepts but Promising When Combined », Department of Computer Science, Kuleuven

8. WEINSTOCK Michael, "Self organisation and material constructions"

becomes confined into a smaller region of its state-space that is called an attractor.

- *Autonomy*. Only the increase in order that occurs to a system in an absence of external control spontaneously is a self-organising behaviour. However, this does not mean that there cannot be any external input to the system, but the way this input will be processed and what will be the reaction to it should be decided within the system. Therefore in order to be able to confirm or negate the self-organising properties of a system, the definition of its boundary is of great importance.

- *Adaptability and Robustness*. This property refers to the ability of coping with changes and perturbations by modifying their structure. “This adaptability implies the need for the system to be able to exhibit a large variety of behaviours. Self-organisation requires the evolution towards a certain attractor in state space (i.e. towards a certain organised behaviour). There are different kinds of attractors, from a point attractor that allows only one behaviour, a limit cycle that allows periodic behaviour, towards a chaotic attractor that allows a very large variety of behaviours. To be adaptable, the system needs to make a selection between behaviours and at the same time consider a variety of behaviours”[9]

- *Dynamical, far from equilibrium*. Self organisation is a dynamical process that evolves over time. In order for the system to maintain its structure throughout the changes in its environment it needs to be in a far-from equilibrium state, which makes it more fragile and sensitive to changes, but also more flexible so as to be able to react. A system devoid of any order cannot exhibit any useful behaviour, nor can a system with too much order as it is inflexible and cannot adapt. It is the systems that are poised between chaos and order that exhibit the most useful and flexible behaviour. The most efficient organisations are those who are “actually teetering on the brink of perpetual collapse”[10]

Most natural systems self-organise to reach a coherent whole
(figure from https://commons.wikimedia.org)

9. DE WOLF Tom, Holdout Tom, 2005 , « Emergence Versus Self-Organisation: Different Concepts but Promising When Combined », Department of Computer Science, Kuleuven, page 8

10. GABBAI Jonathan, YIN Hujun, Wright W.A., ALLINSON Nigel, 2005, « Self-Organisation, Emergence and Multi-Agent Systems », University of Manchester, England, page 5

1.5 Emergence and Self-Organisation

Therefore emergence's most important aspect is the appearance of novel global behaviour, while self-organisation is about the development of an adaptable structure that comes as a result of the increase in order. They are two distinct terms that point out different characteristics of a system's behaviour. They can both exist in isolation, or they can co-exist within a system. They do have similarities such as the fact that they are both dynamic and robust processes. Emergence is in general proportional to the complexity of the system, while self-organisation is more scalable.[1] They can both occur only after an initial threshold on the number of the parts of the system.

Whether we consider self-organisation as a cause of emergence, or we consider it as its effect (emergence results in self-organisation), what is important is that when combined, the two phenomena complement each other. Emergence is a phenomenon found in complex systems whose results can fluctuate from very positive to utterly destructive. "The full, ultimate, positive exploitation of emergence is when it is combined with self-organisation"[2]

A colony of ants self-organises through interactions among the individuals with very simple rules
(figure from http://www.dailymail.co.uk/)

1. GABBAI Jonathan, YIN Hujun, Wright W.A., ALLINSON Nigel, 2005, « Self-Organisation, Emergence and Multi-Agent Systems », University of Manchester, England, page 3

2. GABBAI Jonathan, YIN Hujun, Wright W.A., ALLINSON Nigel, 2005, « Self-Organisation, Emergence and Multi-Agent Systems », University of Manchester, England, page 3

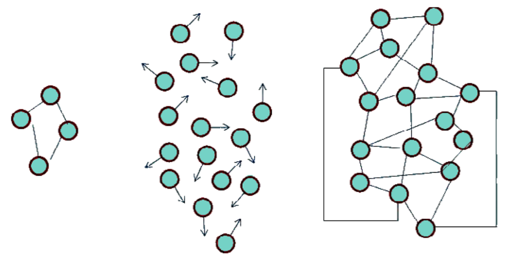
2. The kind of problem a city is

2.1 Organised Complexity

Warren Weaver, (1894-1978) an American scientist and mathematician, in his book Science and Complexity (1958) divides the scientific problems into three categories. The first category are the problems of simplicity, that study linear systems that involve just a few variables and can be solved with traditional mathematics. A classical example of such problems are Newtonian physics. The solutions to these problems, which had been found by the end of the 19th century, allowed for a vast progress of human culture and technology. They brought about the telephone, the car, the airplane, the camera, the hydroelectric power etc. They became catalysts for the industrial revolution and the consequent cultural change.

Then Weaver goes on to specify the second category, the problems of disorganised complexity. These are problems involving billions of variables, which are tackled by taking averages and statistical values assuming that the overall behaviour is the sum of the behaviour of each individual of the system. These problems were solved in the 20th century.

For example, one can easily analyse and predict the motion of one ball moving around a billiard table using the mathematics of simplicity. This problems increases in difficulty though when considering 2 or 3 balls, and becomes unmanageable when the number of balls rises significantly to per se 50 balls, not so much because it poses a theoretical difficulty but rather because it requires enormous amounts of labour. When, however, one considers billions of balls moving around, the problem becomes surprisingly easier as statistical methods can apply to it. Of course the behaviour of every individual ball still cannot be predicted, but there can be made very accurate predictions about the behaviour of the system as a whole, such as how many collisions happen, or how many balls hit the borders of the table per time unit. The solutions to these problems where also very important, as they can be applied to various fields such as economics, thermodynamics etc.



However Weaver points out that not every problem can be solved with those two methods of either zooming in to a very small number of individuals, or zooming out to studying very large numbers of them. There is a particular category of problems in between those two scales which are problems that involve a large number of elements that create connections and interact with each other in a non-linear way and therefore cannot be meaningfully averaged, nor be individually studied. This last category concerns the problems of ***organised complexity***. These are "problems which involve dealing simultaneously with a sizeable number of factors which are interrelated into an organic whole"[1]. It is the complex systems that fall in the last category of organised complexity, that exhibit, wether as its cause or its effect, emergence. Those problems can be found in the life sciences such as medicine and biology, and also in behavioural and social sciences.

One of the first to understand the importance of this for cities was Jane Jacobs, in her influential book "The Death and Life of Great American Cities" (1961)[2]. In the last chapter of her book "The kind of problem a city is", named after which is this chapter of my essay, she defines the city as

1. JACOBS Jane, 1961, « The Death and Life of Great American Cities», New York, Vintage Books, page 433
2. JACOBS Jane, 1961, « The Death and Life of Great American Cities», New York, Vintage Books

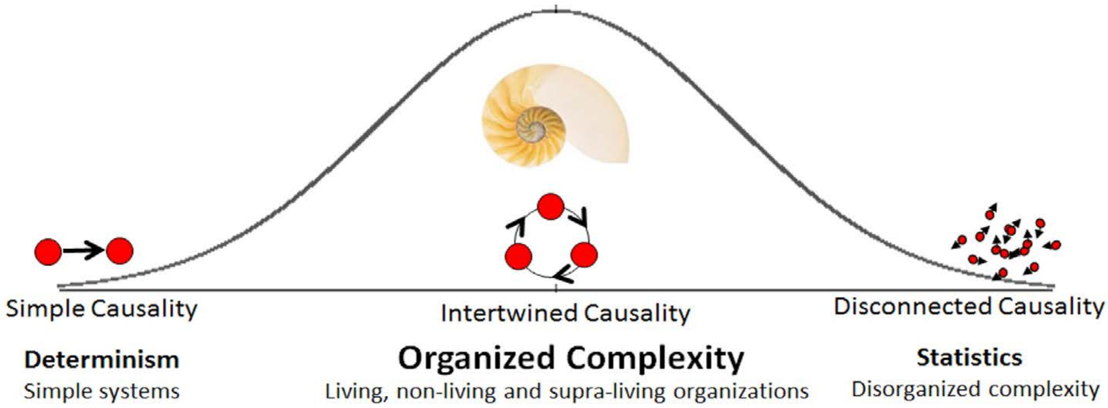


figure from https://journal.emergentpublications.com

a problem in organised complexity. She goes on to attack the modern thought of urban planing which "failed miserably" as it tried to reduce cities to a problem of simplicity, where only a few variables apply such as population and number of jobs, or to a problem of disorganised complexity where there exists one average person, one "modulor", whose behaviour can account for the entire population. The modernistic way of approaching urban design is what Michael Weinstock calls "a generalised anatomical model" which can be summarised as a functional zoning paradigm, in which cities are treated as "discrete artefacts,(…) static arrays of buildings and infrastructures that exist in, but are distinct from, stable environments"[3]. Believing that the complex character of cities was an imperfection rather that a virtue, an evil that had to be done away with, modernists tried to rationalise it through their planning, so as the city meets their expectations of simplicity and logical order. This, Jacob tells us, has lead into the development of inhuman lifeless and badly organised urban aggregations deficient of the ordered complexity that is necessary for a vivid city. What is more, in recent years the study of urban systems has been focused on socio-economic grounds or on demographic facts alone, reducing the urban environment on a few easy to identify and measure parameters, that fail to convey the essence of the city.

The life sciences on the other hand, such as biology, unburdened from this misconception of pursuing simplicity long ago, made a rapid advance, providing urban design not only with some of the concepts needs, but also with strategies with which to start handling the kind of problem cities really are. It is no wonder how often we associate our design with ***metaphors from the realm of nature***, such as the ***ecology*** of the urban environment, green areas being the ***lungs*** of cities, certain uses ***contaminating*** the urban ***tissue*** etc. Nevertheless, the fact that biology and urban design pose the same kind of problems, it doesn't mean that they are the same problems. And what is most certainly not the case is that urban problems can be dealt with abstract theoretical associations to natural phenomena, that remain only in the surface, the "forms" of design.

In his book 'Emergence, The connected lives of ants, brains, cities and software'[4] Steven Johnson presents the city as an emergent system that operates as a dynamic, adaptive system, based on local interactions, information feedback loops, pattern recognition and indirect control. He notes that "like any emergent system, the city is a pattern in time"[5] that displays bottom-up collective intelligence.

Weinstock asserts that cities, through their complexity, "display phenomena characteristic of complex systems: power scaling, self-similarity across a range of scales and 'far-from-equilib-

3. WEINSTOCK Michael, 2011, « Architecture of flows, Integrated Infrastructures and the "meta-system" of urban metabolism », Acadia 2011 proceedings

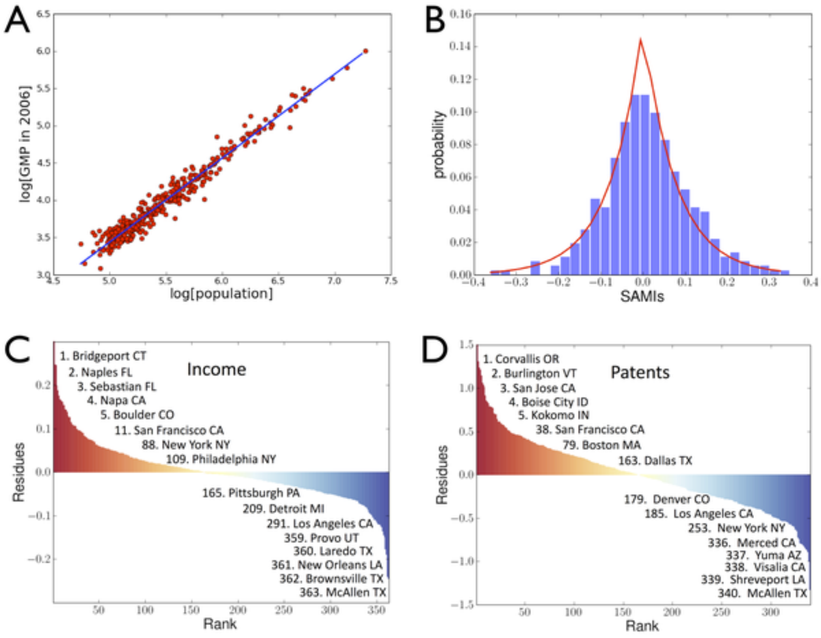
4. JOHNSON Steven, 2001, « Emergence, The connected lives of ants, brains, cities and software », New York

5. JOHNSON Steven, 2001, « Emergence, The connected lives of ants, brains, cities and software », New York, page 104

rium' dynamics"[6]. In his work, he tries to redefine the study of urban environments on a holistic level on a much wider canvas, focusing on evolutionary processes and interconnections at the global scale.

"Considering the city as a dynamic complex system places emphasis on the interactions and connectivity of the flows throughout its infrastructures, and of the feedbacks and critical thresholds that drive the emergence of new spaces and urban morphologies hat are animated by new modalities of culture"[7].

Almost half a century after Jacob's book, informed by the advances of mathematics, sciences, and urban design practices, Bettencourt Luis, a researcher of complex systems, revisits Jacob's "challenge" in his article "The kind of problem a city is: New perspectives on the nature of cities from complex systems theory"[8]. He asserts that cities "are not organisms any more than they are machines" (Kevin Lynch, 1984), but they are a distinct entity, whose most important characteristic is their interconnectivity. Cities are physical, infrastructural, social and economic systems which behave in very particular ways, that he tries to unfold by studying systematically their ***measurable properties***, and deducing **mathematics of their scalability**.



Cities in Numbers
(figure from: "Urban Scaling and Its Deviations" by Luis Buttencourt)

His results are very interesting. Just like every complex system, cities do have certain common behaviours that can be predicted. In summary, he shows that as the population of a city increases, the socioeconomic outputs, such as wealth production, innovation rates, but also crime rate or land price increase in a disproportionally faster rate, while at the same time less infrastructure and less use of energy to keep the city connected is needed per capita. In other words, cities are more intensive land use with higher economic productivity, whose rhythms increase as population increases but in a faster rate, while simultaneously providing more with less energetic cost. The overall performance of the city is given by the interplay between *interactivity* and *relative cost of mobility.* In order for a city to reach its full socioeconomic potential, per unit of energy cost, it needs to amplify its interconnectivity in sustainable ways. As his studies show, those numbers can be predicted fairly accurately for every city of the past or the present.

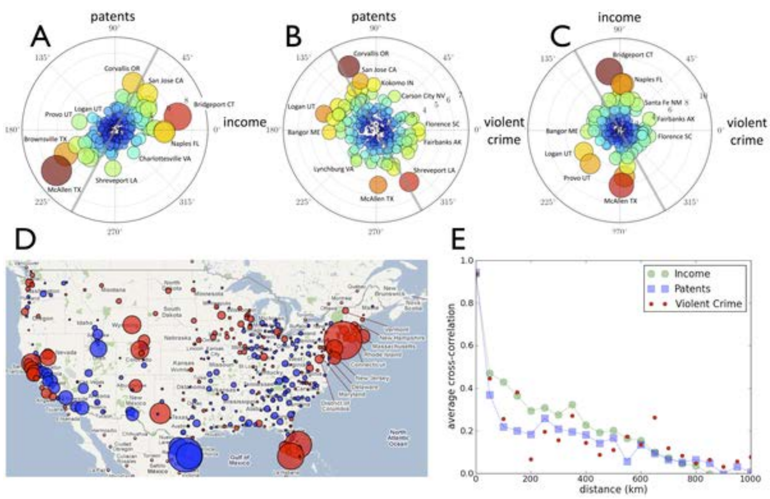
He also shows that rich societies are always urban. The opposite is not necessarily true (urbanised societies are not always rich, for example Brazil is intensely urbanised since the 70s but that does not bring systematic economic growth) but they always tend to be changing societies that go in this direction. So urbanisation does not guarantee growth, but it seems to be a necessary condition for it. In other words, our civilisation appears to know how to become *rich* only in *urbanised environments*.

6. WEINSTOCK Michael, 2011, « Architecture of flows, Integrated Infrastructures and the "meta-system" of urban metabolism », Acadia 2011 proceedings

7. WEINSTOCK Michael, 2013, Architectural Design: System City, page 17

8. BETTENCOURT Luis, 2013, « The kind of problem a city is: New perspectives on the nature of cities from complex systems theory»

Another interesting point, is that urban agglomerations, although being a problem of organised complexity, they do become a problem of disorganised complexity, where statistics can apply, but only when zooming out, and examining areas in extremely small scales. The scales of urban design however, in order for it to be meaningful are much smaller, in other words they are exactly at the area where the system is of organised complexity.



Cities in numbers. Bottom right graph: after a certain scale, cities become a problem of disorganised complexity.
(figure from "Urban Scaling and Its Deviations" by Luis Buttencourt

To return to the previous point, as cities become larger they go faster, burn faster, do more things faster. In other words their metabolic systems augment in a non-linear yet predictable ways. This characteristic is in contrast to what happens in biology, where metabolic rates fall as the size of the organism increases. Cities' mathematics are closer to those of stars that the larger they get, the faster they burn, until they run out of energy and collapse. This is one of the several differences observed between cities and biological organisms, and therefore it is questionable to what extent cities can be parallelised to them. They do however share many common characteristics as well. Cities are natural systems that evolve spontaneously in human societies, and as such they are as natural as beehives or coral reefs. We should move away from the sentimental distinction between the already blurred meanings of the natural and the artificial, the romantic idea of "nature" can and has as Jacobs points out create more problems than it solves.

Nevertheless, key biological concepts, such as adaptation, homeostasis, emergence or self-organisation can inform architecture in order to transmit in the design the vital underlying principles of living organisms. Thus we can envision creating man-made artificial constructions that act as organisms, and can achieve a dynamic equilibrium with their environment.

2.2 The mechanisms at play in the emergence of cities

A city is a collection of various complex systems of flows that affect one another and are affected by their environment. Those flows, that are primarily made through the various infrastructures of the city, constitute its metabolism. There is a tight connection between ***metabolism, energy*** and ***complexity***. The more complex a society, and thus a city, the more energy it demands to sustain itself, and the more energy it is capable of generating thanks to its knowledge and its structures.

The entire history of human civilisation, which can be traced by the study of cities, is a constant circle of the emergence of cities, their development and increase in complexity, their survival through various periods of time, and their collapse and reorganisation. The fluctuating complexities and metabolisms of civilisations throughout history, show how cities can be studied as complex systems of ***flows of materials, energy and information.***

Climate's role is of paramount importance, as it regulates the intricate choreography of the distribution of materials and energy between all the systems. There are exchanges on multiple levels among the atmosphere, the water, the land and the organisms, so that in turn, climate is also profoundly affected by those systems. For example, the emergence of the Cyanobacteria, the first photosynthetic forms, the levels of the oxygen in the atmosphere rose, the ozone layer was created, the temperatures begun to fall, and the first ice age begun billions of years ago.[1]

In this process ***feedback*** plays a very important role. Feedback allows for the result of trial-and-error processes to inform the systems. Positive feedback amplifies change, and negative feedback inhibits it. It is achieved through the exchange of information among multiple levels of hierarchy.

Metabolism is the "fire of life"[2], it is the process that captures energy and materials, transforms them in various forms of energy, and emits other materials as a result. The whole ecological system has emerged and been organised as a result of metabolic processes. In biology, all forms base their survival on the collection, negotiation and mutual transferring and exchanges of energy, processes from which they obtain their morphology, and form their relationships. The way that energy flows in living systems and in cities is not stable. It is regulated by feedback loops, "but occasionally there is such an amplification or inhibition that the system must change, must reorganise or collapse. A new order emerges from the turbulence of the system that has collapsed. The reorganisation often creates a more complex structure, with a higher flow of energy through it, and is in turn more susceptible to fluctuations and subsequent collapse or change through reorganisation, following the tendency of living systems and of cultural systems to ever increasing complexity"[3].

Metabolical processes have also been the driving force for the creation of ***societies***. Humans, just like many social organisms, externalise some aspects of their metabolism by creating material constructions that can often be collectively arrayed and organised. For example, the human body provides for heat in cold conditions. First with the use of clothes, and then with the constructions of shelters, part of this metabolic process of the emission of heat was externalised by profiting from the properties of those inventions. In that way the ***individual metabolisms can become collective***, which helps to smooth the fluctuations, and create more efficient wholes than single organisms. "Social order, distributed intelligence and patterns of mobility emerge from processes of externalised metabolisms."[4] After many years of evolutions, humans have grown completely dependent on this collective metabolism based on their aggregation in collective settlements.

Consequently ***culture*** too is inseparable from the metabolic processes. Culture allows the transmission of complex social and ecologically contextualised information down through the generations, and it acts as a catalyst for the increase of complexity over time. This information is strongly related to the ability to extract and process energy and materials from the environment. This allows groups of organisms to regulate their collective metabolisms and thrive.

Infrastructure is defined as the physical array of systems that provide the 'public services' of transportation, water, energy, information, people, and waste collection and disposal.[5] In other words, it is the infrastructures that allow the actualisation and the amplification of the flows.

1. http://www.globalchange.umich.edu/globalchange1/current/lectures/Perry_Samson_lectures/evolution_atm/, seen on May 2016

2. KLEIBER Max, 1961, « The Fire of Life »,

3. Michael Batty, "The Size, Scale and Shape of Cities," Science 319, no. 5864 (2008): 769- 71; Michael Weinstock, "Metabolism and Morphology," in AD Versatility and Vicissitude, 78, no. 2 (2008):26-33.; Michael Weinstock, "The Architecture of Emergence: The Evolution of Form in Nature and Civilisation" (John Wiley & Sons, Chichester, 2010): 130-7.

4. WEINSTOCK Michael, 2010, « The Architecture of Emergence », London, Wiley, page 249

5. WEINSTOCK Michael, 2011, « Architecture of flows, Integrated Infrastructures and the "meta-system" of urban metabolism », Acadia 2011 proceedings

2.3 Complex society

The evolution of social complexity concerns the change from societies that were small in number, with few distinctions between their members other than those based in biological properties (age, sex etc) to societies that are large, highly differentiated and integrated. For example hunter-gatherer societies have only a few dozen distinct social personalities, while modern societies recognise around 10.000-20.000 distinct occupations. Therefore complexity is characterised by more parts (***higher population***), more kinds of parts (***differentiation***), and higher structure and organisation (***more connections***).

Most systems, including those made by humans, have the tendency to develop to the maximum of their abilities until they reach a ***critical threshold*** and start becoming unstable. In those thresholds the effects produced by small changes in one or more variables can result in changes disproportionally large, which can produce a rapid and substantial collapse of the system, and trigger a cascade of large and non-linear changes.

A ***collapse***, when we refer to societies, is a break of the connections which leads to its rapid simplification. It can be accompanied by a breakdown of authority and central control, less specialisation and long distance trade which leads to the return to local self-sufficiency, and mass depopulation.

As mentioned, complexity does not come for free, it consumes energy. Increased complexity requires higher levels of organisation as it has to support more demanding processes, such as specialists who process, manipulate and communicate greater volumes and more types of information etc. The reason why complexity evolves is that it has a great utility of solving problems. However each increase in complexity requires a further increase in energy. Before fossil fuels people had to find other sources of energy or work harder to support complexity with their labour. Today's society feeds off this extra easy source of energy to support and extend its complexity.[1] However this relationship cannot go on forever augmenting, both because the energy available is not limitless and because the curve of complexity versus energetic returns according to scientists seems to be U-shaped, which means that there is a pick point of what use of energy can serve for, and after that it reduces, meaning that with more energy there is less output.[2] This explains the volatile history of cities even since prehistoric time.

"The chief cause of problems is solutions"
Eric Sevareid

"It is clear that the accelerating informational complexity, extreme velocity and volumes of fuel and food energy flowing immense distances across continents and oceans, and high but inequitable energy and material consumption strongly correspond to the multiple causality of disruption, societal transformation and collapse of great civilisations of the past."[3]
Michael Weinstock

1. TAINTER Joseph, 2012 lecture « Collapse of Complex Societies », 2010 International Conference on Sustainability, https://www.youtube.com/watch?v=G0R09YzyuCI (consulted on may 2016)

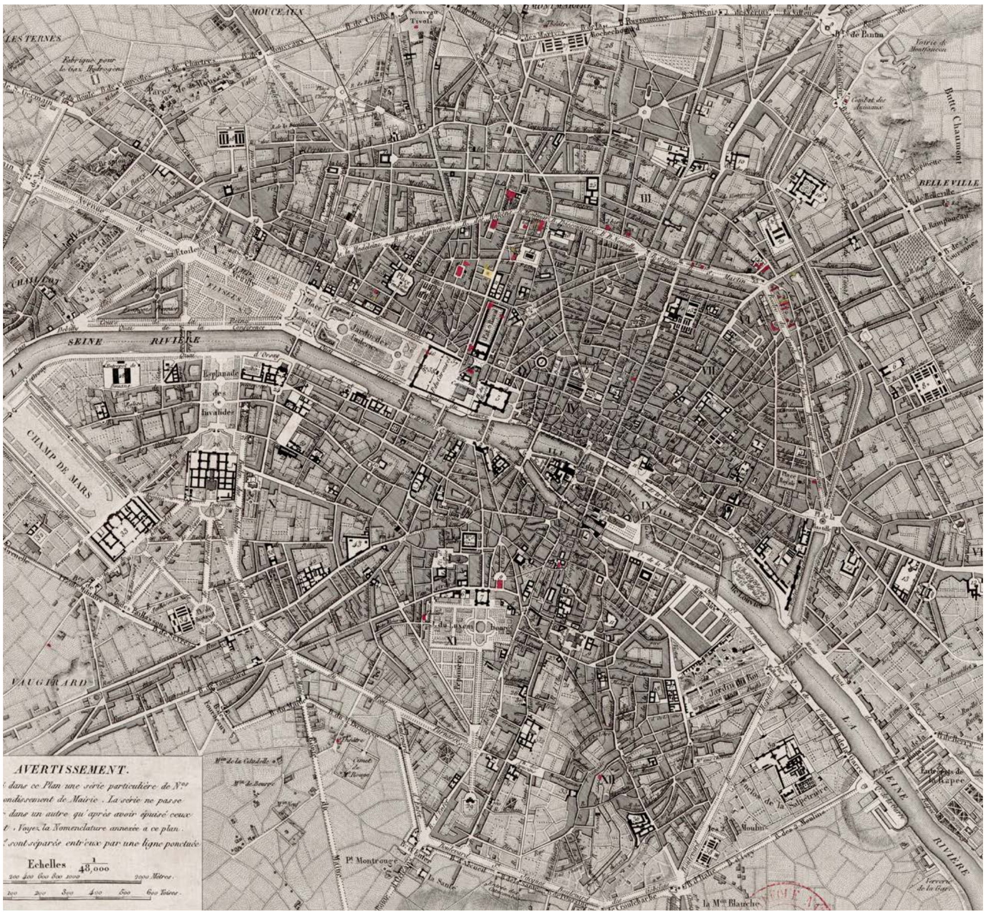
2. TAINTER Joseph, 2012 lecture « Collapse of Complex Societies », 2010 International Conference on Sustainability, https://www.youtube.com/watch?v=G0R09YzyuCI (consulted on may 2016)

3. WEINSTOCK Michael, 2010, « The Architecture of Emergence », London, Wiley, pages 261-269

2.4 Bottom-Up Versus Top-Down

Top-down and bottom-up are both strategies of information processing and knowledge ordering. Roughly speaking, top-down comes from a decomposition of the problem space into sub-problems, while bottom-up comes from organising parts of the solution space into larger chunks. A bottom-up approach is the piecing together of systems to give rise to more complex systems, thus making the original systems sub-systems of the emergent system. A top-down approach is essentially the synthesising of a system and formulating an overview, in order to give answers in a reverse engineering fashion

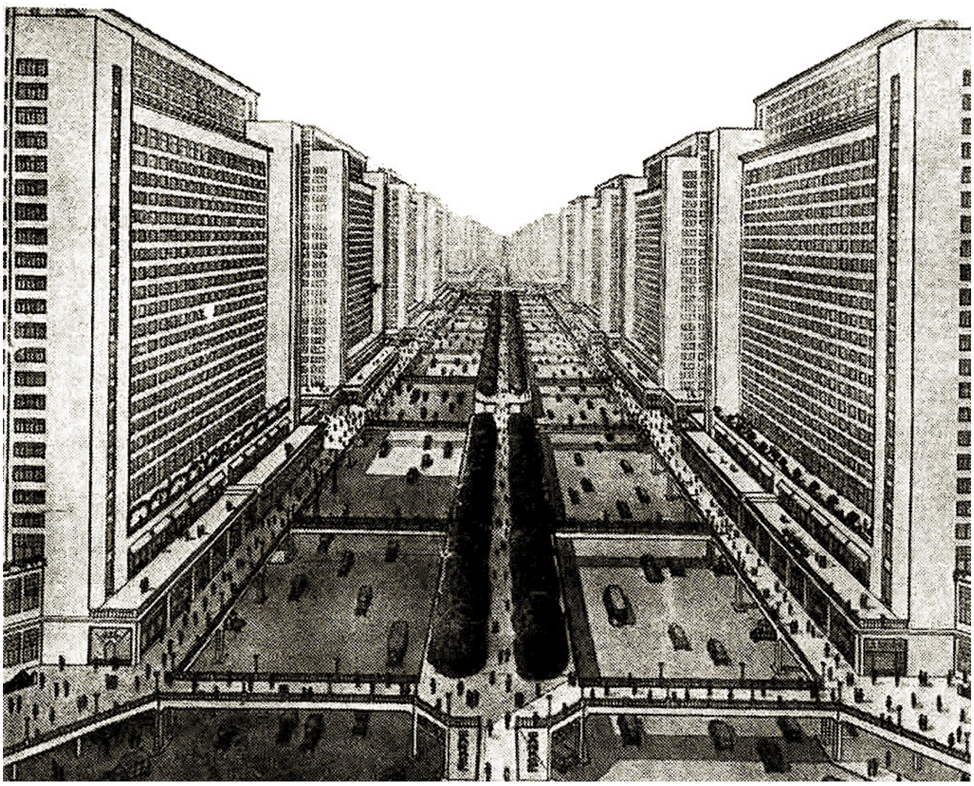
Top-down design has been tied with an effort to simplify the city, as its complexity is way bigger than any sign designer can process. Although there have been pioneering top-down designers that tried to take into consideration this complexity with very painstaking processes as the means of their time did not provide tools to facilitate it, and also managed to implement this complexity in their design, usually by leaving aspects not designed, this was the exception to the rule. Bottom-up processes on the other hand, take the complexity of the society more into consideration, and answers emerge from this complexity, without this necessarily meaning that they always give meaningful solutions to its problems.



City of Paris, 1837
(figure from https://commons.wikimedia.org)

From the pre-historic times, human settlements begun growing organically according to the current needs each moment in time, with bottom-up processes. In the pre-industrial societies, with the exception of certain ancient greek cities-ports, some of their colonies in the Middle east, and the Roman fortresses-cities, urban aggregations had no central planning nor higher rules and grew in the principle of bottom-up. The forms produced where created by the local needs at every point in time, and they were in a constant adaptation to those needs. This process of unplanned organisation was intensified during the industrial revolution, where the urbanisation increased rapidly, resulting in the creation of urban centres with very low standards of quality of life, poor hygiene, polluted air, inadequate infrastructure networks and consequently very low connectivity and other important problems. The Black Death or plague, one of the most devastating pandemics in human history, resulting in the deaths of an estimated 75 to 200 million people around 50% of the population of Europe, found fertile land for spreading within those densely packed and poorly ventilated cities.

Therefore, when the first Top Down initiatives appeared trying to "purify" cities and make them healthier, they responded to very real and imminent problems. Starting with the garden city, and following with the modernist planing that can be summarised in the CIAM's "The Athens Charter" in 1933, the effort was focused on solving the problems of the dense populations of the city centres. Those strategies that started being developed before the first world war, were applied to cities after the destructions of the 1st and especially the 2nd world war. Modernism served the socio-political agendas of the various leaderships of the time. In the Western Europe it allowed capitalism to be fully developed, in the eastern Europe it allowed the socio-economical model of socialist states to be applied, and in the developing countries for the poor masses of population to be better handled.



Le Corbusier, Ville Radieuse
(figure from https://inarchitectureandurbanism.wordpress.com)

Little needs to be said about the results of those planing strategies, as their failures have already been stretched. It lead into the development of inhuman lifeless and badly organised urban aggregations deficient of the ordered complexity that is necessary for a vivid city.

In the 70s with the vast increase of the services economical sector, the fall of the industries, the definitive end of the colonialism and the consequent decline of the modern movement, in the context of the rapidly globalised free market, the development of cities although still organised Top-Down in the most parts, started presenting Bottom-Up initiatives. Many reasons explain this, such as the fact that the state's investments in the housing sector decreased, the costs of land and its ownership rose significantly, the urbanisation continued to develop rapidly and the poor qualities of settlements especially in the developing countries were sometimes desirable by large companies as they offer low-cost workforce. In the West we start observing collaborative design, in the previously communist countries we find private investors entering dynamically in what used to be completely centralised design, and in the developing countries we see the development of informal settlements, known as slums or favelas. All three of those cases are answers of Bottom-Up design to the strictly Top-Down design wether capitalistic, communistic or colonial that prevailed before. In other words, these initiatives put an end to the Top-Down design that reigned for about half a century.

There is one peculiar example where we can observe both extremities be created almost simultaneously, and coexist together. It is a settlement called ***Barrio 23 de Enero***, in Brazil. Here we

Barrio 23 de Enero, Brazil, (photo from http://venezuelanalysis.com)

can see an ensemble of big modernistic housing blocks, with an informal city that has developed around them. The modernist buildings ware financed by the state, but even before the ensemble was finished it was occupied by the poor homeless families, and simultaneously the informal settlement started growing right next to it, to house the households that had not found a place to stay in the building. There is no electricity nor water supply in the site, and the conditions inside the buildings are not very different from those in the informal settlement. We can see how the spontaneously grown houses are in a dialectic both with the big blocks and the environment, and how a functional whole is created.

Another interesting example of a city that exhibited strong Bottom-Up characteristics during the last 50 years is that of the modern city of ***Athens***. This happened mainly due to two reasons. The first was a law that allowed the private sector to build apartment buildings, with small initiatives, little by little, financed by more or less collaborative money from the owner of the site, the developer and sometimes also the future residents of the apartment building. The second was the very usual phenomenon of the violation of the existing urban planning legislation, which lead to informal extensions of buildings, and creation of unexpected forms that replied to the needs of each owner. As a result Athens has the very rare quality of being grown Bottom-Up while having a Top-Down planning

Nowadays, due to the rise of globalisation and the free market whose power is far beyond the power of any central planing, coupled with the questioning of the authority of the state, forms of Bottom-Up urban planning appear increasingly strong.

One question that arises from this very sort and not exhaustive overview of the Bottom-up versus Top-Down design, is the definition of the characteristic(s) of a society that make(s) it turn towards the one or the other design strategy. Is it political, economical, social, does it depend on historical characteristics or is it just a coincidence? This question does not have an easy answer. None of those parameters seem to be able on their own to account for the choice of either system. It cannot be merely a political, merely an economical or merely a social issue as we have seen examples of opposite status quo, that followed the same design strategies. What we can say however, is a few remarks that can be deduced.

When there is one central strong state, then in terms of design we observe an extremity, wether this is top-down (post-war Europe) or bottom-up (medieval Europe). Which extremity appears depends on the policy of the state. We can observe both extremities together when we see very strong inequalities (Brazil). When the state takes full responsibility of the design of the environment, wether in a socialistic or capitalistic political status quo, then we observe a Top-down process. When it is indifferent to it, wether as a roman emperor, a feudal lord, or a contemporary government, then people take initiatives and create the built environment Bottom-Up. If on the other hand, there is a less centralised, more participatory status quo, we see an in-between situation with both top-down and bottom-up elements implemented together. Finally, every time the systems undergoes a significant change, there is a tendency to move towards the opposite trend from the one predominating the previous phase.

What is clear from this analysis is that either strategy in isolation does not produce tangible results. Effectively, the bottom is too “dumb” to produce results due to the simplicity of its operations relative to the scale of the system within the lifecycle of a generation. It needs a large number of iterations, in other words, many generations from the moment that a problem appears in order to start providing solutions. The system, on the other hand, is far too complex for the derivation of universally applicable rules, and its collective conscience too impatient and too demanding to wait for the bottom to self-organise. Thus, the only sustainable solution is to find a way to deploy both processes together.

Athens, Greece, 2015
(photo by Aliki Karanikola)

3. The Agency of Architecture

3.1 The notion of agency

The issue of "agency" for architecture implies the capacity of an agent or actor to act in a given environment. It is a very effective concept for understanding architecture's multiple ways of engaging with the world. It is a particularly multifarious notion, that is hard to define, as it entails multiple notions, related to all of its social, cultural, political, economical and historical parameters. It derives from architecture's multi-disciplinarity and its societal embedding, and is related to the link among the individual, the society, and the architectural object.

A lot of questions arise from the term agency. Perhaps the most obvious question is who or what represents this 'agent', and in turn what defines the world in which it is operating. Are we talking about the agency of the architect? And if so, the agency to do what? or is it rather the power of the architectural project itself, the role of the user, of the environment, of the society or of the potential futures of each civilisation? Also, how do agents operate? How does an object exert agency? How do they, together object/actor and agency, shape or affect a certain situation or condition? 'why?' and 'to what effect?' [1]

Questioning the notion of agency allows to explore ways of understanding current architectural needs, possibilities, and capacities for action. We hoped to shift the focus away from the objects of architectural production towards an investigation of their processes, their wider context and possibilities. It also addresses the big social and political questions in this period of rapid global environmental change.

Agency is a central notion in the ***humanities and social sciences***. In the theory of Marxism, agency is associated with the intention to effect social change against existing societal structures. In this worldview agency is opposed of structure. However in architecture, this fundamental dichotomy between agency (as action and intentionality itself on the one hand), and structure (as the existing "rigid framework") is being questioned, because it no longer seems to cohere, in the contemporary word of non-linearity, flows and networks. The concept of agency ceases to be meaningful once it is disengaged from its coupling with structure. It needs to be understood in a much broader sense, and by doing so, the very notion of intentionality in architecture is expanded.

Scott Lash explains the "problem of the agency of the Western-thought"[2] and suggests that we need more a relational, more long-term and more transactional way of seeing it, that goes beyond the attribution of individual intentionality.

> *"Agency comes from the classic notions developed by Weber and Parsons, and presumes two kinds of actions: ends-oriented and means-oriented ones. However in the Western notions of agency, it presumes only a goal-directed notion. […] Against this, I would like to suggest the notion of activity. Activity is much less goal-directed, it is much more situational. […] This also involves abstract thinking, but of a different kind than agency-type thinking. Agency-type thinking presumes a subject-verb-object kind of thinking: this is the object, and this is my plan. It's almost a kind of scientific model you follow."*

1. Academic journal "Footprint", issue 4, TU Delft, http://www.footprintjournal.org/,
2. Academic journal "Footprint", 2009, issue 4, page 8 , TU Delft, http://www.footprintjournal.org/,

3.2 Spatial Agency and Architecture

Spatial agency is a project by Nishat Awan, Tatjana Schneider and Jeremy Till in the University of Sheffield, that started with the belief that a building is not necessarily the best solution to a spatial problem. The project attempts to uncover a second history of architecture, one that “moves sharply away from the figure of the architect as individual hero, and replaces it with a much more collaborative approach in which agents act with, and on behalf of, others”[1]. It is an awareness of this interdependency of systems that the spatial agency brings to the table.

Anthony Giddens says that agency ‘presumes the capability of acting otherwise’[2]. He brings about a new sense of what it may mean to be an architect, one in which the lack of a predetermined future is seen as an opportunity and not a threat.[3]

By challenging the norms of professional behaviour he does not dismiss the role that professional knowledge may play, this knowledge should be used within other ways of acting. To be an agent, for Anthony Giddens, is to act with intent and purpose, but that purpose ‘cannot be adequately defined [...] as dependent on the application of learned procedures’. Purpose is also guided by hunch, intuition, negotiation, and other conditioned reflexes, which are based on one’s experience in the world, as both professional and human. In contrast to what he calls ‘discursive consciousness’, in which matters are explicit and explainable, mutual knowledge is ‘practical in character’. But - and this is the key point - the discursive and the practical are by no means mutually exclusive: ‘the line between discursive and practical consciousness is fluctuating and permeable’[4], he argues, suggesting that each draws on the other in the act of agency. In that way he is challenging the traditional principles that architecture functions with.

However, in contrast to Giddens’s theory of agency where agents intervene in the world directly, an architect does so indirectly, through buildings. The human agency of the architect is thus always mediated by the non-human presence of matter and in this mediation, his intent might be compromised, or even blown apart. Instead of considering the human (architect) in opposition to the non-human (building), spatial agency sees the whole process as a continuity, motivated in the first instance by intent, and then open to adjustment, ‘acting otherwise’, as it unfolds in time.

An inevitable outcome of this worldview is that the architect is exposed to issues of power, and in particular questions of how power might be used and how it might be abused by architects acting as spatial agents. While agency might first be understood as the power and freedom to act for oneself, when examined in the context of architectural profession and research community it also involves the power to act on behalf of others. Throughout history, architects have always tended to become embedded in existing power structures, usually at the service of those in control: this is manifest at various scales, from the body to the building, then on to the city, the continent, and even the globe. Antonio Gramsci accuses architecture of supporting and maintaining the prevalent ideologies of the status quo.[5] What is for sure is that the role of architects and academics cannot be neutral: if played out uncritically it reverts to the interests of those in power.

Agency, as Giddens reminds us, is strongly connected to power - an early definition of agent in the Oxford English Dictionary is: ‘one who exerts power or produces an effect’[6]. However spatial

1. http://www.spatialagency.net, seen on April 2016

2. GIDDENS Anthony, Social Theory and Modern Sociology, page 216.

3. GIDDENS Anthony, 1976, “The world as constituted by a stream of events-in- process independent of the agent does not hold out a predetermined future”, from the “New Rules of Sociological Method” ,London: Hutchinson, page 75.

4. Giddens, The Constitution of Society, page 4.

5. Gramsci named two types of intellectuals, traditional and organic; he observed the role both played within existing power structures, but argued for the potential to transform these roles for different socio-political ends. See: GRAMSCI Antonio, 1971, “Selections from the Prison Notebooks”, London, for example p.10 and 43.

6. GIDDENS Anthony, “The Constitution of Society”, page 9. See also the section ‘Agency and Power’, pp. 14ff.

agency proposes a different definition: “the agent is one who effects change through the empowerment of others. Empowerment here stands for allowing others to ‘take control’ over their environment, for something that is participative without being opportunistic, for something that is pro-active instead of re-active”[7].

Architects in history have often distorted the role of their agency, and as a result seem to have often had a particular problem with the public. Frank Lloyd Wright for example had the opinion that “the only person who can run a city is an architect”. There’s a whole cultural history starting with “Metropolis” in the 1920’s, all the way to “Matrix” in the 00’s where the principle villain of the city is the architect. Architects and planners have a cultural presence as the crazy ruler who is trying to impose terrible conditions on people and then imprison them. It is no wonder that an opinion widely accepted is that “architecture is the imposition on the world of structures we never asked for and that existed previously only as clouds of conjectures in the minds of their creators” (Rem Koolhas, 2014)

7 . Academic journal “Footprint”, issue 4, page 99, TU Delft, http://www.footprintjournal.org/,

3.3 Agency in Computational Design

The theme of the 24th annual ACADIA conference in 2014 was “Agency”. This time, the focus was put on redefining the term “Agency” through the lens of computational design strategies such as simulation, fabrication, robotics, and novel integrations from science and the media arts. The sub-categories defined to cover the broad sense of agency in the computational design were: Design Agency, Fabrication Agency, Parametric Agency, Material Agency, Temporal Agency and Data Agency.[1] This list of agencies might not be exhaustive, but each one of them has a certain autonomy and refers to a particular feedback between designer, agent, and environment. The designer mediates between multiple agencies. He engages in a dialogue with the given material, fabrication or data structure, discovering its capacities and acting as a catalyst for them to operate. Following the proceedings one sees that computational design gives new insights on how the notion of agency can be realistically accomplished in architectural practice in todays society.

‘*Design Agency*’ suggests that design itself has a certain autonomy over the designer. It interrogates the idea of control, perhaps redefining not only the term design but the entire culture of design itself. We are no longer the designers of spaces and things but rather designers of the processes and experiences that produce them or are produced by them. It questions if there can ever be a truly ‘Top Down’ or ‘Bottom Up’ strategy, and implies that there is always a feedback, an interdependence between the designer and the designed, which results in a weak form of authorship of the result of the process.

Roland Snooks, underlines the links of the design agency with the intention of the architect, and the capacity to encode this intention within algorithmic processes of design. In this context, design agency is closely related to multi-agent algorithms, which describe a process of local interactions of autonomous agents, and embody inherently distributed and bottom-up strategies. The non-linearity of the interactions of those systems allows the negotiation of different design intentions and agencies simultaneously.

> *“What is of interest here, and more specifically at stake, is not the application of multi-agent algorithms to various aspects of architecture, but the capacity to reconceptualise the op-*

1. GERBER David, SANCHEZ Jose, HUANG Alvin, ACADIA 2014 Design Agency Proceedings, Introduction, Los Angeles, California

eration of design intention through a behavioural approach. I describe this approach as behavioural formation - a generative design methodology that draws on swarm intelligence and operates through multi-agent algorithms. This strategy functions by encoding simple architectural intents or decisions within a distributed system of autonomous computational agents. […] This represents a shift from traditional design to the "orchestration of intensive processes of formation through the design of the underlying behaviours of matter and geometry."[2]

This agency is about the capacity of the designer to "tease out" emergent behaviour and complex rder from these processes. Their value ultimately lies in the quality of the architectural intention and its capacity to be successfully encoded, rather than the opposite, i.e. the architecture deriving value from its processes. "New form is not conceived, it is coaxed out, flushed from its virtuality"[3]

According to Roland Snooks, there are two fundamental mechanisms through which agency operates in the design process: the agency of architectural matter, and the agency that organises or restructures architectural matter (matter being the substrate within which design operates, wether geometric or programmatic). The first category refers to agents creating forms with their "bodies". To illustrate this, we can take the example of ants who form bridges with their own bodies so that their comrades can overcome big obstacles. The second category refers to agents who act by reorganising matter. For example, termites move mud as a result of pheromone stimuli from the interactions with the rest of the population of termites

Ants forming a bridge,
(photo from https://gr.pinterest.com)

Termites nest,
(photo from http://www.harunyahya.com)

2. SNOOKS Roland, Session Introduction of Design Agency, ACADIA 2014 Proceedings, Los Angeles, California

3. MASSUMI Brian, 1998, « Sensing the virtual, Building the insensible, Hypersurface Architecture », Architectural Design, vol 68, no 5/6

4. Emergent Urbanism

4.1 The concept of “wholeness”

> *“We have a vision of buildings taking their form continuously through a smooth step-by-step process in which each step preserves the structure of what was there before.”* [1]

Christopher Alexander, an influential Austrian architect and design theorist, in his four-volume treatise on “The Nature of Order” (2002-2004) attempts to understand how the parts of a system have their proper place in the whole, as well as how the processes of life work.

In his concept of life, the process of its creation is of paramount importance: “living structures are the result of a structure preserving process of becoming”[2]. The position of elements which creates structures is guided by forces that influence their movement and evolution. Those forces are the result of the context or the environment of each element. This is and idea that has existed for almost a century before this book, first expressed by the British biologist D’Arcy Thompson, who states in his book “On growth and Form” (1915) that “the form of an object is a diagram of forces, in the sense, at least, that from it we can judge the forces that are acting or have acted upon it”[3].

Therefore order emerges and is preserved over time, and it is expressed by a dynamic equilibrium that forms a wholeness. Wholeness is a structure that exists at many levels of scale, and covers the interrelationships of the configurations at different scales. Assemblies that fail to achieve wholeness do not become stable enough and as such they do not persist. They re-enter the process of becoming, and until they achieve a new equilibrium they appear to be in disorder. Throughout the era of human evolution and existence, the wholeness evidenced by the arrangements that persist has informed what humans have come to understand as “natural”. Therefore what we perceive as natural is the dynamic order which resulted from the laws of nature with which we happened to coincide.[4] This wholeness is “where each part’s structure and function flows into a continuity of the whole”[5].

What is very interesting about this theory is that, inspired by the early 20th century gestalt psychologists who wrote extensively about the perception and cognition of wholeness and of wholes, Alexander carried out experiments in which he proved how wholeness can be seen and instinctively identified by people[6]. When well done, says Alexander, this coherence offers a sense of harmony, which “fills and touches us”.

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1. ALEXANDER Christopher, The Nature of Order An Essay on the Art of Building and the Nature of the Universe: Book ||| - A Vision of a Living World, Berkeley, CA, 2004
2. ALEXANDER Christopher, The Nature of Order An Essay on the Art of Building and the Nature of the Universe: Book II - The Process of Creating Life, Berkeley, CA: The Center for Environmental Structure, 2002, page 4
3. D’ARCY Thompson, « On growth and form: the complete revised edition », 1992, Dove publications, New York
4. WAGUESPACK Leslie J, 2010, Thriving Systems Theory and Metaphor-Driven Modelling, chapter 2: Christopher Alexander’s Nature of Order, Springer.
5. ALEXANDER Christopher, The Nature of Order An Essay on the Art of Building and the Nature of the Universe: Book I - The Phenomenon of Life, Berkeley, CA: The Center for Environmental Structure, 2002, page 8
6. ALEXANDER Christopher, A.W.F. Huggins. (1964) On changing the way people see Perceptual And Motor Skills. 19, 235-253

4.2 Emergent urbanism

"Every generation must build its own city"
Antonio Sant'Elia (1914), Manifesto of Futurist Architecture

Cities are composed by stable elements, and elements in movement, in constant flux. Those elements are tightly correlated in a complex whole. Manuel DeLanda points out that a model of agent-based behaviour could be developed to understand the decision making processes within an actual city. We arrive thus to the term 'emergent urbanism' which lets us envision a computational method that may act predictively according to the dynamic urban system.

In emergent urbanism there is an important shift of focus from the object to the ***process***, from the master-plan to the ***master-algorithm***. Generative methodologies using swarm intelligence suggests an alternative understanding of typology in design: a typology of the process in stead of the typology of the form. Design methodologies based on multi-agent systems allow to encode architectural intentions and decisions within a distributed system. This generative approach is completely different to the linear way traditional design works. As Roland Snooks explains in his article "Behavioural Matter"[1],this implies a shift from considering society and matter as inert receptors of imposed forms, to emerging or "growing" forms and thus matter, based on the behaviour and the interactions of localised entities within a complex system.

The use of such systems involves highly volatile processes in which form, topology, dimensions and relations remain unstable, while the qualitative characteristics emerge and persist after multiple iteration. The embedding of behavioural design methodologies within urbanism offers a step forward in bridging the gap between Top-Down intervention and the Bottom-Up emergence of complex systems. ***The design operates on a local level, but it is also informed by constraints and architectural intent on the global level***. In other words, multi-agent systems allow for a bottom-up design with implemented external rules that ensure the optimal organisation of the whole. Thanks to the non-linearity of the process, the process can even transcend its own logic, and let singularities emerge, i.e. novel identities that go beyond its rule sets.

Rather than designing a model that meets a group of demands and criteria, urban imperatives are codified into agents that self-organise negotiating those inputs. The task of the design is to try to anticipate the evolution over time. As Neil Leach explains, the objective "is not to simulate actual populations or their occupation of architecture, but to devise processes operating and much greater levels of abstraction that involved ***seeding design intent into a set of autonomous design agents which are capable of self-organising into emergent urban forms***"[2]. The focus is not on simulating natural processes or predicting the behaviour of people, but rather to "re-conceptuaze design as behavioural act, the ***behaviour of architecture***"[3]. Therefore design becomes a flexible decentralised process where micro and macro decisions occur simultaneously and are mutually informed. This strategy will eventually give a result of a city in constant flux, a city in an equilibrium in-between chaos and order that will be responsive to changing circumstances, that feeds off the instabilities of the systems and survives thanks to its dynamical character.

1. SNOOKS Roland, «Behavioural matter, pulsations of the Swarm», published inside the book by GOLDEMBERG Eric, 2012, «Pulsation in Architecture», J.Ross Publishing
Accessed in April 2016 in the site: https://books.google.fr/books?id=HMBJE7b8Nr4C&pg=PA410&lpg=PA410&dq=kokkugia+docklands&source=bl&ots=9Hj9Nj_EN8&sig=X6cK_MMtuOd-nLMlZZK6W0JnN9w&hl=el&sa=X&redir_esc=y#v=onepage&q&f=false

2. LEACH Neil, June 2009, « Swarm Urbanism », Architectural Design, Special Issue: Digital Cities, Volume 79, Issue 4, pages 56-63

3. SNOOKS Roland, «Behavioural matter, pulsations of the Swarm», published inside the book by GOLDEMBERG Eric, 2012, «Pulsation in Architecture», J.Ross Publishing

4.3 Multi-agent systems (MAS)

One of the methods for approaching complexity and profiting from the emergent and self-organising properties of complex systems, are Multi-Agent Systems.

The concept of the "agent" is not new. In the research for artificial intelligence we can see symbolic reasoning "agents" from 1956-1985. However in the case of multi-agent systems (MAS) there is a key difference in the concept of the agent, which can be summarised in the degree of its "intelligence". Ultimately artificial Intelligence apparatus aim to build systems that can understand, analyse and think cognitively. On the other hand, MAS focus rather on a large number of rather "dumb agents" following the principle of "a little intelligence that can go a long way". It is emphasised that the focus ought to be shifted from designing ***intelligent-agent*** systems to designing intelligent ***agent-systems***. "A collection of dumb agents is often better suited to a problem than a single smart one"[1]. Although this might seem strange at first, in fact there are studies that show that as agents get smarter, their functionality tends to reduce.[2] Therefore in the design of MAS, much more importance should be placed in the interactions between the agents, rather than their individual characteristics.

It might be difficult to define the term "agent" as there is no agreed universal definition,but we can try to give a comprehensive list of its attributes. Independence and autonomy seem to be very important, but there are also other requirements such as physical presence, the ability to somehow sense its environment, mobility and social abilities.[3]

A proposed definition of Multi-agent systems is "a collection of autonomous, social actors where, through local interaction and social communication, emergent global behavior occurs"[4]. They consist of multiple autonomous entities having different information and/or diverging interests. Their applications extends in a large variety of disciplines, such as mathematics, game theory, transportation, communication, logistics, robotics, economics etc.

At least three distinct research directions relevant to the use of MAS for understanding, predicting and studying the urban environment can be identified, one that focuses on the ***simulation of movement***, one concerning the ***dynamics of the land use***, and a third one about the ***planing process*** itself. There are also many hybrid projects that make use of aspects from several directions. Two main kinds of objectives can be found within this research: exploratory research, which concerns exploring, testing and building theories and predictive research, which concerns reproducing specific real world systems to make realistic predictions.[5]

Advantages

MAS have several advantages as opposed to a single agent or centralised approach. First of all, MAS distribute computational resources and capabilities across a network of interconnected agents. Whereas a centralised system may be plagued by resource limitations, performance bottlenecks, or critical failures, and thus suffers from the "single point of failure" problem. Furthermore, MAS allows for the interconnection and interoperation of multiple existing systems which can be incorporated into an agent society. What is more MAS efficiently retrieves, filters, globally coordinates information from sources that are spatially distributed and provides solutions equally

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1. HOLLAND, J. H., 1996, "Hidden Order. How Adaptation Builds Complexity", New York, Helix Books
2. PARUNAK H. V. D.,2000, "Industrial Applications of Agents," presented at 2nd European Agent Summer School, Saarbrucken
3. GABBAI Jonathan, YIN Hujun, Wright W.A., ALLINSON Nigel, 2005, « Self-Organisation, Emergence and Multi-Agent Systems », University of Manchester, England
4. GABBAI Jonathan, YIN Hujun, Wright W.A., ALLINSON Nigel, 2005, « Self-Organisation, Emergence and Multi-Agent Systems », University of Manchester, England
5. BARROS Joana Xavier, 2004, « Urban growth in Latin American cities », UCL, London

spatially and temporally distributed. Finally MAS enhance overall system performance, specifically along the dimensions of computational efficiency, reliability, extensibility, robustness, maintainability, responsiveness, flexibility, and reuse, and they can benefit from all the positive effects of emergence and self-organisation.[6]

What is more, MAS promote modelling of complex processes without demanding a profound background in mathematics. They can also easily be translated into programming code and allow the consequences of a previously theorised model to visually unfold, undergo analysis, and be improved.[7] The agents in the computational systems, just like in real life, can be setup so as to gradually optimise their decision making processes through iterative adaptation and evolution.

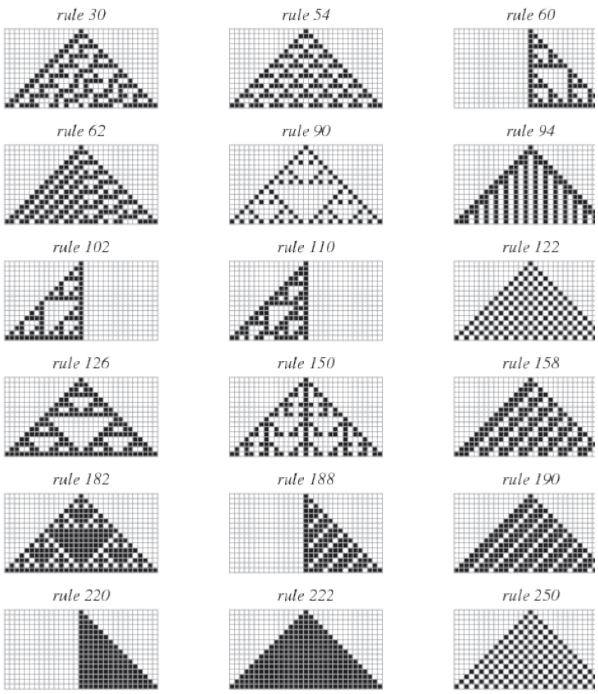
6. https://www.cs.cmu.edu/~softagents/multi.html, seen on May 2016

7. VON MAMMEN Sebastian, TARON Joshua, July 2012, « A Trans-disciplinary program for biomimetic computing and architectural design », University of Calgary, New York

4.4 Cellular Automata

Cellular Automata (CA) models are a special category of multi-agent systems where agents are spatially fixed cells. A CA model is composed of a grid of finite-state cells with each cell linked to the cells that surround it. All the cells are identical and update their state simultaneously. The state of a cell at every moment in time depends on its previous state, and on the state of its neighbours. The four principles that define a CA are: cells, states, neighbourhood and transition rules.

CA have very often been use to simulate urban phenomena as the way in which they determine local exchanges through vicinity rules is very close to the way urban space is organised in neighbourhoods. However, their use has also been criticised mainly due to the restrictions posed by the spatial mobility of the cells, and the strict layout of the model. Even though by themselves they might not be able to model pertinently the complexity of the model environment, they do provide very useful insights into urban dynamics, and especially when combined with other types of multi-agent systems, they can be very helpful.



Cellular Automata
(figure from http://mathworld.wolfram.com/ElementaryCellularAutomaton.html)

4.5 Evaluation of MAS

There are two evaluation steps: verification and validation, which concern, respectively, the correctness of model construction and truthfulness of a model with respect to its problem domain.[1]

More specifically, validation concerns how well the model outcomes represent the real system behaviour, and its methodology depends on the objectives of the simulation. For example, if the objective is accurate predictions, then the validation necessitates measuring the accuracy of the outcomes. If the objective is to understand and explain general patterns, then then it is necessary to measure how well the simulation produces critical system properties.

To perform verification, on the other hand, a sensitivity analysis of relationships between a model's parameters and its outputs is usually deployed.

1. BARROS Joana Xavier, 2004, « Urban growth in Latin American cities », UCL, London

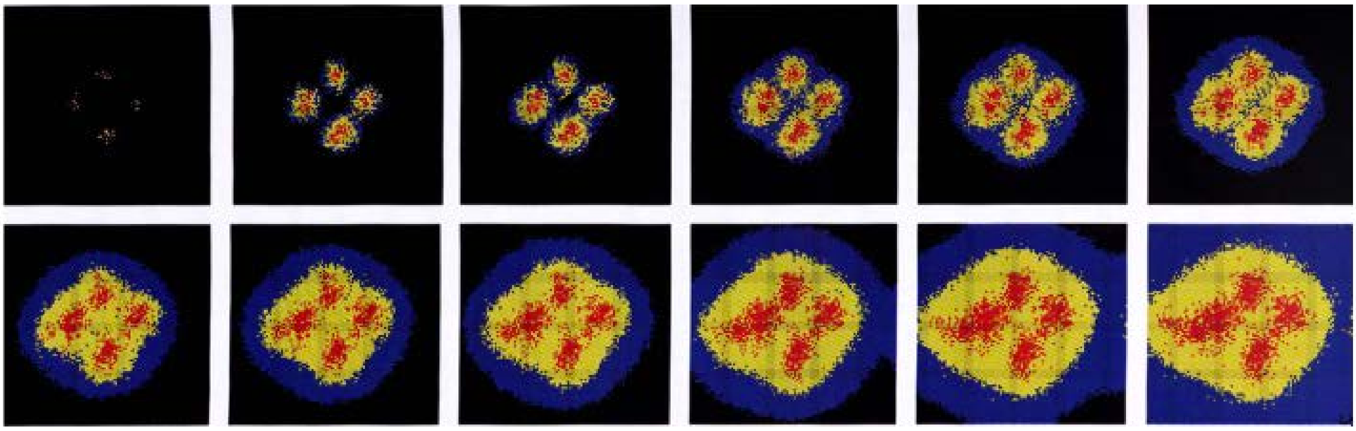
5. Case studies

The cases were chosen with two basic criteria. The first is that they are cases from different parts of the world, and the second is that each model introduces one particular element that I consider to be very pertinent for the practice of multi-agent systems simulation. This element is always highlighted in the beginning of presentation of each example.

5.1 Case study 1, Latin America

Exploring Urban Dynamics in Latin American Cities Using an Agent-Based Simulation Approach

Gradual step by step addition of variables and behaviours to a simple initial model



The simulation developed by Joana Baros focuses on a specific kind of urban growth in Latin America called 'peripherisation', which refers to the formation of low-income residential areas in the peripheral ring of the city.[1]

Workflow

Her workflow begins with studying urban growth and dynamics in Latin American cities. After that she forms her exploratory simulation step by step by adding features to a simple logic, so as to gradually increase the model's complexity. The behavioural rules used are as simple as possible. In the end she runs several tests and evaluation processes, she compares the results with the reality and she draws conclusions

The simulation model

The basic idea is the rather simple assumption that residential locational patterns in Latin American cities can be explained by essentially two concepts. The first is the idea that the composition of society, or how society is divided in groups, has a great impact on spatial development. The second is that restrictions rather than preferences generate the spatial pattern. Once these two factors are established, urban development appears to become locked in a vicious circle with high-income groups located in the best locations, while low-income groups are pushed away from all urban facilities.

Step 1: Peripherisation

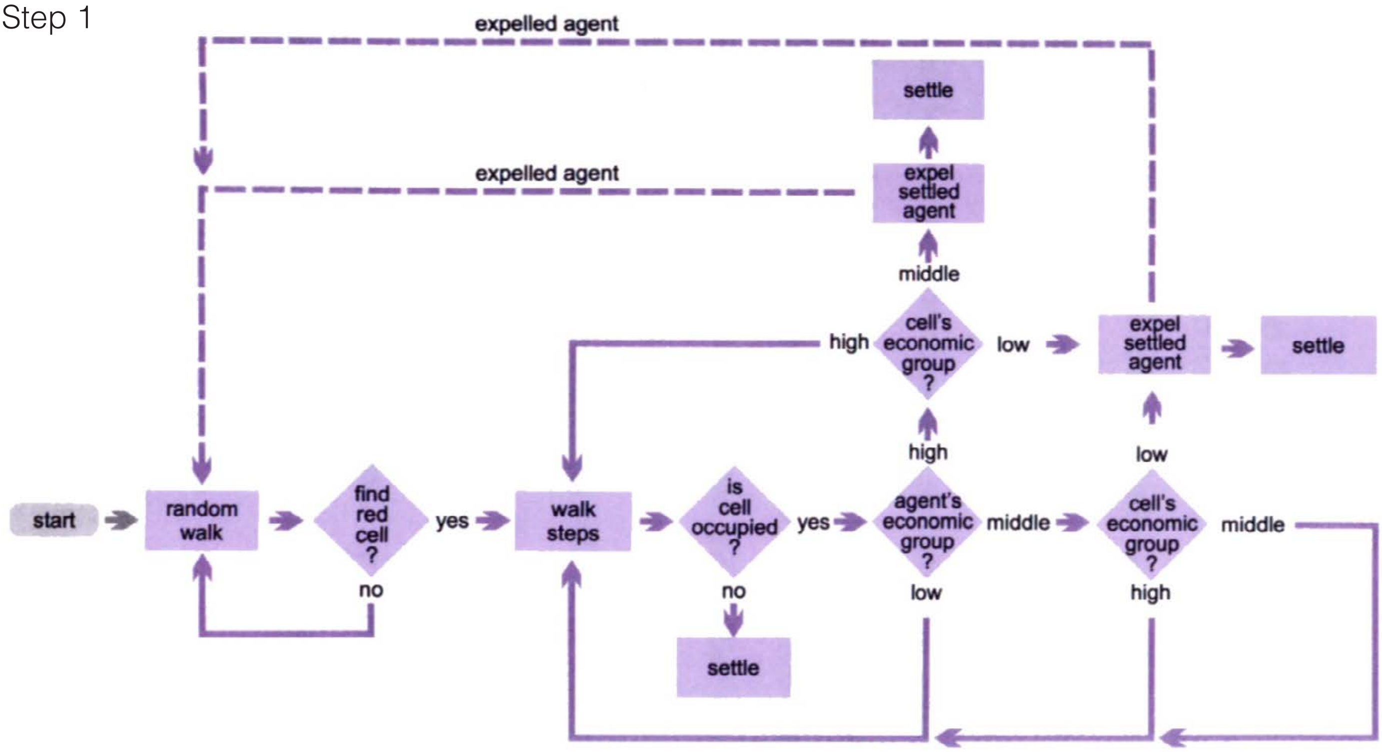
1. BARROS Joana Xavier, 2004, « Urban growth in Latin American cities », UCL, London

This first module simulates in a very simple way the basic residential locational processes of the three distinct economic groups (high, medium and low income) according to the pyramidal model of distribution of income in Latin American countries. The agents represent individual households. They are mobile and walk randomly over the grid space. The model assumes that all agents regardless of their economic status have the same objective: to be located as close as possible to the areas better served by infrastructure, with nearby commerce, job opportunities and so on, but they have different restrictions according to their economic power. As a result, the high-income agents can locate in any place they want, the medium-income agents can locate everywhere except where the high-income group is already located, and, finally the low-income agents can only locate in vacant space. Some agents can occupy other agents' cells, which means that the latter are 'evicted' and must find other places to settle.

Variables:

- Steps: the number of cells that the agent walks before trying to settle in a place (cell)
- Proportion of agents per economic group

Step 1



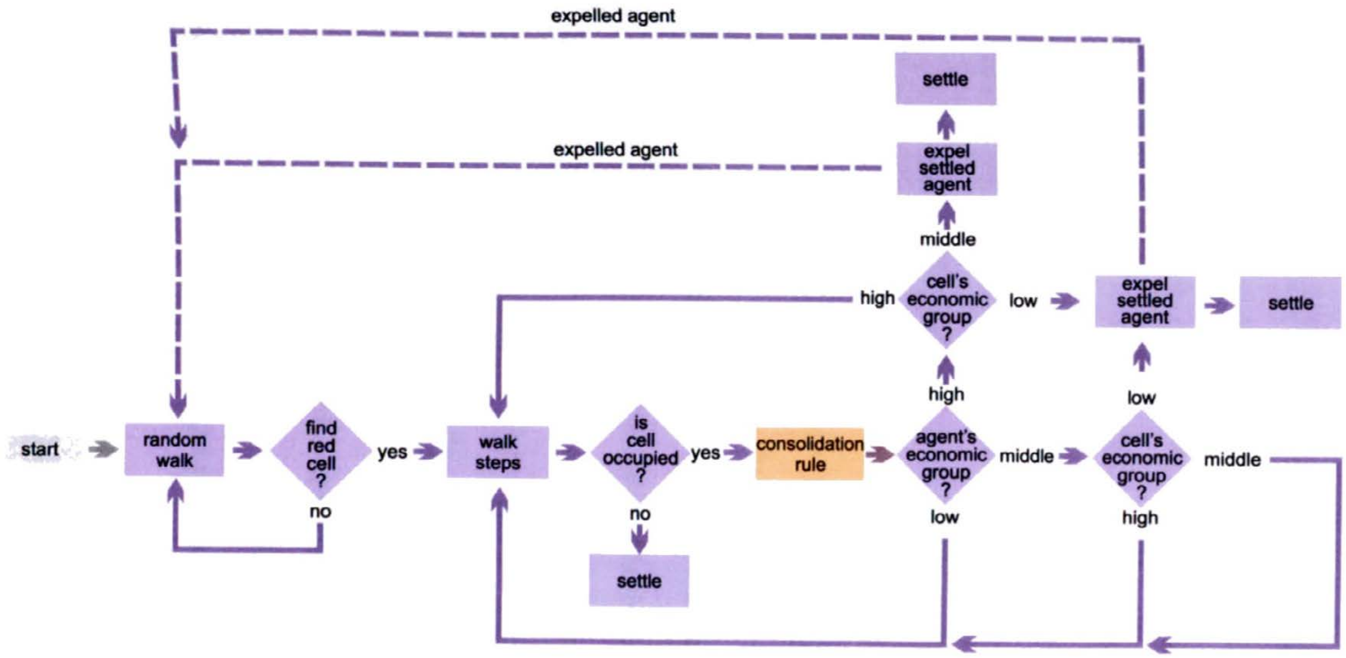
Step 2: Spontaneous Settlements consolidation

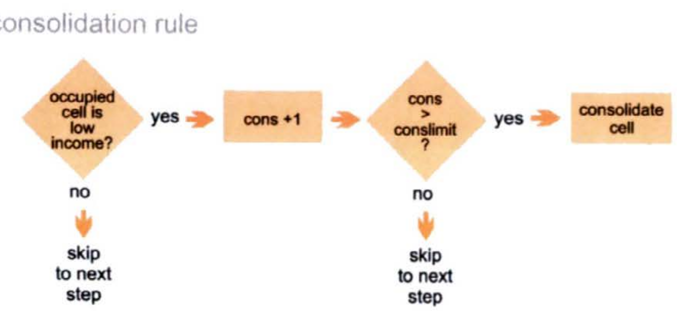
In this step a consolidation rule is added in the previous model. This rule represents a process with which informal low income settlements after some time are upgraded in quality, and they become stabilised, thus cannot be evicted.

New Variables:

- Consolidation limit: a certain threshold (moment in time) when a low income settlement cell becomes consolidated

Step 2





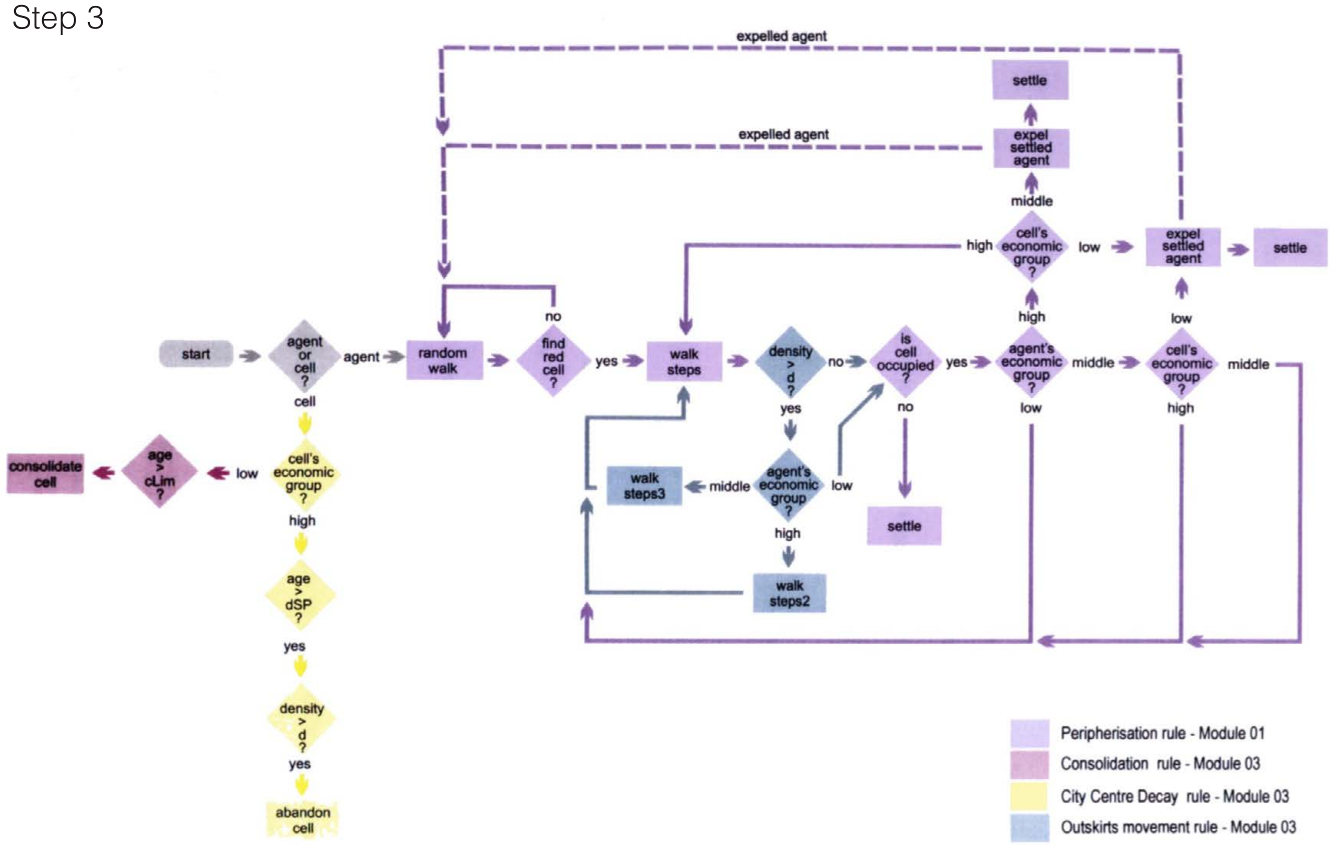
Step 3: Inner city processes

In this step the processes of gentrification (upgrade) or re-occupation and regeneration of older housing in attractive inner city districts is added. Also new behaviours are implemented, namely the movement of the upper income agents towards the suburbs, and the possibility of agents to change their economic status (either upwards or downwards). Finally new variables are added such as neighbourhood density and cell decay.

New Variables:

- Age of occupied cells
- Density of neighbourhood
- DecayStartPoint, the moment in time (depending on the age of a cell) when decay is activated.
- Decay of a cell. When decay reaches a certain level, if the cell is occupied by a higher income agent, then the agent moves towards the periphery and the cell becomes available for lower income agents

Step 3



Step 4: Spatial Constraints

The objective of this step is to introduce spatial constraints, such as water, hills etc, where agents are not allowed to settle

New Variable:
the spatial constraints of each cell

Evaluation and simulation tests

Four sets of simulation exercises were performed, each exploring one of the steps mentioned above. This allowed the exploration of a number of aspects of dynamic change and the questioning of some of the main assumptions of urban growth in Latin American cities.

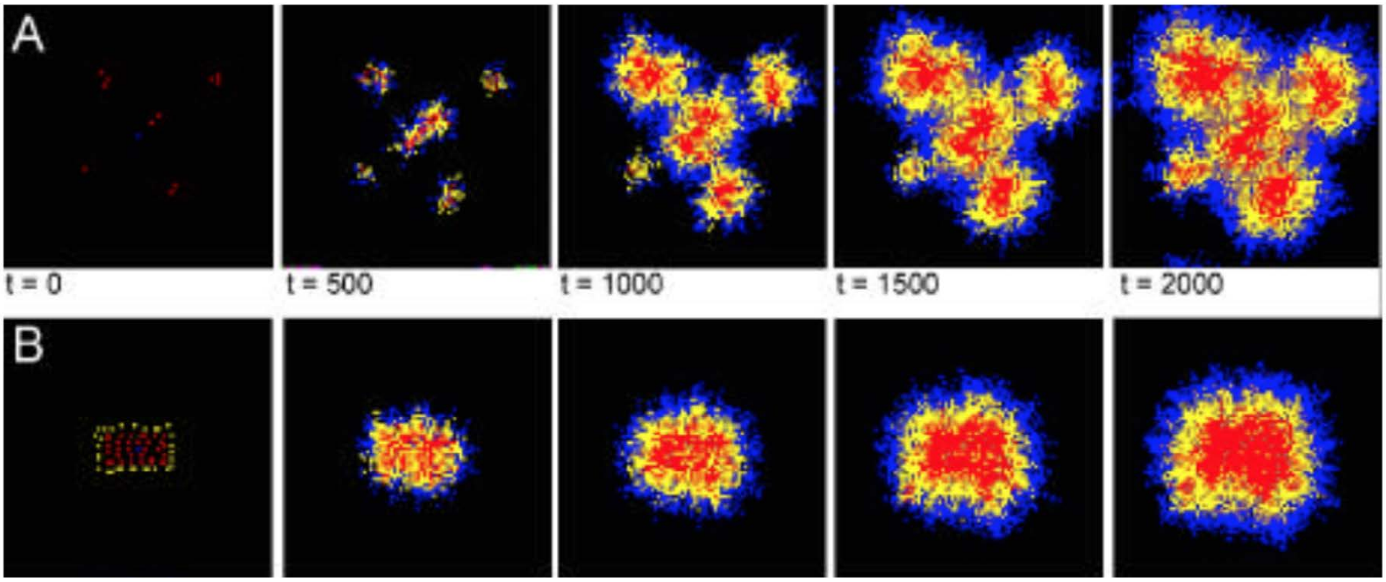
As mentioned before, the evaluation encompasses the processes of validation and verification. The verification was performed with sensitivity tests (changing the input parameters and observing the changes in the output).

The validation is performed by comparing the models output with the real world phenomena. Two main differences are observed: the first is that the reality is not as concentric as the patterns produced by the simulation model, and the second is that that high-income groups are not as concentrated in the centre of the city. This proves that there are many more dynamic processes in action than those simulated in this model.

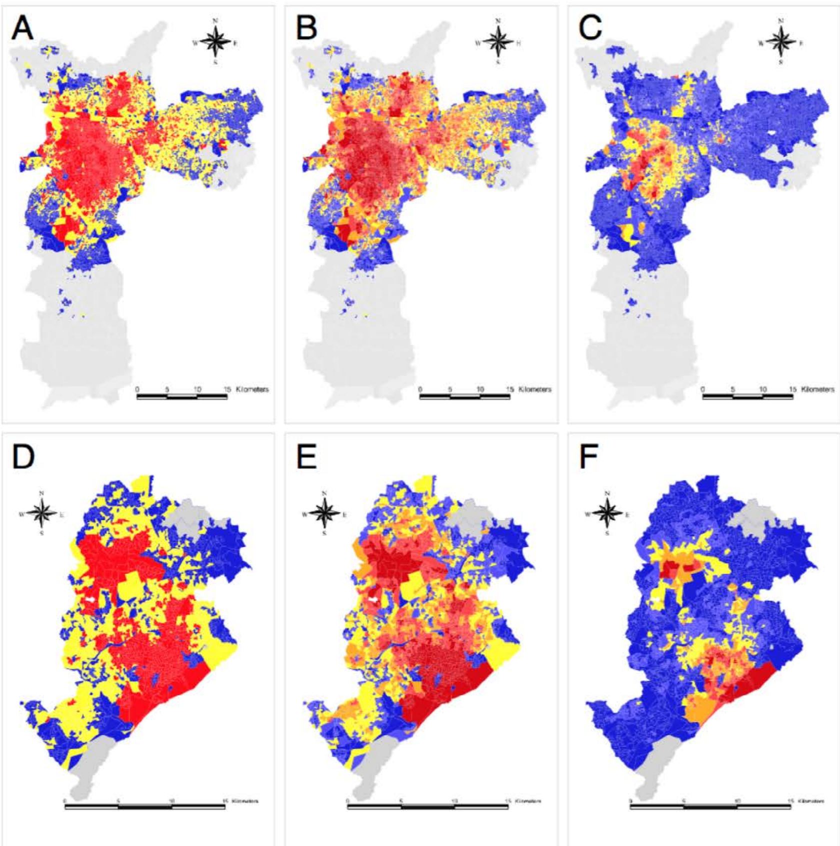
Extensions proposed

Barros finishes the description of her simulation by proposing future work for the model to be improved. Her proposals are:

- Introduction of an economic framework
- Introduction of the housing ladder concept
- Development of a matrix of change in land value
- Introduction of the effects of historical change
- Use of real data



Simulation with different initial conditions, polycentric (A) an colonial (B)



Maps of the real cities
Sao Paulo (A to C) and Belo Horizonte (D to F) showing distributions of income in the urban area. Maps A,B,D use quantile breaks and maps C,F use natural breaks

5.2 Case Study 2, Spain

How real estate agents behaviour affects urban growth: an agent-based model approach

Simulation of different roles of human actors

This model explores the major transformations brought about by the fast urbanisation in Spain, by simulating the three main actors involved in the process: urban planners, real estate agents and population.[1]

Workflow

The study of the urban dynamics provides the researchers with the underlying rules of behaviour of the three groups of actors. Those behaviours are codified into agents and tests are run. The model is still under development, as a result it has not yet been evaluated.

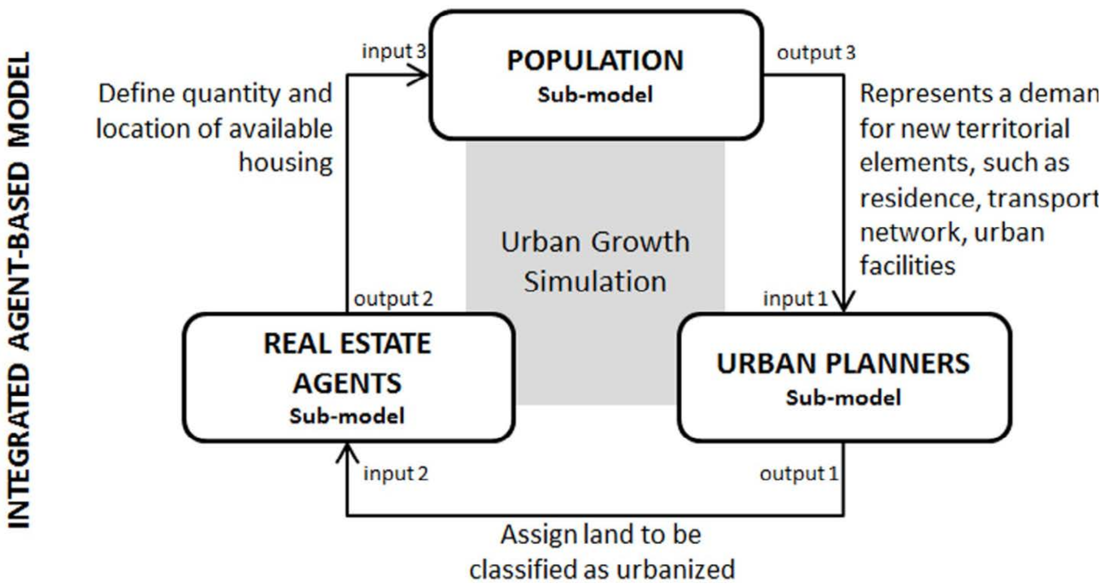
The simulation model

The model developed consists of three independent but integrated sub-models, each simulating the behaviour of one of the three actors of the urbanisation process in Spain.

The *Urban Planner*´s decision-making process consists of selecting new areas to be urbanized according to physical restrictions (i.e. protected areas, high slopes, proximity to hydrographic bodies), distance to elements of interest (i.e. roads or consolidated urban areas), and the amount of growth required to attend existing demand.

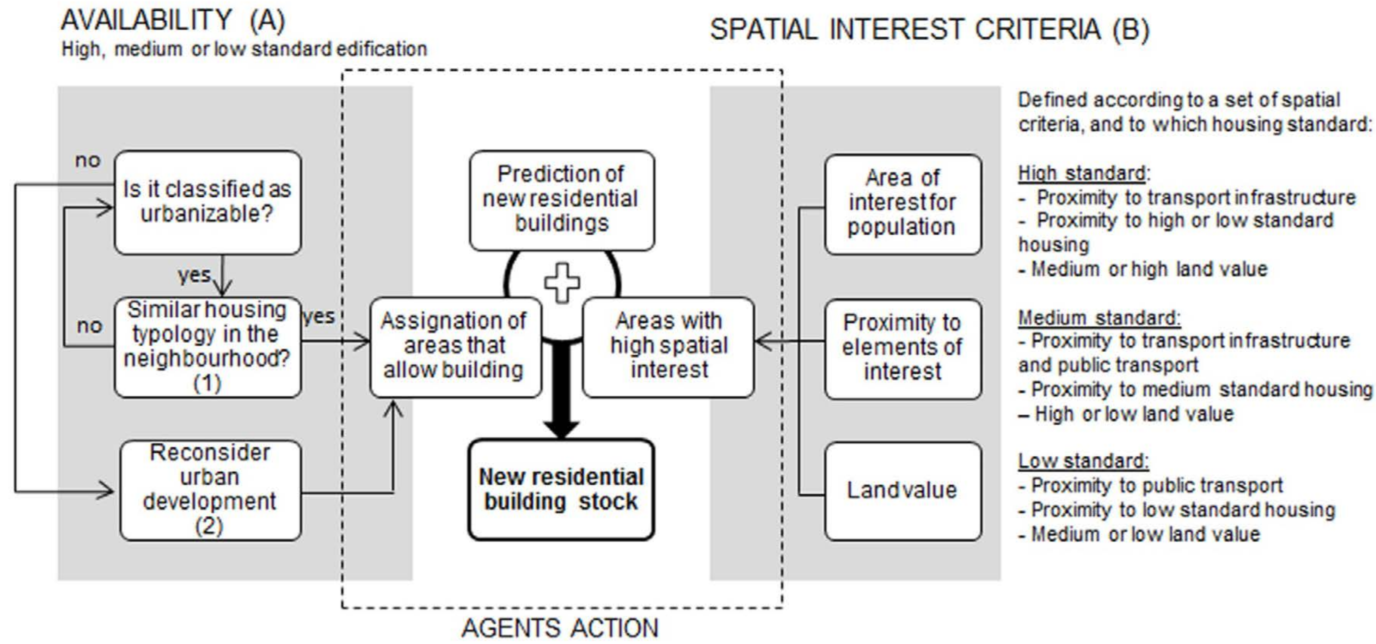
The *Real Estate agent*'s decision-making process consists of building new residential developments, deciding where to build them, how many developments must be built, their size, and their target economic group.

The *Population* agents look for the best place to move according to their economic restrictions and location preferences, such as distance to public transport network, education facilities etc.



1. CANTERGIANI Carolina, BARROS Joana, DELGADO Montserrat Gómez, 2014, «How real estate agents behavior affects urban growth: an agent-based model approach », Birkbeck University of London, UK, and University of Alcalá, Spain

Real Estate Agent’s decision process



(1) Except for the construction of high standard buildings, when there is the possibility to generate isolated settlements
(2) For example, interior development

5.3 Case Study 3, France

Modelisation and simulation of the urban dynamics: application on residential mobility

Combination of a Cellular Automata model with mobile cognitive agents

This research studies residential choices of households in the context of suburbanisation, a process of an augmenting urban sprawl from in the outskirts of the French cities. It focuses on residential mobility, in other words, the change of residence, and how spatial qualities of the urban environment influence those choices, as well as social hierarchies of various scales. For the simulation it uses a combination of a multi agent system and a cellular automata grid. The area of the study is the community of Saône in France.[1]

Workflow

The study begins with a vast research in mobility schemes observed in Europe today, how these can be quantified through time, and what their effect is on space. After that, follows a structural and dimensional analysis of the area of study. Then the simulation model is created, and different scenarios are tested.

The simulation model

1. AGBOSSOU Igor, 2007, « Modélisation et simulation multi-agents de la dynamique urbaine : application à la mobilité résidentielle », Université de Franche-Comté

For the simulation of the *city*'s spatial dynamics a *Cellular Automata* system is used. The city is seen as an aggregate of complex systems that give her temporal, spatial and functional dimensions.

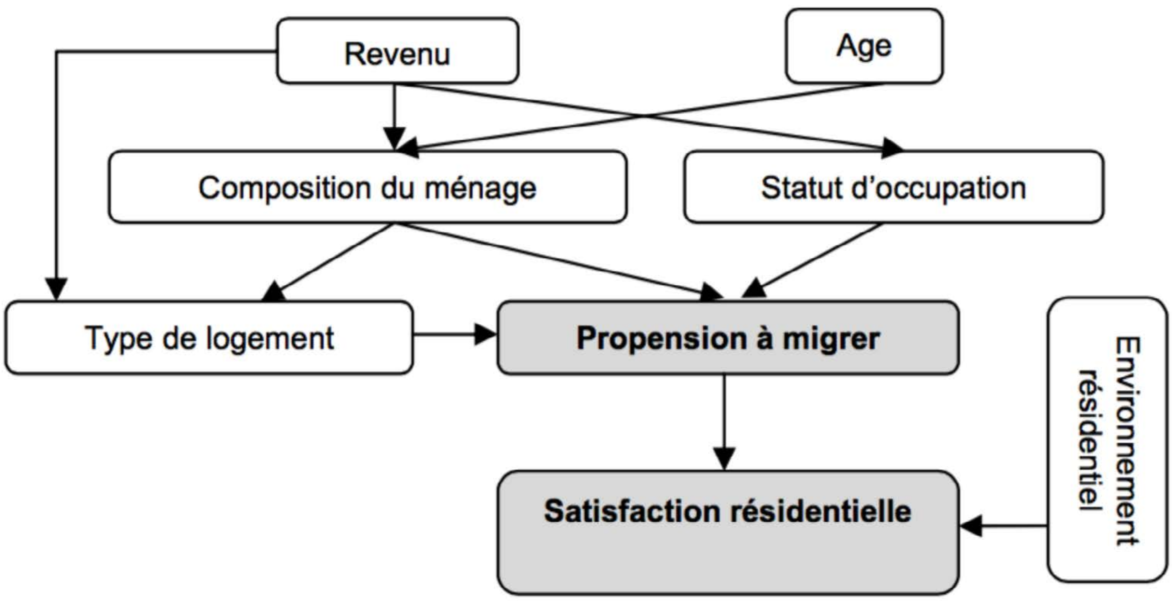
The variables of each cell are:

- the cellular network: a set of cells arranged in space connected topologically
- the state of the cell: There are three catecories of states, the dynamic states which materialise land uses that are likely to change their nature (rented apartment, bought apartment, rented house, bought house), the static states (water, earth, concrete, network, green space), and the pseudo-dynamic states (within or without a construction zone)
- the states of the neighbouring cells
- the initial configuration

The ***households*** are represented by a group of ***mobile cognitive agents***. Each agent is the type BDI (Belief, Desire, Intention) and represents one household. Its behaviour consists on deciding when to change its residence, and what new type of residence to chose.

The characteristics of each household (such as age and income) are determined by data from statistics. The dynamics of households' demographics are also taken from the same sources. New households can be formed, or old ones can disappear.

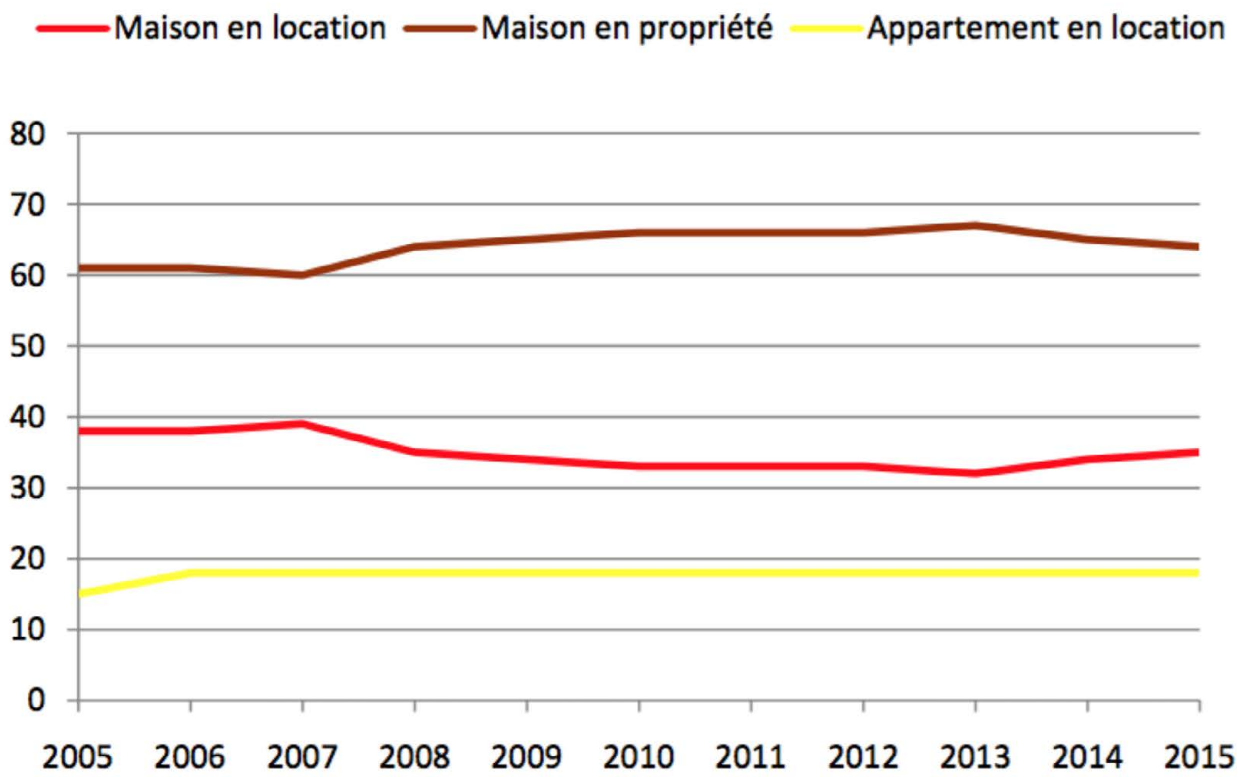
Before deciding wether to move or not, the household evaluates its current satisfaction based on the following diagram



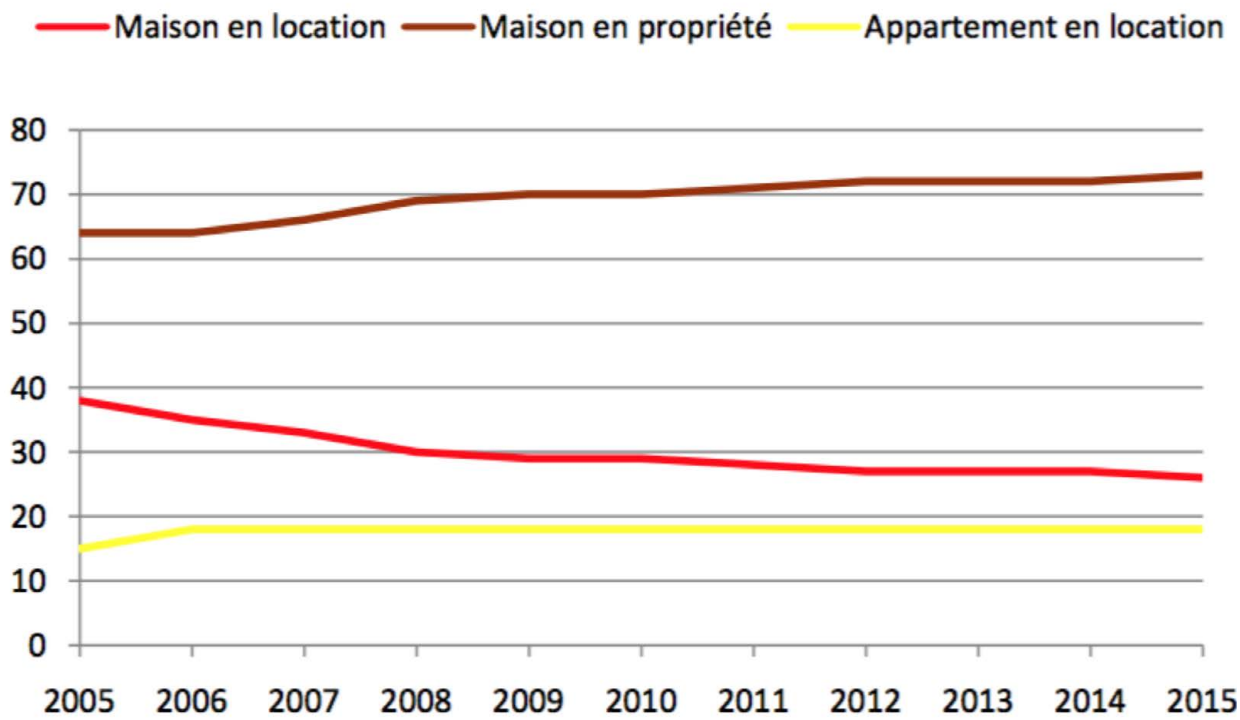
After that the household specifies its goals, and the strategy to achieve them with. The desires of a household can be: search for a house or apartment to buy or to rent. When this desire has been identified, the household can calculate its migrating need from a global function with al its variables. The final step is to decide the exact place of the new residence. Then the next iteration begins with each household re-evaluating its satisfaction.

Calibration and simulation of different scenarios

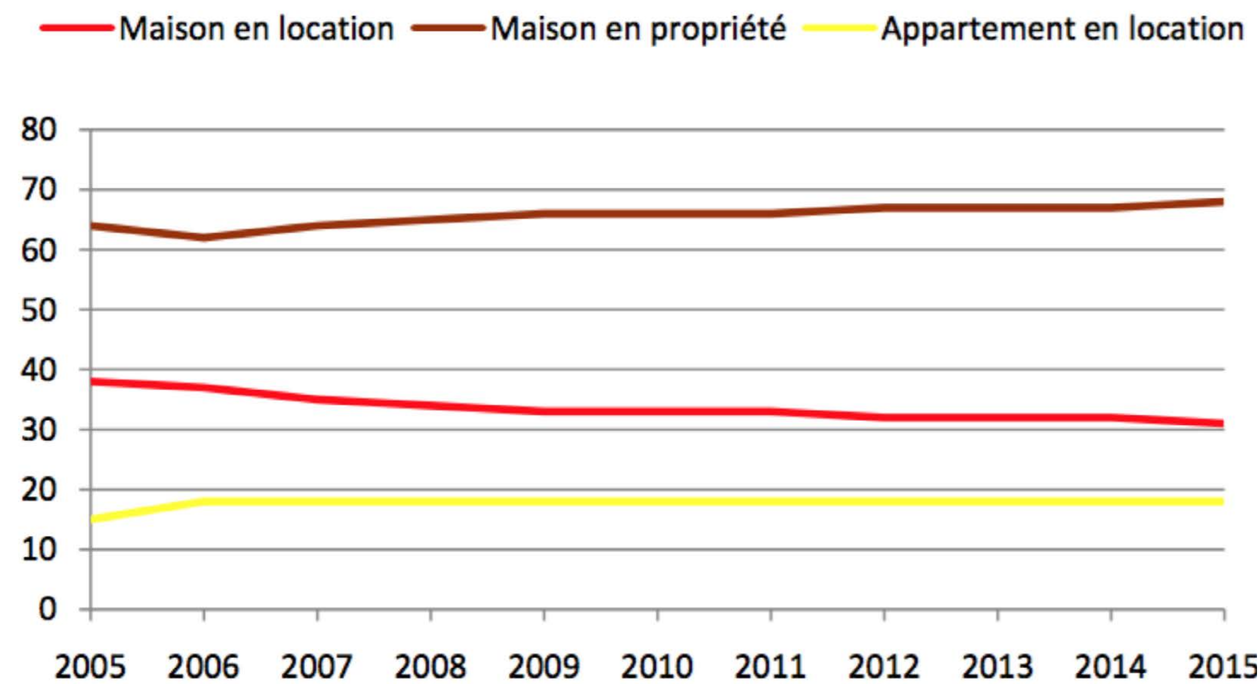
The calibration of the initial data was based on raw data acquired by a state's survey on household relocations on 2004-2005. Every simulation was run for a span of 10 years starting from 2005. Three different scenarios were simulated. The first one starts with a "pleasant" living environment for everyone within a demographic balance, the second starts with a mediocre quality of life and lower balance in the households' demographics, and the third starts with a high quality of life for the house-owners and a mediocre quality for those who rent their house.



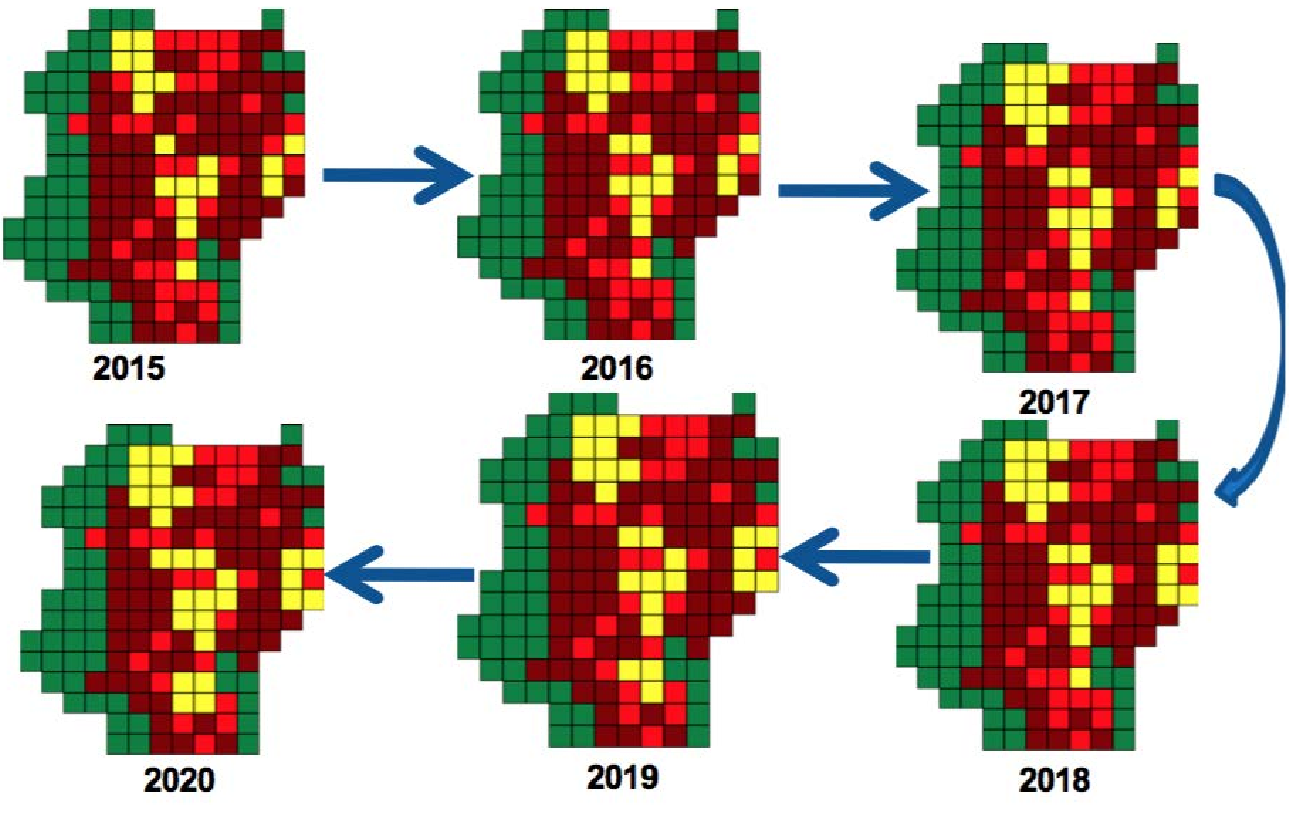
Evolution of residences in the 1st scenario ("pleasant" living environment for everyone within a demographic balance)



Evolution of residences in the 2nd scenario (mediocre quality of life and lower balance in the households' demographics)



Evolution of residences in the 3rd scenario (high quality of life for the house-owners and a mediocre quality for those who rent their house)



Spatial results of the 2nd scenario

5.4 Case Study 4, China

Spatial-temporal patterns of urban growth in Shanghai, China: monitoring, analysis, and simulation

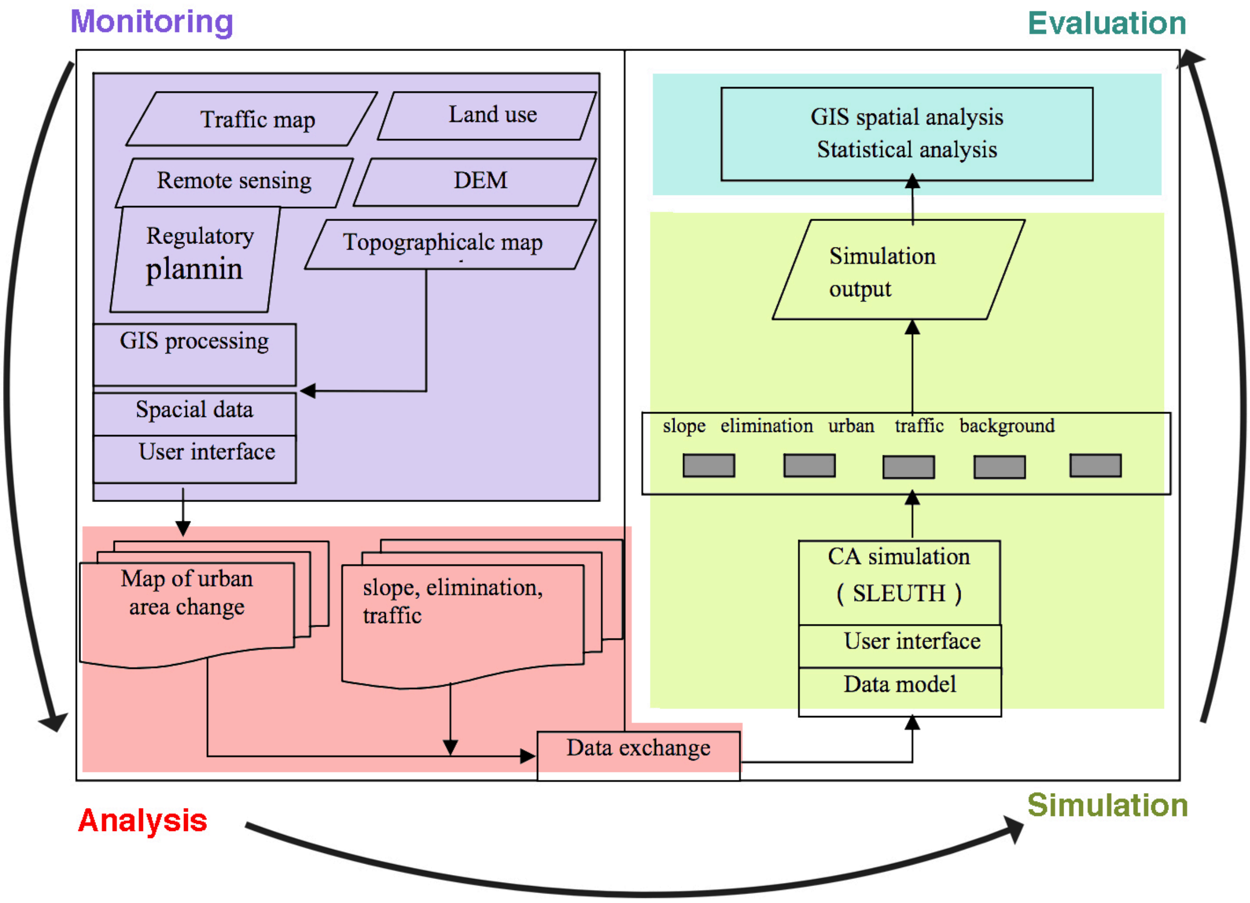
Use of computational techniques to generate the rules of the simulation module

The overall objective of this research is to investigate the integration of remote sensing, spatial metrics, and spatial-temporal models in the monitoring, analysis, and simulation of urban growth in Shanghai, China. Its aims are to analyse urban sprawl happened in Shanghai, understand how it is spatially organised and make predictions about how it might look in the future. It uses a special kind of multi-agent system called Markov–Cellular Automata.[1 2]

The difference it presents in comparison to the rest of the projects studied is that it uses monitoring and analysis computational techniques based on optical images from satellites in order to draw conclusions about the urban dynamics before forming the multi-agent simulation. What is more, it uses computational techniques to determine various characteristics of the simulation and its values throughout the process.

Workflow

The study workflow can be described in four steps: *monitoring, analysis, simulation, and evaluation*



1. ZHANG Qian, 2009, Spatial-temporal patterns of urban growth in Shanghai, China: monitoring, analysis, and simulation, Royal Institute of Technology (KTH), Architecture and the Built environment, Stockholm, Sweden

2. YIN Changeling, YU Dingquan, ZHANG Honghui, YOU Shengjing, CHEN Guanghui, 2004 « Simulation of urban growth using a cellular automata-based model in a developing nation's region », Changsha, China

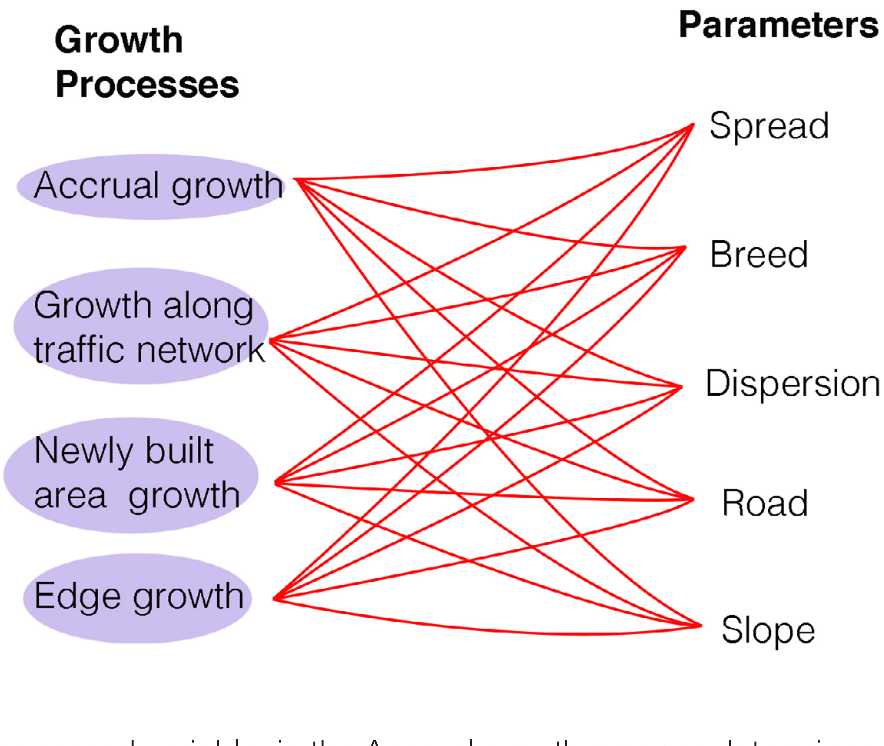
It begins with techniques of remote sensing as a tool to monitor urban dynamics using optical images from satellites from different years with the help of spatial metrics. Using optical data, this part is mainly focused on monitoring urban impervious surface sprawl. After that he introduces a Markov Cellular Automata (CA) model for the simulation, with which he attempts to represent the complexity of urban development affected both by humans and nature, while simplifying those behaviours in the format of simple rules. He then uses computational techniques to calibrate the parameters used, based on the analysis made. Finally he simulates several scenarios and draws conclusions.

Monitoring and analysis before simulation

The conceptual model used for this purpose assumes that land cover in urban areas is a combination of three components: vegetation, impervious surface, and soil. The transformation from vegetation (agriculture, forest, etc) to impervious surface (residential, industrial, commercial land, etc.) is the dominant trajectory of urban growth. Therefore by detecting the changes of the materials of the ground throughout time (six land-cover types, included water body, transportation, industrial, infrastructural, commercial land, and greenbelt were extracted from the satellite images), it comes to very pertinent conclusions about the urban growth of the area.

The simulation model

A grid is applied to the images introduced by the satellites, by considering each pixel as one cell. The interactions between the cells are described in four processes: accrual growth, newly built area growth, edge growth, and growth along traffic network. Each process has five variables: spread, breed, dispersion, road, slope. So in total there are 20 variables that depend on the position of each cell and its neighbours.

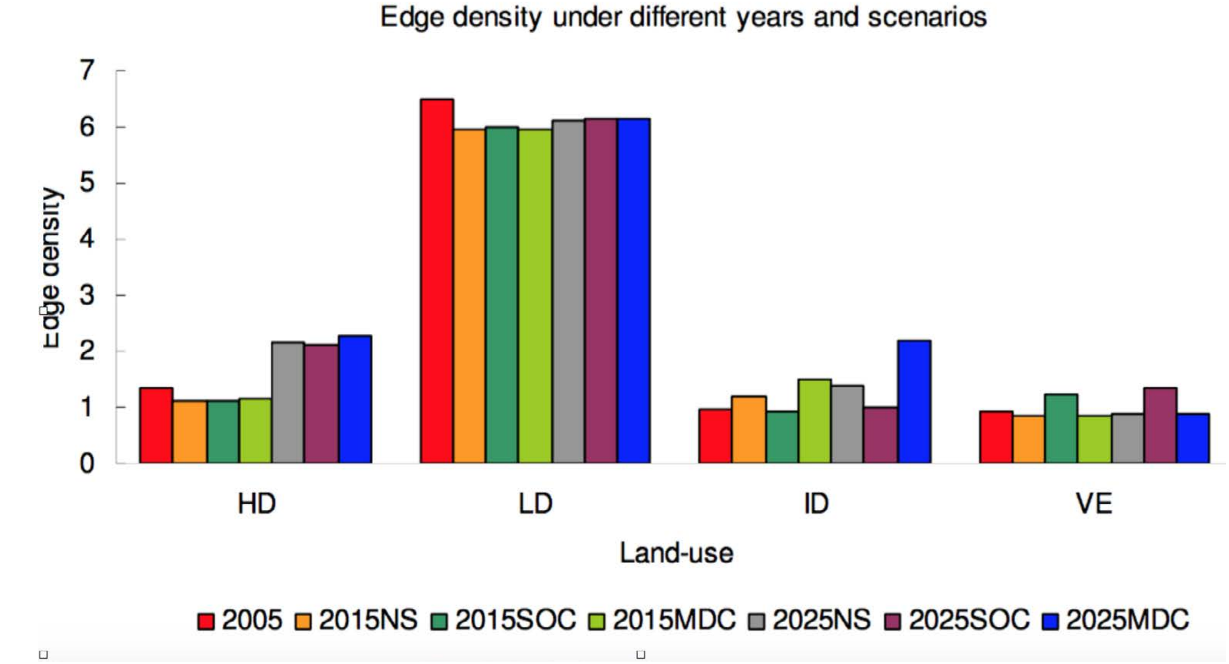


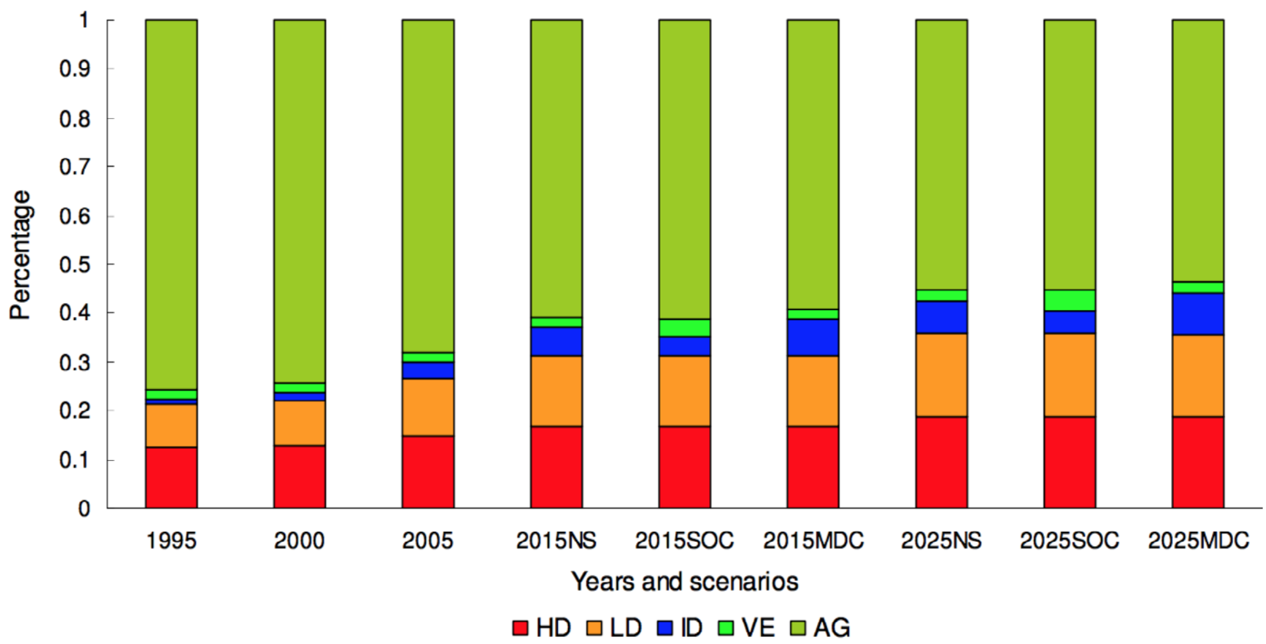
For example, the spread variable, in the Accrual growth process determines the time a cell will be picked to become an urban unit, while the same variable in the Edge growth process determines the possibility to urbanise the nearby cells of a random already urbanised cell. The dispersion variable in the growth along traffic network process determines the distance from the closest road unit and so on. Only the slope variable has the same meaning for all processes, as the higher it is, the less likely a cell will be urbanised. The model is not affected separately, but synthetically by all the variables and all the processes. However among the five variables, spread and road weigh most, which means that the urban areas expand from the centre to the outskirts mostly along the roads. On the other hand, the low value of dispersion shows it is not necessary that urban units form automatically in low density area.

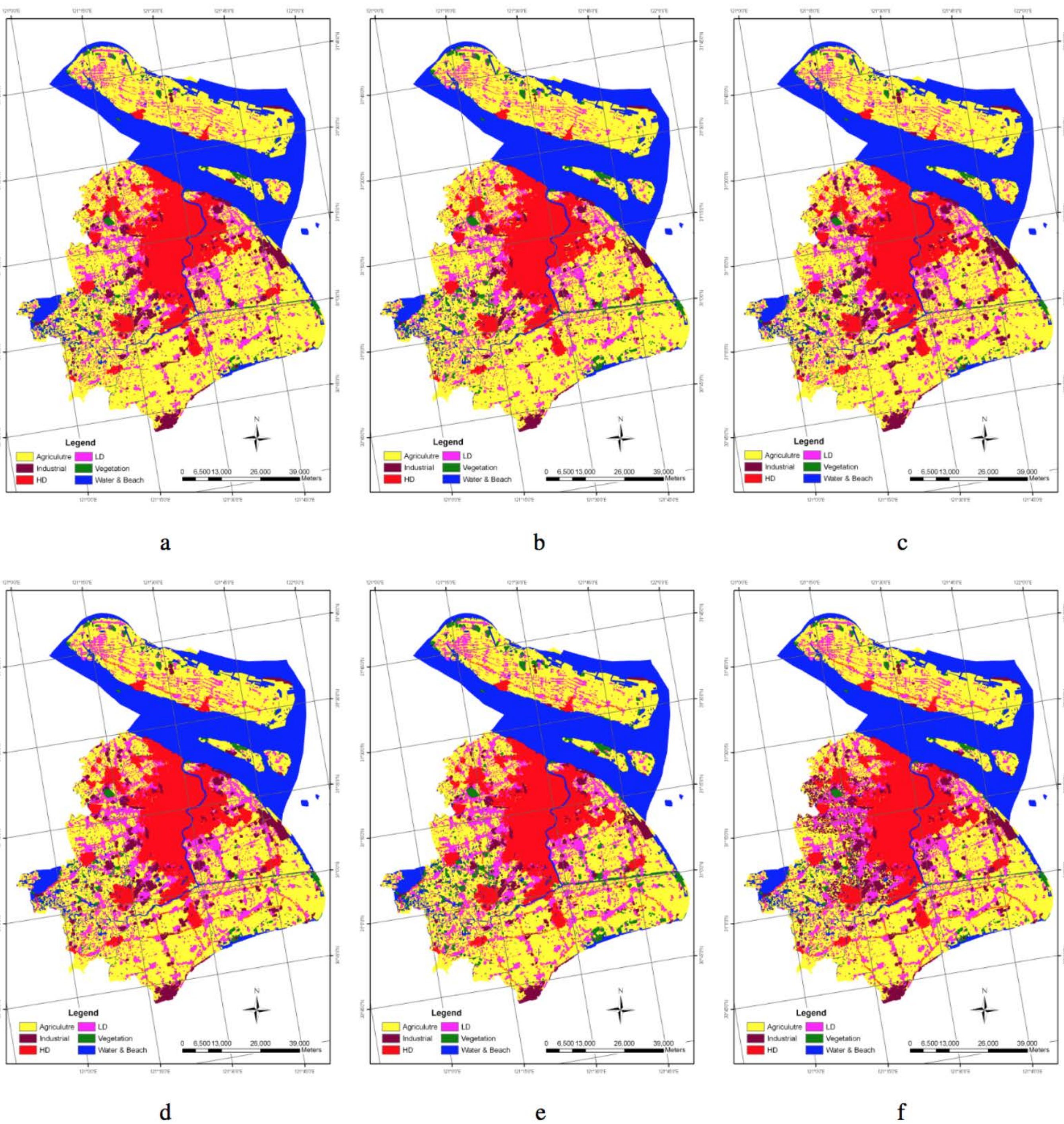
Calibration, simulation of different scenarios

The calibration of the variables (determination of the initial values) is done with the use of historical data. There are 3 stages in calibration, coarse calibration, exact calibration and final calibration, and each stage includes a large number of Monte Carlo iterations. In each step the model compares the training results with real data and evaluates their matching degree. After calibration, the model adjusts the obtained growth coefficients with a self-modification to make the process to be closer to real situation.

Three scenarios were simulated based on existing urban development schemes. Conclusions were drawn concerning which uses are primed in each scenario, which tendencies will appear, and predictions were made about the percentage of the total built-up areas, the edge density and other variables in each scenario.





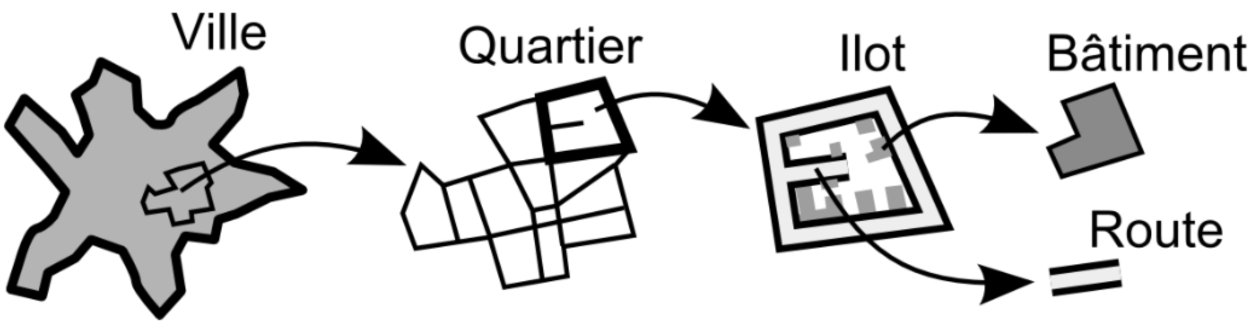


Urban Simulation Map Series in 2015 and in 2025 under three different scenarios

5.5 Case Study 5, France

GeOpenSim

Use of a hierarchy scale of agents from the building to the neighbourhood



...to be continued...

Conclusion

The study of those examples gave great insight on the practical side of the use of multi-agent systems for urban design. It helped me understand how a simulation is developed, what is the process, what tools can be used, what decisions have to be made, how variables and behaviours are determined, and how the model can be evaluated.

The first observation one makes by going through those examples, is how heterogeneous are the variables, the agents and the behaviours created. Each simulation has a specific goal, one particular area that it applies to, and it covers one time span. Consequently it is very different from the other ones. This proves that multi-agent systems simulations are not a global solution. In the contrary, each place and each question requires its own unique approach which has always got to be coupled with very extensive painstaking study of the site and the goals.

Another remark concerns the multi-disciplinarily of the process. The creation of a pertinent simulation of the urban environment requires the cooperation of many researchers coming from different fields along with the urbanist. The theoretical and technical knowledge required is very difficult to be covered by one person. What is more, the process becomes more meaningful when more data from various sources are added in all the stages of the process. It can be photos from satellites, statistics, socio-economical studies or any type of big data. When combined with the agents' bottom up approach, it can lead to really fruitful outcomes.

The evaluation of the process and of its results is a particularly difficult task, as emergent phenomena transcend our logic. That is why the outcome of such studies must be analysed very carefully before being taken into consideration, and more reliable techniques of evaluation have to be developed.

What is more, a necessary comment concerns the dimensions of the simulations I have studied. So far, they all seem to take into consideration 3 dimensions: two spatial dimensions and time. However, cities have three spatial dimensions. The dimension of height is of paramount importance, and it should also be implemented in these studies.

Finally, I would like to pose a question regarding the complexity of the urban environment. Inspired by natural systems, such as a colony of ants, that create complex structures from simple rules, we hope to explain the urban environment by finding the simple rules that organise it into a complex whole. However, as we have seen, emergent systems exhibiting self-organisation have multiple hierarchies that vary from the simple elements, to various levels of intermediate complexity, until the complex whole. The fact that in the colony of ants, the rules that create the whole happen to be within the realm of simplicity, does not mean that for the human cities the same thing is true. I would argue that the rules we are looking for, even though they are in a lower hierarchy that the complex whole, they can still be within the realm of complexity, and have other simpler rules underneath them and so on. In that case, in order to reveal those rules, we would need a process of addressing complexity rather than simplicity. For example we could need computational techniques in order to arrive at the rules that can then drive the simulation of the urban environment. We cannot know how many levels of the hierarchy of complexity are, until we manage to get to the bottom, to the simple elements, or at least to elements simple enough to be addressed with the cognitive power of our brains.

For that reason, I believe that the 4th case study on China introduces a very interesting concept: it uses computational techniques for studying the site in order to develop the rules for the simulation. I believe that there lies a very promising field of study.

The role of the architect

The traditional paradigm of architectural practice seems to have reached its limits as to what can be achieved, and it can no longer be applied to the contemporary networked, interconnected and constantly changing society, whose complexity is exponentially intensified, whose demands are not stable nor can be traditionally defined and where the lines between physical and digital are increasingly blurring.

As a result, the role of the architect is changing and the difference between architecture and other disciplines is being erased. Rather than designing the final object/building/proposal, designers are beginning to be more interested in conceiving the processes that will make emerge a range of solutions to the problems posed via the use of algorithms and programming. The role of the architect of tomorrow is to be able to trigger these processes that will allow him to conceive and pursue the unknown.

The nature of authorship and responsibility on generative design differs fundamentally from the traditional meaning of the term. The encoding of architectural intent within abstract processes does not weaken it, quite the contrary. The change form the design of the form, to the organisation of the process that generates it gives the designer much more potential without however disconnecting him from the final product.

The use of multi-agent systems has a great impact on architectural practice. However the essence of the architectural synthesis in its very core, remains unaltered. New responsibilities and creational freedoms appear, taking the place of the ones that are lost. The process remains always dictated by the architect, even though in a different level. The process might not be controllable, but the initial parametrisation, as well as the final result are entirely subject to the decisions of the architect. How the parameters must be chosen, where and which arbitrary decisions should be taken, how much randomness, or flexibility should be given to each system, when the dynamical process of its emergence should be frozen in time (if it should) to be used for the generation of architecture. All of these, as well as the criticism of the final result, and many more, are architectural decisions based on criteria that architects have always been using in the process of synthesis. As such, they are prone to be questioned and to be subject to criticism. But they also allow the necessary freedom for the integration of artistic and aesthetic concerns, ethical, philosophical and ideological positions. Therefore, the underlying qualities of the conception with its traditional meaning remain entirely in the design that makes use of MAS. The only difference is that the architect is now able to exploit the computational power of the computer along with his own brain.

What is more, as mentioned, emergence can be a very controversial phenomenon. An ant colony, everyday city traffic and a tornado are all emergent phenomena. However impressive they might be, undoubtedly their usefulness for people is not the same. How can the positive or negative effects of emergence be recognised in less obvious cases, such as emergent architectural design? When the architectural product is always impressive and complex, how can we tell apart if we've just created the architectural analogue of a tornado, or that of the ant colony? In each synthesis architects must be able to determine that the emergent system in use exhibits behaviour with "positive" results. Which parameters, criteria and decisions determine this? Of course this cannot be predicted from the multi-agent system parameters, because of the very nature of emergence, whose unpredictability is part of its seduction. Therefore, what architects can do is learn to criticise this result. Learn to tell apart the emergent traffic, from the emergent smooth self-organised circulation. Sometimes this might be obvious, and some other not. Thus here the architectural synthesis, where the architects acts according to his inspiration, beliefs, intuition, and imagination comes once again to the foreground.

“But I would not like to push my endeavour beyond a certain limit: I would get cities too realistic to be true”

Italo Calvino

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