Emergence in Urban Environments

Agent-based Simulation of Environment Reconfiguration

Dissertation Thesis

By

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Affirmation

I, Peter Buš, hereby confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstrakt (CZ)

Paradigma emergence, o kterém hovoříme v souvislostech s jinými vědními obory (umělá inteligence, kybernetika, evoluční biologie, teorie systémů), se objevuje i v architektonické a urbanistické tvorbě jako základ postupů a metod tvorby při vytváření konceptu nebo vzniku architektonických a urbanistických forem, při pozorování a simulacích chování urbánního prostředí a ověřování jeho charakteristik v různých aplikačních scénářů a podmínkách prostředí s využitím digitálních informačních technologií. Jev emergence, kdy komplexní systém spontánně vzniká jednoduchými interakcemi svých vnitřních složek nižšího stupně, je možné aplikovat v oblasti architektury a urbanismu v tzv. konceptu bottom-up strategií vývoje prostředí, kde na základě interních dohod mezi obyvateli-participanty a /nebo budoucími uživateli a interakcemi složek v prostředí vzniká komplexní sofistikovaná městská struktura dle požadavků a pravidel stanovených ve výchozích vstupních podmínkách. Tato strategie vývoje městské urbanistické struktury může více zohledňovat současné nároky a požadavky obyvatel na své prostředí v dnešní proměnlivé „tekuté“ post-digitální době v porovnání se standardním a obvyklým konvenčním dlouhodobým plánováním měst (top-down strategie). Tento nelineární jev vývoje prostředí je možné zkoumat z různých perspektiv a hledisek a popisování tohoto jevu v kontextu architektury a urbanizmu je v současnosti stálým objektem zájmu vědeckého bádání s jistým deficitem, který se architekti a urbanisté ve spolupráci i s jinými profesemi stále snaží doplňovat. Jednou z oblastí k pochopení tohoto jevu v kontextu architektonické a urbanistické tvorby je využívání informačních technologií a sofistikovaných metod simulací jevu emergence pomocí reprezentací agentově orientovaného modelování, celulárních automatů, fraktálů nebo difuzně-reakčních modelů pomocí užití iteračních protokolů ve výpočetních metodách.

Město jako komplexní fenomén nebo objekt se vztahy (v objektově orientované ontologii je město objekt, z filozofického hlediska a Teorie asambláže dle Manuela DeLandy je město definované jako tzv. emergentní asambláž) a souhrn událostí, jeho nepředvídatelné komunikační toky (datové a telekomunikační sítě a jejich přístupové body), distribuce energií, zboží, materiálů, pohyb uživatelů a jejich prostorová interakce s prostředím vytváří dnes už bez pochyb nové podmínky a nároky na jeho prostorové uspořádání, infrastrukturu, na jeho organický růst a zahušťování. Urbánní prostor je souhrnem komplexních dynamických procesů, které se spolupodílí na jeho konfiguraci a které se vzájemně ovlivňují. Je to živá strukturální substance s vlastním metabolismem. Město tak vykazuje emergentní vlastnosti a obsahuje vícevrstvé scénáře vlastního vývinu a rekonfigurace v čase. Tuto vrstevnatost není možné obsáhnout jediným modelem lineárního predikovaného návrhu (top-down strategie). Architekti ale mohou tato specifika obsáhnout v predikci nebo kvalitativním popisu vývoje prostředí s

vícevrstvým výsledkem, která mohou zohledňovat vybrané požadavky a nároky v nižším stupni (bottom-up strategie). Simulační modely měst, které architekti mohou využívat jako analytické nástroje pro svůj návrh nebo popisování chování složek urbánního prostředí, slouží právě k pochopení a porozumění hlubšího fungování města jako dynamického živého systému, jeho vnitřních uspořádání, hierarchie a vztahů mezi jeho jednotlivými složkami, které spoluvytvářejí komplexní městský celek. Toto chování je možné měřit, modelovat, analyzovat a vyhodnocovat v různém stupni komplexity.

Cílem tohoto partikulárního výzkumu v disertační práci je modelová prostorová simulace vývoje prostředí, která bude na základě vybraných požadavků z nižšího stupně simulovat jeho vývoj, růst, zahušťování a rekonfiguraci prostředí a jeho kvalitativní popis. Tato simulační platforma by sloužila jako rozhodovací nástroj pro architekty při aplikacích několika možných scénářů prostorového vývoje prostředí jako podklad pro územní rozhodování ve fázi návrhu. Jádrem zájmu tohoto výzkumu je definice prostorového uspořádání urbanistické struktury na základě bottom-up požadavků nižšího stupně a to konkrétně dostupové vzdálenosti do míst zájmů ve vybrané oblasti, odstupových vzdáleností urbanistických prvků a simulování vhodné zrnitosti a hustoty urbanistické struktury – rovnoměrné rozptýlení urbánních aktivit a objemů v struktuře a tím definování vhodného diverzifikovaného prostředí s různou mírou hustoty prostorového uspořádání, tj. simulace prostorových vztahů a definování kvalitativních potenciálů v již existujícím vybraném prostředí, případně definování jeho nedostatků.

Emergentní chování struktur v geometrii je možné simulovat pomocí pokročilých skriptových technik v oblasti agentově-orientovaných systémů a iteračních protokolů, v tomto případě v jazyce Processing, zohledňujíc prostorové nároky a pravidla v nižším stupni. Vizualizací těchto prostorových vztahů a pravidel je možné obsáhnout složitější komplexní strukturální a prostorovou konfiguraci městského prostředí. Výsledkem výzkumu je tak softwarový simulační nástroj, se kterým bude možné pracovat i v prostředí internetu. Tento simulační model může sloužit i jako generativní podkladová platforma pro návrh městské struktury dle jednoduchých pravidel v nižším stupni, která ve výsledku simuluje složitější komplexní městský celek.

Dizertační práce dále zahrnuje filosofická, teoretická a modelová strategická východiska v oblasti jevu emergence v architektuře a urbanismu a jejích významů pro architektonickou tvorbu a urbanismus v současném post-digitálním architektonickém diskursu.

Abstract

The paradigm of emergence that we are dealing with within the framework of several scientific disciplines (e.g. artificial intelligence, cybernetics, evolutionary biology, systems theory, cognitive sciences and others), also appears in architectural and urban context as an essence of design processes and methods of production or development of architectural and urban forms. This concept can be applied in observations and simulations of the unpredictable behaviour of the urban environment as well as validation of its characteristics in various simulated environmental scenarios and conditions by means of using information technology. It is a spontaneous creation of an organized whole out of a disordered collection of interacting parts. This phenomenon is very well legible in the field of architecture and urbanism as so called “bottom-up” concept of environmental development, where city urban structure emerges from low-level rules and negotiations between local participants to a higher-level sophisticated environment. This bottom-up strategy of city urban development should promote better understanding of inhabitants' needs or demands in our dynamic post-digital era in comparison with standard long-term urban planning (top-down strategy). This phenomenon with its own characteristics based on nonlinearity and uncertainty can be examined from different perspectives and points of view. One of them is the qualitative description in the context of architecture and urban design, which is currently an object of the interest of scientific research with certain deficiency that architects and urban planners are still trying to complement in collaboration with other professions. One of the area is dealing with computer based models and sophisticated simulation techniques in order to obtain better understanding of this phenomenon within artificial behaviour of the city and exploring its dynamic properties that can lead to certain predictions in its further growth or thickening. Typical formal simplified techniques and methods for modelling emergent behaviour are using appropriate agent-based models, fractals or cellular automata.

A city as a complex phenomenon and an entirety of events (according to object-oriented ontology a city is defined as an object with relations or an assemblage), its communication flows (information and data telecommunication networks and their access points), energy, goods and materials distribution and movement of users themselves and their spatial interactions with the environment nowadays no doubt has been creating new conditions and demands on the city's spatial organization, infrastructure, its growth and its thickening. Urban space today is an aggregate of complex dynamic processes that contribute to its configuration and mutually influence each other. Thus, urban environment shows emergent qualities and contains multi-layer scenarios of its own development and reconfiguration in time. This stratification is impossible to be comprehended by a linear model of a single predicted concept

(top-down strategy). Architects and urban planners may, however, cover these specifics by a prediction of space development with a multi-layer result that would take into account the requirements of users at the lower level (bottom-up strategy).

Architects can use simulation models of cities as analytical tools for their designs and decisions in order to make relevant and proper qualitative description of behaviour of internal components of urban environment. Such a model would be acceptable to serve as a platform for better understanding of wider characteristics of a city as a living dynamic system in terms of its internal alignment, relationships, hierarchy and connections between its particular constituent parts which participate in the city as a complex whole.

The aim of this particular research is therefore a spatial simulation of city environment development which would simulate its growth and reconfiguration based on demands and requirements on a lower level and its qualitative description. This spatial simulation would serve as a decision-making tool for architects when applying various spatial scenarios of environment configurations and thereby it would create a basis for spatial planning decisions in subsequent stages of zoning processes, mainly in the early design stages. The core of the interest of this research is definition of the spatial alignment of the urban pattern based on bottom-up requirements. In particular, this embodies approach walkable distances in the places of interests in the selected urban environment, the stand-off distances between the urban elements, and the definition of appropriate graininess of the urban fabric and its density. In that manner it is possible to specify an equable spread of urban activities and volumes in the structure and therefore define a relevant diversity of the environment with different measure of the densities of the spatial alignment. As such, the observer is allowed to simulate the spatial relations and explore its qualitative potentials in already existing environment, eventually define its inadequacies.

Emergent behaviour of structures in geometry can be visualised by using advanced scripting techniques in the field of agent-oriented systems and iterative protocols, in this case in the Processing language taking into account spatial demands and rules in the lower-level. We can encompass more complex structural and spatial configuration of the urban environment and better understand its behaviour by visualising these spatial relations and rules. The final result of this research shall be a simulation geometrical model of spatial environment reconfiguration that could be serviceable also in the internet environment. This result implemented in a software tool can also serve as a design platform of urban structure based on simple rules of a lower level that would, however, consequently simulate the complex urban entirety.

The dissertation thesis contains also computational strategic base in terms of emergence phenomenon simulation models in order to define its significance for architectural and urban design within the framework of contemporary post-digital architectural discourse. The thesis summarizes selected philosophical and theoretical approaches of emergence as well.

I. Introduction

1. Preface

1.1 Motivation

The phenomenon of emergence which many scientific, technical, social or natural disciplines deal with as well as other fields (visual and performative arts, religion, gaming industry, etc.) and which is explored and interpreted from different points of view has been implemented today into the field of architecture and urbanism with advent of advanced modelling techniques by means of using information technologies. The tools and methods that architects used to operate in the past are not competent in the contemporary post-digital era because it is not possible to reflect and articulate current dynamic uncertainty in architecture in terms of original design approaches and tools that are becoming obsolete nowadays. Architecture of the current time period operates with additional and broader categories and bases which interpret the reality (existing reality itself and virtual as well, invisible data relations, data flows, hidden information, information technology operating with big data approach) and claims extensive interdisciplinary knowledge and the interconnections with other scientific disciplines in order to enhance its expressional and technological potentials. For the time being the field of emergence phenomenon in architecture and urbanism has still not been explored enough. The contemporary research aims to elucidate this phenomenon as well as to discover and describe its characteristics which can yield new creative stimuli within its matter and bases into the field of architecture. This dissertation work would like to attempt to enter at least partial input of a new knowledge into this wide field of emergence paradigm and information architecture.

1.1.1 The Emergence Phenomenon

The whole world and its processes that constitute the world itself and which we know in a common way are described and interpreted from several perspectives – from philosophical, religious, artistic to rigorously scientific, when each field has its legitimate entitlement for its own descriptive way of the reality itself, phenomenon within the reality or outside it or even virtuality. One of them is a world description by a phenomenon which deals with all these fields. This phenomenon is called *emergence* and it is explored by its own position in every of these disciplines and in a peculiar way. This interdisciplinary approach leads to the knowledge that allows us to deal with it in the field of architecture and urbanism as a design strategy approach in terms of observation, simulation or creation of the concept of the architectural an urban environments or predicting its development in a variety of scenarios or directly in materialisation or fabrication of resulting designed architectural and urban structure or object.

The concept of that kind of insight regarding the reality where all living and non-living beings (Fig. 1) are involved in and that we characterise as emergent, has been described besides the other scientists by John Stuart Mill (1843) and Julian Huxley (1947) [19]. Despite the fact that this way of understanding the reality and the world has occurred in philosophy since the era of Aristotle who described this concept in his Metaphysics, the term *„emergent"* was firstly used by philosopher G.H. Lewes (1875) in the work *Problems of Life and Mind* [19]. The current well known definition of the term emergence was declared by economist Jeffrey Goldstein (1999). There are many definitions of emergence provided by several scientists in the past and also in present, who operate with this phenomenon in terms of their own scientific work in an appropriate field. The term is narrowly implemented in the field of system theory, it occurs in economy, it is handled by several natural sciences, cybernetics, artificial intelligence, religion, visual and literary arts, cognitive sciences and, last but not least, in the field of architecture and urbanism as well.

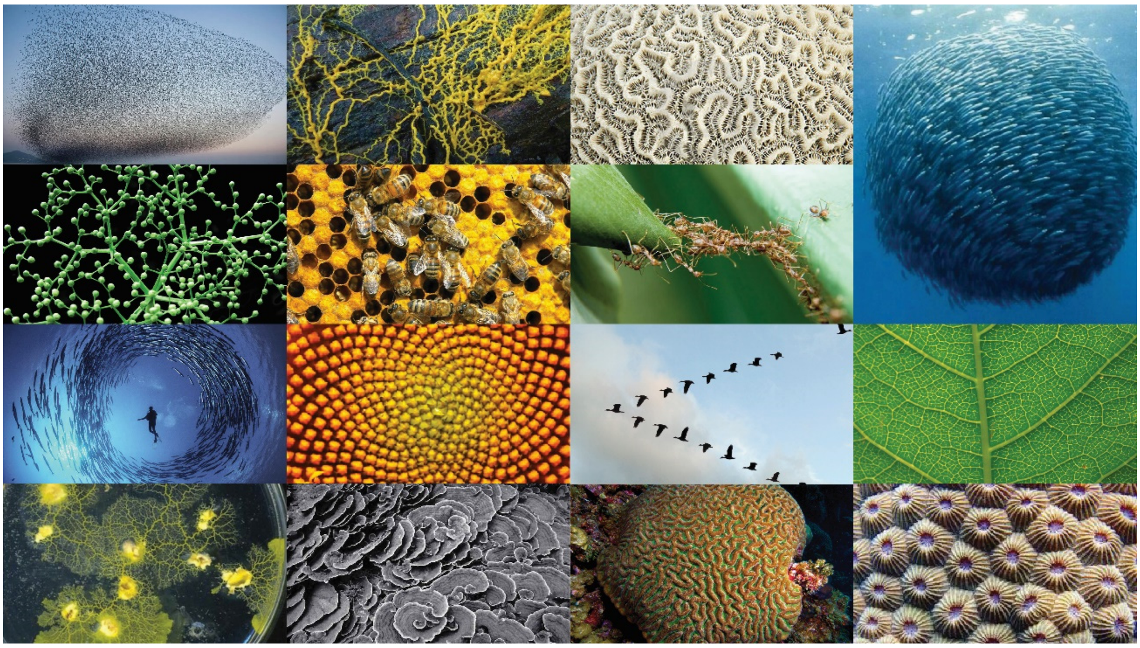


Fig. 1 Emergent patterns in nature. A lot of species forms a different low-level rules complex wholes. The simple logic of these processes yields unpredictable formations. Is it possible to define geometric and spatial behavior of these patterns by means of information technologies? Accessed April 14 2015 [52].

1.1.2. Definition of Emergence

In philosophy, systems theory, sciences and arts *emergence* is a way how complex systems and complex structures, patterns, orders or regularities spontaneously arise from the simple interactions of its components in a lower level (Johnson, 2001). The term *emergence* comes from the Latin word *emergere*, which means *arise, emerge, and appear*. In the simplified definition emergence is a phenomenon in which complex organized whole or a system emerges spontaneously based on interaction of its internal components which do not show at their level complex behaviour. These interactions at an earlier stage have the character of a simple behaviour, but it is impossible to describe and read the nature and properties of the complex whole in later stage when the whole emerges only from its interacting parts. The behaviour of the whole is much more complex than the behaviour of its internal parts (Holland 1998). According to Holland (1998) this phenomenon is normal, stable and corresponding to normal life, but that does not mean it is easy to explore or describe. Holland notes one important feature of an emergence, which is based on mutually hierarchically interlaced mechanisms: The mechanisms in the complex system at each level are always based on the mechanism at previous level (e.g. atoms are composed of smaller particles, liquid is composed of molecules of atoms, etc.) and defines the hierarchy of interlocking disciplinary dependencies, which influence the level on each stage.

Architects Hensel, Menges and Weinstock (2004, 2010) provide the definition where emergence is „*a process* […] where *natural systems have evolved and maintained themselves* [...] and as *a set of processes for the creation of artificial systems that are designed to produce forms and complex behavior and perhaps even real intelligence*. Emergence is a phenomenon „*when new coherent patterns emerge from within processes in a complex system*. It their *simplest commonly used definition, emergence is said to be the properties of a system that cannot be deduced from its components, something more than the sum of its parts*." In other words „*emergence is a process by which new and coherent structures, patterns and properties emerge from within complex systems.* "

Johnson (2001) defines emergence as „ *the movement from low-level rules to higher-level pattern arising out of parallel complex interactions between local agents*" and declares four principles of emergence: local interaction of neighbours, pattern recognition, feedback and an indirect control.

Goldstein (1999) initially defined emergence as: "the arising of novel and coherent structures, patterns and properties during the process of self-organization in a complex systems". Goldstein's definition can be further elaborated to describe the qualities of this *definition in more detail: "The common characteristics are: (1) radical novelty (features not previously observed in systems); (2) coherence or correlation (meaning integrated wholes that maintain themselves over some period of time); (3) A global or macro "level" (i.e. there is some property of "wholeness"); (4) it is the product of a dynamical process (it evolves); and (5) it is "ostensive" (it can be perceived)* [19].

A lot of strategies and attitudes are known based on emergence paradigm in urban planning and design. They will be more described in a State-of-the-art chapter later in this thesis. The usage of the word *emergence* in architecture has been increasing a lot recently and it is understood as a model of exploring the potentials in advanced techniques and evolution of methodologies, on experimentation and the development of new instruments and repertoire of architectural and urban design. This concept can be modelled by means of using the algorithmic, mathematical or chemical/physical models as well as geometrical ones. The current research of this concept in architecture or urban strategies focuses not only on morphogenetic approaches or exploring the emergent materiality and novel tectonics, fabrication techniques but also includes observation in an urban scale, city development, city-making or city-occupying strategies, its configuration of urban patterns in terms of non-directive uncertain urban growth. The technological and scientific shift of understanding this concept is consequently reflected in the field of architecture and urbanism as well.

The phenomenon of emergence, when the complex whole is set-up, has the characteristics of unpredictability. This complexity of processes that accumulate in such a system thus exhibits nonlinear behavior which cannot be estimated or predicted. Emergence as a basic strategy with operations within architecture and its representation seems to be a speculative construct in some extent which, however, of course reflects the reality of the world, society and its dynamic non-persistent image. Complexity of the environment and its emergent properties are understood not only from a mathematical, physical or chemical point of view, which assigns from other disciplines, from the natural world or from the system theory, but it is presented as a re-application and re-interpretation of its possible usage in creative architectural activities. In these sources, the issue of emergence is presented as an integral and legible part of understanding and constructing the world as such as it is, recognizable especially in growth-flared structures for human settlements either during the city developments and movement or displacement of civilizations (Weinstock, 2012, Burry, 2010).

1.2 Research Field

The paradigm of emergence interpreted by its characteristics of non-linearity and unpredictability in the field of urban settlements and patterns is becoming the significant movement in the exploration and understanding of its geometrical behavior, organizing, growth and configuration. In the perspective of so-called bottom-up strategy of urban development, this concept is understood as a distinguished insight into the city environments. Such a concept is declared as a complex whole where its particular elements of urban pattern are being involved as parts of the interaction on a lower level. Michael Batty (2007, 2011) discerns city environments that is growing and developing as a system of social interactions by individual parts (agents) with physical solid environments (cells) (Batty et al..1999).

The issue of non-directive design and planning of the urban environment is very topical in the context of contemporary architecture and urbanism. One of the possibilities of city growth and development of the existing urban structure is the organic emergence of a new environment based on individual and group bottom-up decisions. The participation of future residents of new areas in the city planning or in the creation and completion of the existing urban environment based on real needs and potentials of its inhabitants currently presents a great challenge for architects to simulate these unpredictable processes of spatial development using relevant digital technologies. Architects and urban planners conduct the role of expert surveillance of this way of urban development and they also evaluate and influence this set of development processes. Taking into account the development of the urban environment based on this bottom-up strategy, a city can be considered as a complex set of sub-processes where each of the mutually interacting entities and systems create a self-organized complex whole (Albeverio et al., 2008). The city shows an emergent behavior. Since this approach is different from top-down planning, we can state that in this bottom-up strategy.

„Cities grow organically as the product of millions of decisions and in the face of this complexity, it is not surprising that top-down controls have little effect on their structure(...).During this time, a new model of how cities function has gradually emerged. The analogy of a city with a physical system has been replaced by that of a biological system (Simon, 1999) and as we know from our own experience, biological systems grow from the bottom up.“ Batty (2007).

Thus the phenomenon of emergence is recognizable in the context of architecture as a process when architectural or urban whole is changing and reconfiguring based on demands, interactions and negotiations between individual parts of this whole on a lower level. It is not predictable how the whole will be configured and what will be the result of this kind of configuration. We call this non-direct process a bottom-up strategy of the environment development (Fig. 2, 3).

Fig. 2 Marrakech - a bottom-up emergent urban pattern, Bruno Barbey 1979, MOROCCO. Marrakech. A sprawling and labyrinthine city of courtyards... accessed April 18 2015, http://www.magnumphotos.com/image/PAR35963.html.

"Our new understanding of how cities function is predicated on action from the bottom up. Cities are built by actions exercised by individuals on behalf of themselves or larger collectives, agencies and groups mainly configured as local actions. Global patterns emerge, best seen in how different parts of the city reflect the operation of routine decisions which combine to produce order at higher and higher scales. Cities are fractal in their form and function [...].Traditional planning and design that fights against such self-organization will fail and in this, the best principles for design must reflect organization form the bottom up: the metaphor is

evolution, the way nature works is magic." (Batty and Hudson-Smith in Pasquero and Poletto, 2012).

1.3 Identification of the Research Problem

A city can be interpreted as an aggregate of complex dynamic processes, which contribute to its configurations or changes in urban pattern (Forrester, 1998, Châtelet, 2007). It contains communication and distribution flows, movement of users, environments are in mutual interaction and changes appear in volume units based on bottom-up stimuli.

Thus a city as a complex phenomenon and an entirety of events, its invisible communication flows, information and data telecommunication networks and their access points (Mitchell, 1999), energy, goods and materials distribution and movement of users themselves and their spatial interactions with the environment nowadays no doubt has been creating new conditions and demands on the city's spatial organization, infrastructure, its organic growth and its thickening. The urban environment in that way shows emergent qualities and contains multi-layer scenarios of its own evolutionary development and reconfiguration in time. This stratification is impossible to be comprehended by a linear model of a single predicted concept (top-down strategy). Architects and urban planners may, however, cover these specifics by a prediction of space development with a multi-layer result that would take into account the requirements and demands of users at the lower level (bottom-up strategy).

Fig. 3 *Caracas - an example of an emergent city, accessed In Living Color - Caracas Barrios, accessed April 18 2015, http://caracas1010a.blogspot.sg/.*

The research problem is to find the appropriate way to simulate these emergent characteristics (unpredictability of the pattern development, uncertainty) of a city in order to use this kind of information for better understanding the behaviour of the city environments for the needs of architects, stakeholders and decision makers.

1.4 Research Questions

>How to simulate, using information technologies, the ex-ante unpredictable development of the urban environment in a specific existing site on a local scale?

>In which manner is it possible to capture these dynamic processes in simulation in order to be able to predict or model city configuration or directly model the emergent characteristics of the environment?

>How to simulate spatial metamorphoses of the environment in 2D or 3D model in certain time horizons?

>How to achieve a bridging of real data in the context of digital simulation, which could serve as a guide for architects and urban planners at different levels of planning?

>Is it possible to verify a multilevel environment scenario of the urban configuration?

1.5 Hypothesis

By emergence we can identify phenomena in a dynamic system through simulation and therefore we can assess a given urban environment in terms of its potentials and deficiencies. An emergent approach through simulations allows a wide range of parameter settings than can yield fast and diverse results.

1.6 Main Research Goal

The main goal of the dissertation is to assess the applicability of simulation of emergent strategies in the urban environments in a particular exploratory simulation model of the already existing environments through the usage of digital technologies. It will be a simulation of the selected urban dynamic phenomena that yield creation or reconfiguration of the already existing environment based on emergence paradigm. The verification will be conducted by exploring the paradigm in an already existing urban environment.

The objective involves the enhancement of design and decision making potentialities for architects and urban planners in the early design or decision stages, thus this spatial simulation would serve as a decision-making tool for architects when applying various alternative scenarios of the environment development and thereby it would create a basis for spatial planning decisions in the subsequent stages of zoning processes. This tool would operate with the emergence phenomenon in the field of modification, reconfiguration and continuity of the city environment.

1.6.1 Secondary Research Goals

> Summary and reflection of existing state-of-the-art bases in terms of theory, philosophy and urban design by selected theorists, contemporary research studios or established university courses worldwide.

> Tracking and simulating selected city environments in a case study of existing territory in order to define equally urban graininess within the urban environment.

> Spatial simulation of the urban environment in local scale based on requirements on the lower level which would simulate complexity, growth, thickening, reconfiguration and continuity of the urban space.

> Development of a generative and decision making simulation software platform for architects and urban planners. This spatial simulation would serve as a decision-making tool for architects when applying various alternative scenarios of environment development and thereby it would create a basis for spatial planning decisions in the early stages based on simulation of measurable bottom-up spatial characteristics.

1.6.2 Outcome

The aim of the research is therefore a spatial simulation of an environment development, which, based on the requirements on the lower level, would simulate the complexity of the environment, its growth, thickening and reconfiguration.

The final requested result of this research shall therefore be a simulation software tool - visualised algorithms in a simulation prototype of the geometrical model of the spatial environment reconfiguration. This result implemented in a software tool with own GUI can also serve as a creative generative platform for creating urban structure based on simple rules of the lower level, that would, however, consequently simulate the complex and comprehensive urban entirety.

1.7 Methodology

For the research purpose, the emergent behavior of structures in the simplified model is conceived as a spatial interaction of the internal lower-level components, which figuratively represent the inhabitants and their demands or the individual elements constituting the urban spatial context. Such a model can be modelled by using the method of agent-based modelling.

The agents form a complex whole - a spatial system where geometry is based on defined rules and attributes of lower-level agents posted into links and interactions with other agents and with the existing environment. Modelling of this platform in the research framework is carried out in the scripting language Processing, because this language allows open editing of the script at any time with a clear result in our own modifiable graphic user interface [9] (Reas, Fry 2007). The language is based on an open-source strategy and following that idea it offers a rich possibility of functional replenishment with additional parameters and codes in further research work in cooperation with other programmers or developers. The core script could be at any time entered and enriched with new features and functionalities or edited and complemented with the core functions that had already been implemented.

1.7.1 Agent-based Modelling

Agent-based modelling is the way of simulation of spontaneous operations and interactions in a complex system between its particular parts in order to visualise, understand or predict its emergence and further non-linear behavior. The particular elements of the system are in this case defined as agents. They interact among themselves and this interaction is based on the lower-level rules. By means of this interaction, agents are allowed to create an organized complex whole whose higher-level behavior is based on lower-level interactions [14].

1.7.2 Interpretation of the Agent

Element / particle is the particular entity of a complex whole which shows simple behavior against the whole itself and performs its behavior without external intervention. The agent can interact with other agents as well as the environment by specified rules and it can perceive its surroundings – physical world through the graphical user interface (GUI). It can react on an environmental change or it is allowed to reconfigure it by itself or by collective behavior [14].

For this particular research purpose in the thesis the agent is understood as a representative of selected amount of environmental users-participants in terms of pedestrians, traffic elements or as a particular entity of urban distribution flows in the simplified model. The case study will deal with various types of agents that will search for their demands. In this case the model will operate with flows in a simplified way, it will not be a crowd simulation or an exact urban mobility simulation itself. Agent flows will represent dynamic and movement behavior of urban interactions in a more natural and abstracted way.

II. Theoretical Framework of Emergence in Context of Simulation Models

2. Emergence Theory

2.1 Weinstock´s and Holland´s Interpretation

The phenomenon of emergence can be described in terms of more general context of the development of a certain environment (natural, artificial, civilizational) as a complex phenomenon into which the whole and partial effects of other environments and contexts can be embedded in a mutual interaction by its internal actions in order to create some form of the known or observable environment (Weinstock 2010).

The complexity of the environment and its emergent properties are based not only on mathematical and physical matter of the structured world, which is assigned to an appropriation from other disciplines and can be described in that way, e.g. from the natural world or from systems theory, but its re-application and re-interpretation is introduced as a possible design principle in the creative activities of an architect.

The understanding and the description of these phenomena and their structural properties of complex behavior in a certain mathematical, geometrical, and physical expression of reality is already a subject of current research in the field of architecture and urbanism.

Just in examining the development of the urban environment one can see that this phenomenon is based on more extensive geometrical and constitutive shift in an architectural discourse. If we perceive it in terms of non-directive strategies, a city emerges by non-linear and unplanned way at a lower level as contrasted to modernistic top-down planning.

An emergence is a synonym of "creation", "arising". This concept represents the creation of forms and their behavior in the system, which has the property of their irreducible complexity, i.e. the characteristics of the system cannot be reduced to the characteristics derived from the sectional internal components. The property of the whole is more complex than the properties which are the sum of its parts. As Weinstock claims, complex processes create, maintain and enhance the forms of natural or civilizational and cultural systems involving exchanges of energy, materials, information and the environments are mutually correlated.

Holland (1998) in his work systematically introduces the concept of emergence in several perspectives and describes this phenomenon by key model examples and provides a comprehensive discussion of its principles. It is based on three basic concepts: mathematical (logical) concept, system concept and so-called informal or general concept of the emergence.

The first concept deals with objects within the phenomenon where each object is equivalent to another component and they have their own features. Thus they interact and correspond with other components. The components operate with the functions on the basis of universal rules and laws that are determined by conditional clauses (if ... then ...). A set of rules is a basic concept of the whole modelling and observation of emergent phenomena. Holland compares these observations to the rules of a table game where rules make boundaries in such a system. Conditional clauses specify the possible interactions, which are illustrated very well in the exemplary of agent's behavior.

The next concept operates with three intentions of emergence: state of the system, the transit system functions and strategies in the system. The system state is described by all its previous "history" of conditions and future conditions that can be interpreted from the current state of the system. It is illustrated well on the example of the board game. State game essentially cannot be captured as a whole from the level of current positions of the pieces on board only, the state is related to previous strokes and expected future shifts in the game. The game is not easily definable from the current state. Transit function involves communication between the system states and operates with input information. It always takes two states, followed one by one and lead to the third condition which emerges from previous coups and leads into results. An example of the transit system functions are three consecutive coups in the game. The third component - a strategy emerges when the system receives input information and affects the sequence of states, which are arranged in the desired mutual relation. The strategy is established when each game state is related to the input information and produces unique consecutive sequence of states.

The third concept is a general view of understanding the emergence. The key role is the concept of "building blocks". This concept is dedicated to the field of physics, when the world itself is taken apart into more understandable objects and parts. It is a way of extracting, distribution of recurring events that ultimately lead to emergent phenomena. By using this modelling principle of these phenomena in a simulation models one can describe and define the emergent behavior. According to Holland the most common and fastest way to model the emergence behavior is modelling the interaction of agents that can adapt and learn from previous interactions.

Hollands's concept of emergence is crucial for capturing the modelling principle of an emergent behavior into the simulation models that are simplified in the framework of information technologies. There is a lot of techniques well known in the context of architectural modelling. The agent-based modelling (ABM) seems suitable for the spatial purposes in the context of architecture or urban design as well. ABM and its wide potentials shall be explored in this framework and it still has not been comprehensively observed in a proper fulfilled way.

2.2 Reflection of Delanda´s Theory of Assemblage and Simulations

Contemporary distinguished American philosopher, writer, sociologist and artist Manuel DeLanda in his theoretical work (2011) analyses some selected phenomena in terms of observation of emergence in relevant types of simulations (from ordinary physical phenomena or natural phenomena in the atmosphere through a bacterial ecosystem, intelligence of insects, through cellular automata representation of structural flows, genetic algorithms, neural networks to multi-agent systems) from the philosophical, historical and social point of view, as well as in terms of computer science and technology. Understanding of the world in this framework of so-called Theory of Assemblage is based on appropriate tendencies and capacities of structures and acts that can create new possible entities of being with other beings. DeLanda explores the relevance of using computation technologies in order to simulate these phenomena on the basis of their "singularities" as Graham Harman writes „*...a long term tendencies of a system*“ (Harman, 2010) or certain properties and rules that are essential to life's entities. DeLanda calls emergent entity *a universal singularity*. Each entity, a complex whole is *an assemblage.* Therefore emergent whole is not only defined by the characteristics of its parts, but on the other hand by its tendencies and capacities. *„Tendencies can encourage a whole to be various, may even thereunder change its character and identity, for instance an ice block has tendency to melt. Capacities in turn encourage a whole in order to show its aspects of own identity that was previously hidden. While the tendencies form a certain set of properties that appear to be permanent, capacities lead to understanding the whole as a certain unpredictable structure which it is impossible to categorize in advance, because it is not possible to estimate the universality of such a unit.“* (DeLanda, 2011)

Availability of technology that can operate with emergent phenomena is an advantage in various scientific fields, emergence became a laboratory phenomenon that can be modelled, observed and validated. Thus simulation plays an important role in laboratory experiments and enhances the role of mathematics in the field of further possible knowledge about structural phenomena and their possible contexts.

DeLanda understands the emergence paradigm (similarly as Holland) in a hierarchical way. His Assemblage Theory reflects the fact that every entity in the world is assembled from other entities. He argues that *„it is not possible to eliminate larger entities by accounting for the behavior of their tiniest physical parts*. […] *Every sort of entity is an assemblage.“* (Harman 2010). Graham Harman explains DeLanda´s Assemblage theory in a way where entity itself is

„*an emergence*". But it is something more than the fact that entity simply emerges, entities or assembled wholes are not assembled only by other assemblages. They create objects that each of them is in mutual relation and in a relation with outer world. They exceed themselves and form a new reality. This concept is essential also in architecture and urban planning context. It seems as a different kind of a design strategy where architectural reality is declared and composed by fragmented species assembled into the architectural or urban wholes in order to form larger systemic structure where elements are in relations (spatial, mental, social). Every assemblage is autonomous and re-creates another autonomous objects while it is irreducible and decomposable with certain emergent properties making the entity as an individual singularity (DeLanda, 2011, p.188). The relations create significant functions of a larger system and according to this fact the whole is impossible to be reduced only to its pieces. Emergence concept in this case is taking into account relations between entities and an environment, casual effects between entities themselves, processes flowing through the system itself and other systems outside the one and furthermore entities are able to create new parts of entities or even entity wholes. And a city is a typical example of that model of emergence and by simulations we are more capable to understand that phenomenon in a proper way. The complexity concept starts to be crucial for understanding the cities and their behavior, growth or further development.

DeLanda hereafter argues that philosophy in turn is a mechanism that these learned pieces of knowledge synthesizes within the materialistic worldview where matter and energy paves the way for the implementation of its creative power. Given the importance of such simulations we are using information technology in order to describe the world and how it works, how it changes or how it is capable to develop. DeLanda´s work is a contribution to the philosophical image of the world in terms of understanding things and events that are happening around us, but on the dividing line of real philosophical arguments, applied research and objective reality.

2.3 Computational Models of Emergence

Computational simulation models play an irreplaceable and crucial role in the field of modelling dynamic systems comparable to the emergence phenomena existing within reality. These models help us to comprehend its characteristics and yield certain insight into its behavior and its potential evolution. Providing the rules that determine model behavior one can establish a simulation model platform which can be observed, visualised, and evaluated for own further consideration. According to Holland's argument, computational models have an ambivalent basis. They shared both theoretical framework and experimental observation (Holland 1998). The rules how the model works reflect theoretical principles that lead to experiments where it is possible to verify and explore better these properties. Model simulation representations nowadays are very well involved within architecture and urban design in order to enhance the architectural intention.

2.3.1 Emergence as a Paradigm for the City Environment

The relation of emergence and architecture can be expressed by the following thesis by architects Hensel, Menges and Weinstock (2010): buildings within their environments are not singular and fixed separated structures from their context and environment. „*Those structures are complex energy and material systems that have a lifespan, exist as a part of an environment of other active systems, and develop in an evolutionary way.*“

As Holland declares the overall emergent behavior of a whole is not only a sum of the behaviours of its parts. For instance an ant colony is not simple sum of the behavior of a group of average ants. (Holland, 1998, p. 121): „ *The overall coherence of the ant nest far exceeds anything predictable in terms of simple summations.* “ He argues „*technically these interactions, and the resulting system, are nonlinear. However, we can reduce the behavior of the whole to the lawful behavior of its parts, if we take the nonlinear interactions into account.*“ (Holland, 1998, p. 122). What kind of hidden matter or principle stands behind this uncertainty and nonlinearity? Urban system involving these interactions seems unpredictable also in terms of its changes, distribution and dynamics phenomena which is significant for the contemporary model of the city environment.

An emergent approach in the framework of architecture and urban design reflecting the graduality, changeability, figurability, fluidity (Sola-Morales, 2001, Bauman 2008) and openness of an environment is another basis for enhancing the overall image of the essence of urban territories. It is another intelligible layer with characteristics of energy flows, fluidity, changes and movements which nonlinearly influence the solid matter in an urban fabric. When we deal with urban formation in terms of shape and type, these units pass away from archetypal formation into own expressed language morphology which reflect existing forms in nature allowing better application of variability, arrangement and distribution of motion. We can simplify these emergent properties in order to describe and model self-organizing phenomena into geometrical matter which would serve us as a medium for capturing these characteristics. This simplified representation can be driven by computational models observing e.g. branching, L-systems, cells and clusters, particles, volumes, etc. The phenomenon of self-organization in the field of urban planning would be understood as a principle of an arrangement or an alignment of urban fabric and infrastructure in a physical manner and at the same time the alignment of invisible mental relations and network connections and distribution. In such a fabric it is possible to align volume formation with self-sufficient internal regime in terms of intrinsic rules and without any external forcing influence. In this case the essential interconnections within the structure between elements are significant (participants among each other, participants and the environment, particular elements within the environment) because they define the behavior and the organization within the rules.

This model of self-organized emergent environment can represent the dynamic model of the city (zone, area) where ongoing interactions of people, elements and various particular environments run. Simply this model approximates to the principle of agent-modelling, where the components of the system (agents, entities) are located in a certain area (country, city) and based on interaction and perception of the environment, these components achieve some common objectives, while each component can fulfil their individual goals. According to this fact the city can be considered as a complex system with its own collective intelligence, where individual components in a common environment are trying to achieve their common "higher" goals. This system is decentralized, actually it has no control "from above", and entities govern their interaction and organization by themselves. The issue of self-organized urban planning application opens many interesting questions that need to be examined in order to explore other opportunities for growth and regeneration of the city.

We can simulate emergent properties by simplified computational models. Emergent behavior of the structures in terms of spatial and geometrical characteristics is possible to be observed through several approaches and concepts where we can establish and choose the proper one for the purpose of our research as a base for suitable methodological approach. The principle concepts for emergent modelling can be represented by agent-based modelling, cellular automata concept or L-systems. Each of these methodologies is a centre of many scientific attitudes.

2.3.2 Selected Examples of Computational Algorithms of Emergent Formations

Iterative protocols by means of using the scripting techniques can provide certain unexpected results characterized by unpredictable formed structures driven by simple ruled-based systems as drawing machines (Fig. 4, 5, 6). Thus system is able to assume the agent-based behavior e.g. with focus on swarming behavior, or stigmergy, the strategy that many nature species use to exchange information through the environment by means of a read-write process often implemented via a chemical agent such as a pheromone.(Eriolli, Pheromonics workshop, Fig. 8).

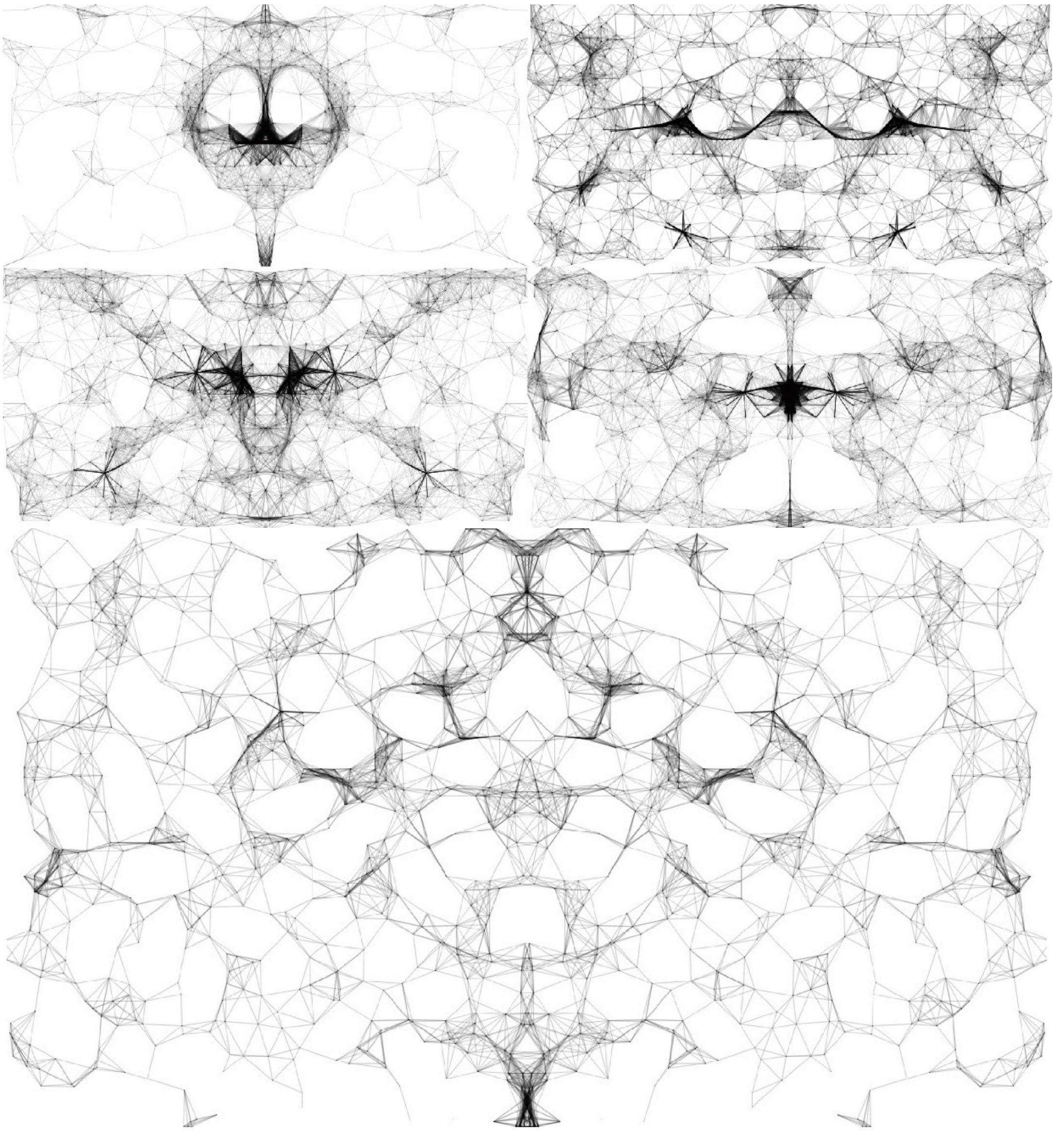


Fig. 4 An example of the simple rule based algorithm which yields more complex behavior of the pattern even in a symmetry.

The agents coordinate themselves through local sensing-feedback logics resulting in more complex behavior that can represent a city-space or a kind of a city-making or city-occupying network. Such a system leads to colonization of an empty land area.

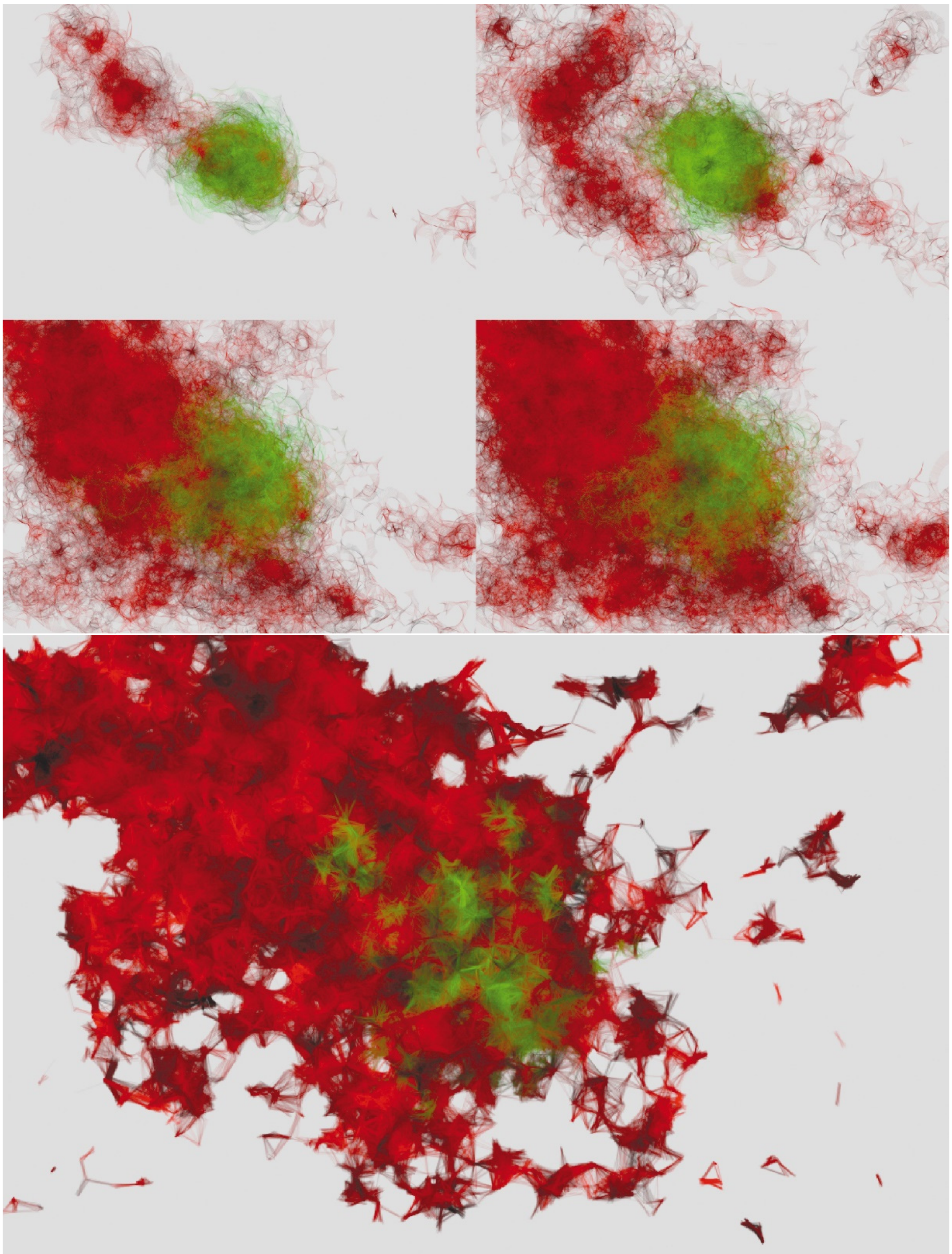


Fig. 5 Another example of the simple rule based algorithm, in this case pattern concentrates into denser formation.

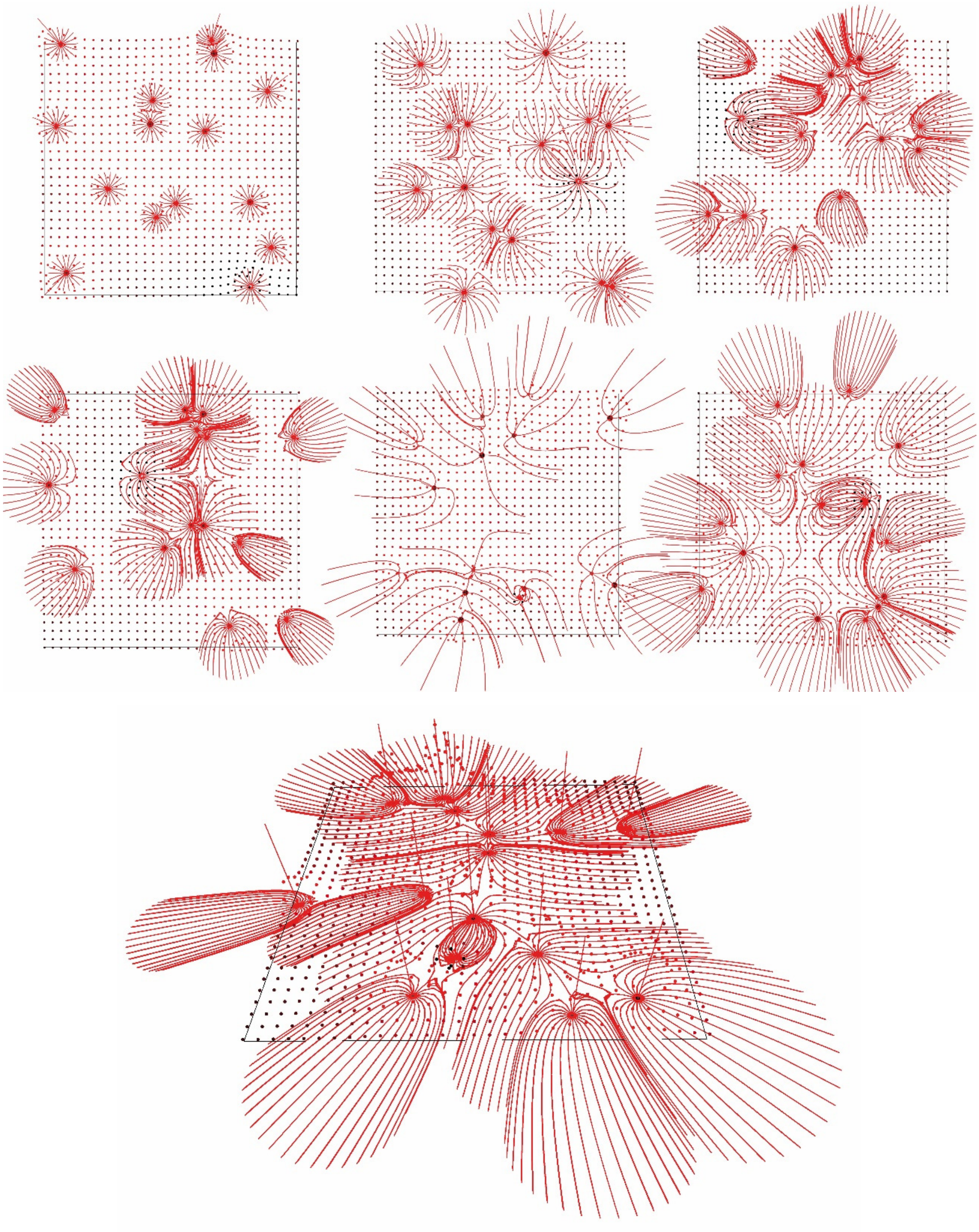


Fig. 6 Basic agent movement in 2D based on simple rules on a lower level yield unpredictable behavior of the geometry. Magnetic fields between the agents as a force strategy can influence defined line and grid geometries. A new kind of an urban pattern? The code is based on Processing programming language. Zomparelli, Alessandro, "Iterative Protocols, Processing Workshop", Workshop and lecture, - Co-de-iT , 3D-Dreaming.com, Vienna, November 23-25, 2012.

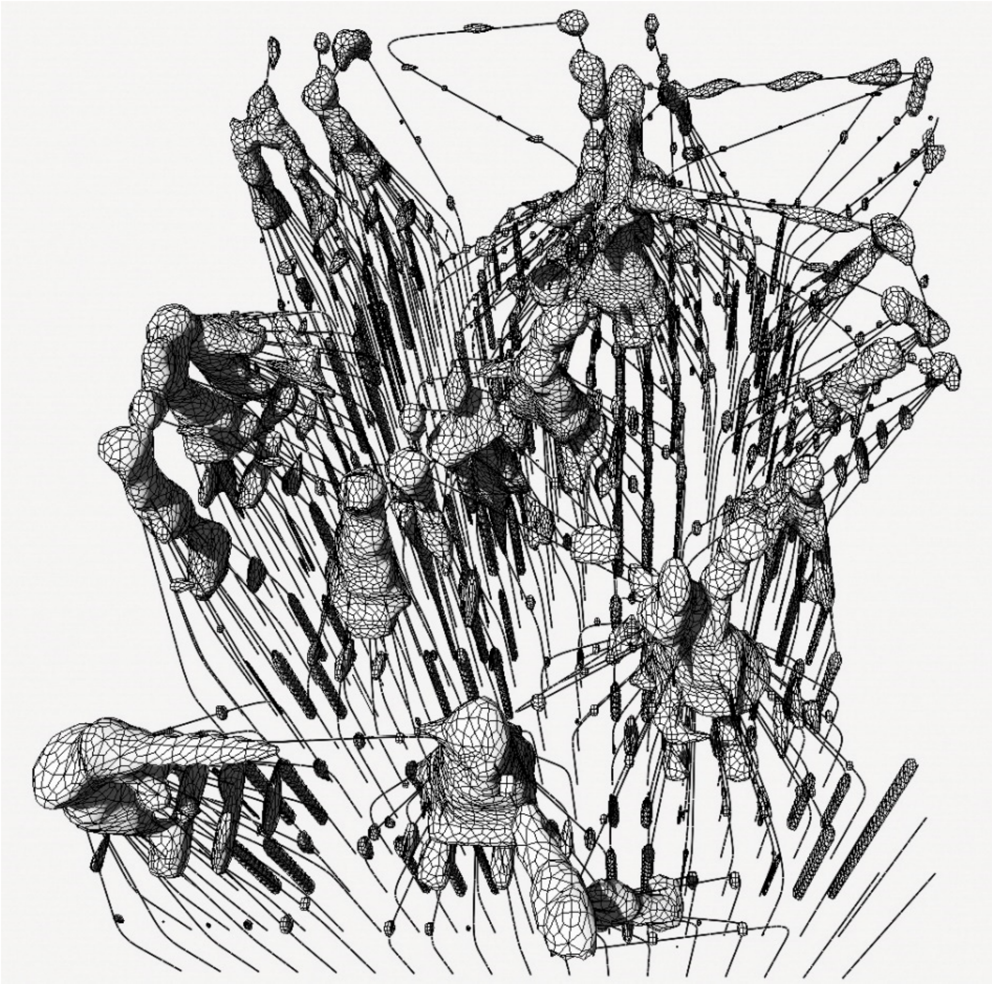


Fig. 7 *Agent flow influences the static geometry of the defined objects. By that way the object geometry is adapted in order to configure different spatial scenarios. The object can represent various architectural or urban design objects (Disruptive Eco-logics 2013, summerschool workshop at the IoA, Urban strategies, University of Applied Arts in Vienna, Die Angewandte, led by Bruno Juricic, UCLA, MLAUS, June 21-July 19, 2013).*

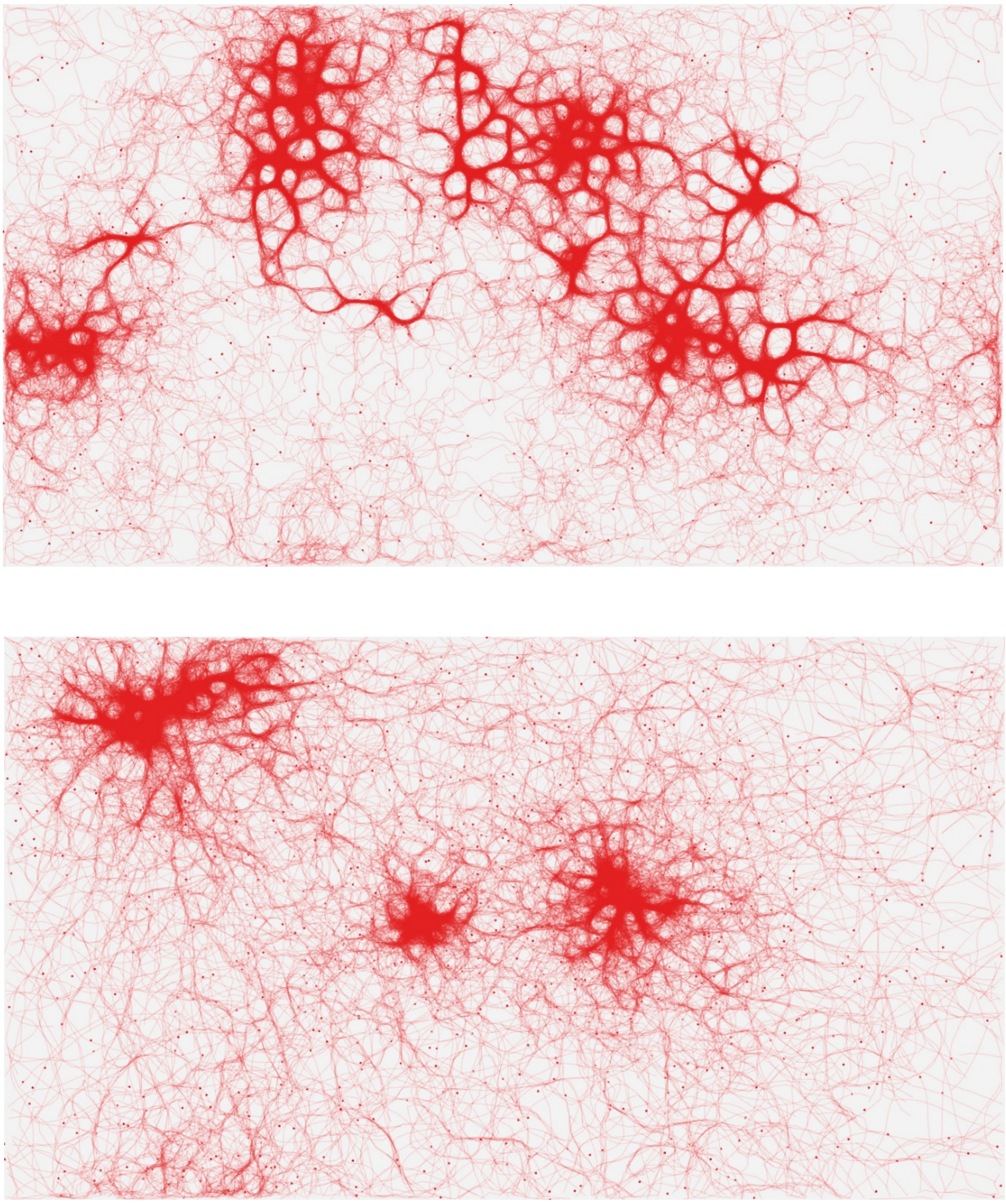


Fig. 8 Pheromonics strategies. Agents leave behind the pheromone trail in order to establish a movement agent flow similarly as ants in nature. By means of this network strategy it is possible to observe new networking and occupying process of an empty area. Eriolli, Alessio. “Pheromonics|Processing Workshop Prague - Co-de-iT“. Workshop and lecture, UMPRUM, , Co-de-iT and ReCoDeNature.org, Prague, June 23-28, 2014.

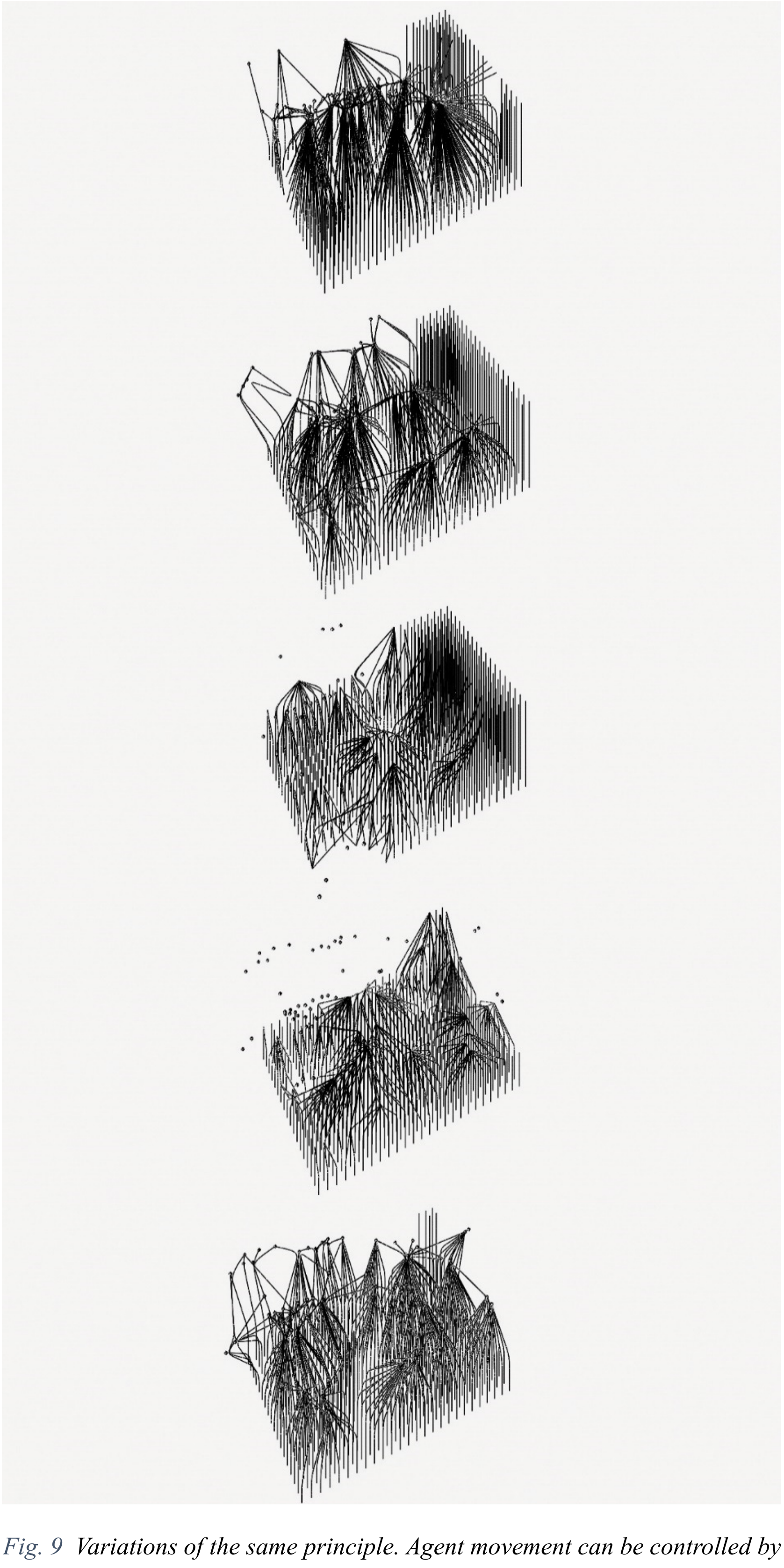


Fig. 9 Variations of the same principle. Agent movement can be controlled by user in the GUI in Rhino/Grasshopper application (Disruptive Eco-logics 2013, summerschool workshop at the IoA, Urban strategies, University of Applied Arts in Vienna, Die Angewandte, led by Bruno Juricic, UCLA, MLAUS, June 21-July 19, 2013).

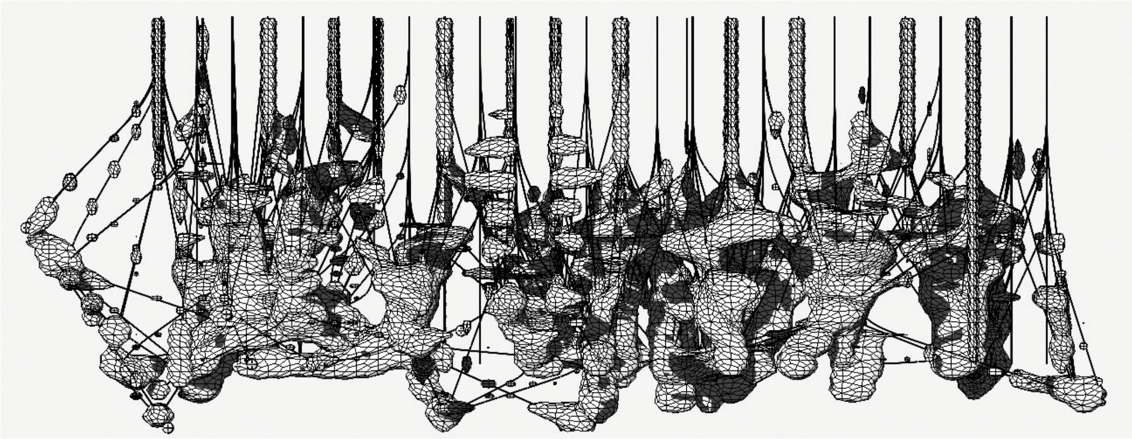


Fig. 10 Geometry formation based on isosurfaces.(Disruptive Eco-logics 2013, summer school workshop at the IoA, Urban strategies, University of Applied Arts in Vienna, Die Angewandte, led by Bruno Juricic, UCLA, MLAUS, June 21-July 19, 2013).

Another computational concept yields exploration of new design potentials reflecting disruptive processes in nature and their further development and implementation into certain speculative architectural or urban objects. (Disruptive Eco-logics 2013, Fig. 7, 9, 10, 11). Several objects influence each other and create re-modelled and re-wired environments based on previous geometry manipulations in an already abstracted way. Agent system is able to influence and deform other types of geometries in order to achieve unexpected results. This non-linear process can be programmatic and systemic strategy for exploring boundaries of architectural and urban design potentials. Such a concept yield objects that can maintain themselves outside the human mind in a virtual world, influence each other and create different entities or assemblages with new characteristics, uncertain behavior that can be interpreted in an architectural or urban speculative synthetic landscapes.

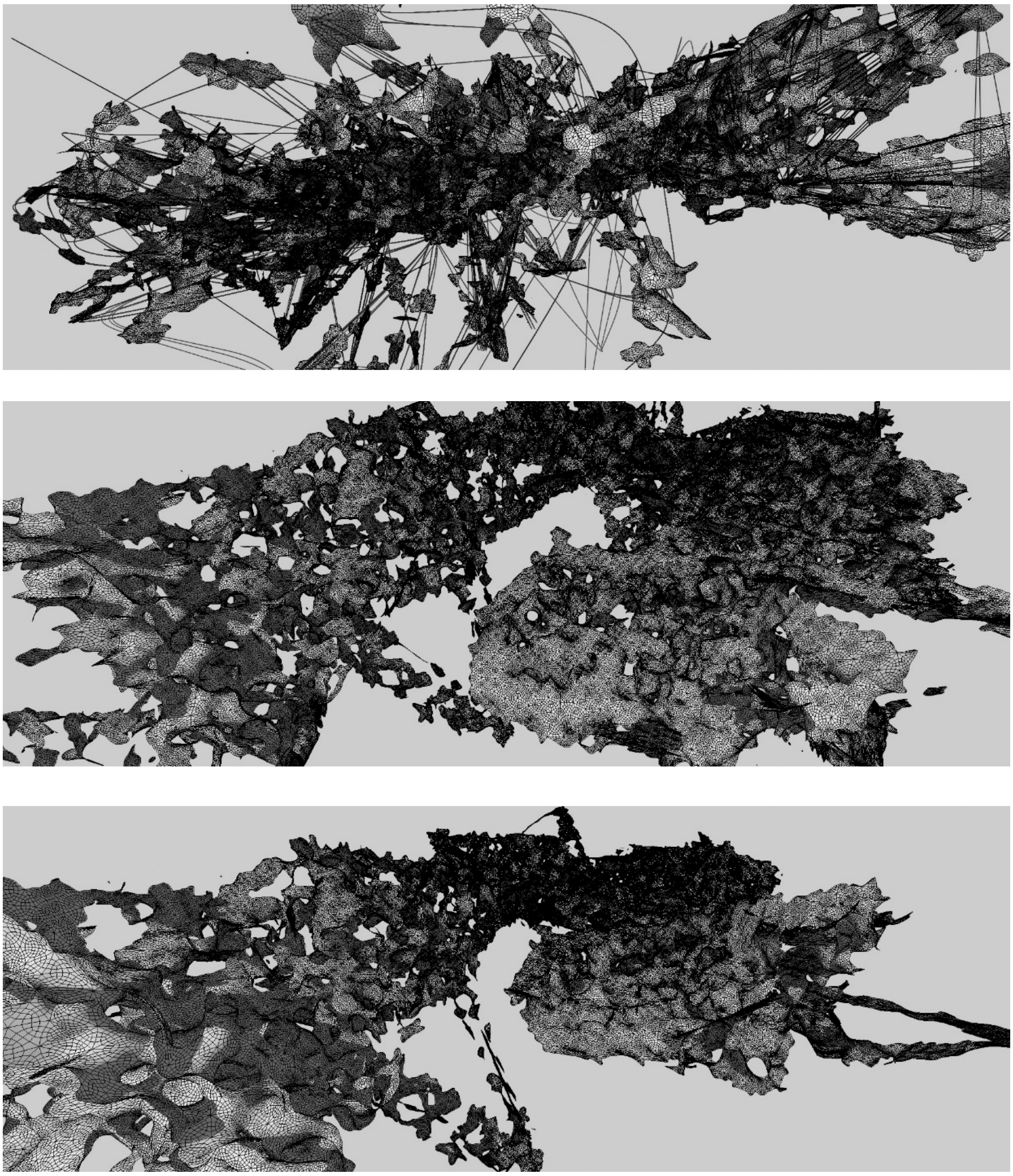


Fig. 11 Synthetic landscape objects established by behavioural strategies of the agents' movement. The constructed geometric network is rewired by agents in the space. The final mesh geometry is reinterpretation of the captured geometric construction network in certain key frame in the animation (Disruptive Eco-logics 2013, Workshop and lecture, the IoA, Urban strategies department, University of Applied Arts in Vienna, Die Angewandte, led by Bruno Juricic, UCLA, MLAUS, June 21-July 19, 2013).

2.4 Chapter Conclusion

The definition of emergence has been established from several points of view. The theoretical approaches provided by Holland and DeLanda show facts that the simulation models play their crucial role in the context of understanding of how the world is perceived and constituted in terms of its emergent characteristics, creating wholes as certain assemblages and as unique patterns with their own history. This argument refers also to DeLanda`s Assemblage Theory whereby emergence concept is well provided and introduced by means of society and its behaviour. In that way a city can be understood as a self-organizing and self-maintaining entity that can produce and provide new unexpected characteristics and behaviour which is observable by means of simulation models. However, the complex information about the city still needs to be reduced onto particular objectives because one cannot simulate complex information within the city at once, in one computational model. This limitation still has occurred as a technological and conceptual issue within the computer science, urban simulation field or complexity theory.

Harman's concept of the emergence in terms of object-oriented ontology can be a paradigm for a city modelling whereas a city can be considered as a certain dynamic relational object with its own identity constituting the spatial, social and mental relations with other objects within the environmental conditions. Even in such a system a lot of internal conditions, behaviours and relations run that affecting the tendency how such a complex whole is allowed to provide a new uncertain and unpredictable result.

And finally several computational approaches have been introduced for better understanding by visual outcomes whereby one can observe the relational and spatial emergent qualities in the models of abstracted architectural environments or urban objects.

III. State-of-the-art: Agent-oriented Modelling in Urban Context

3. Simulation Models with Emergent Matter

3.1 ABM Simulation Model Platforms in Urban Context

There is a lot of simulation approaches and research agendas worldwide which operate with ABM simulation within urban scale and urban design context. The thesis partially introduces and makes the comparison only between selected simulation platforms with proposed EmCity simulation model (which will be introduced in the next chapter) in terms of selected emergent phenomena and non-linear development of urban patterns. Certain models presented here are still in progress. This thesis does not aspire to explore all potentials of each simulation platform tool or analyse every aspect of the simulation. However, it demonstrates certain insight into the broader spectrum of content of the tools that can operate with different conditions, different data structures or scenarios that can be observed and estimated.

The thesis for the illustration and comparison of the state-of-the-art purposes introduces selected existing simulation tools or research agendas. It provides at least a selected part of the wide field which could be enhanced by further attitudes and approaches. The criteria for selection of below introduced models were mainly their potential for urban or landscape design and the implementation of the local-decision concept, i.e. bottom-up approach. There are many other urban tools concerning analytical or visual outcomes, but these are not considered into the state-of-the-art framework of this thesis because they do not operate with the generative potentials based on an emergent matter or unpredictability of the pattern development. Information about the tools operating with the urban patterns in an uncertain and unpredictable way of urban development using agent-based methodology of modelling is provided further. For the illustration purposes three well-known non-ABM simulation systems have been involved into the comparison for their strong analytical and visualisation potential for urban design consideration (UrbanCanvas, GeoCanvas and CityEngine).

3.1.1 Computational Taxonomies, AA DLR London

Theodore Spyropoulos has established several computational taxonomies and approaches within his research agenda at the AA DLR in London with students and other architects in order to specify certain ABM methodologies and attitudes how to observe and model selected emergent phenomena within architecture and urban design strategies (Spyropoulos, 2013). Students and researchers developed various computational concepts how to exchange agent-based modelling into to systemic matrix agenda for further implementation and integration into the design processes [13]. The concept and strategies are well introduced in his Adaptive Ecologies book wich explores several approaches yielding different architectural or urban scale projects reflecting the nature systems of living species and create the platform for exchanging the information bases for further research. It mainly concentrates on a theoretical and computational approach as a sub-part of the issues of the digital attitude, computation design and interaction agenda and how these aspects could potentially change the understanding of the urban future or a city – making development taking into account various adaptive nature experiments and principles of generative evolutionary processes.

3.1.2 G A M A Platform

G A M A (Drogoula et al, 2013) is a modelling and simulation platform focusing more on a large scale models in order to observe several different scenarios in the multiple environments levels as well as levels of agencies. It is being designed and developed by an active group of researches coming from different institutions in France and Vietnam [20]. The model does not provide any urban design attitudes, it rather concentrates onto analytics and advanced visualisation for the building spatially explicit agent-based simulations, e.g. in a certain catastrophic scenario. It operates with the GIS data, statistical models with the graph and chart representations and network optimizations. Its advantage is in modelling of several urban dynamics - water flowing, plant growing, land market or demographic evolution. It is capable to integrate cellular-automata representation and deals with 2D or 3D environments. By that way it is possible to simulate e.g. the epidemiological dynamics. GAMA provides a rich and accessible modelling language based on XML, own developed language GAML that allows defining complex models integrating entities of different scales and geographical vector data simultaneously. Gama does not provide any generative or evolutionary processes which could lead to certain spatial configurations for architectural or urban planning purposes.

3.1.3 SIMPOP Models Family

The SIMPOP project [21] is based on collaboration between teams of computer scientists and geography scientists as a first multi-agent application system used in geography led by Denise Pumain. Models involved in SIMPOP family models concentrate mainly onto large scales urban systems. They are trying to observe relationships between the cities and focuses on spatial-temporal urban dynamics in order to better understand the possible interaction between cities. They are focused more on social and economic functions and interactions over time taking into account relative position of city networks within the landscape. Various strategies and methodologies are used in these cases: swarming behavior (simpopNano, Simpop2), netLogo simulation platform (simPoplocal), growth simulation and expansion of the urban systems (Simpop2 Generic Model) whereby agents represent geographical entities: town and cities. Such a model provides certain insight into the urban attributes in order to achieve urban dynamics simulation and asses the hypothesis provided by urban theory that „*the dynamics of a town or a city depends on its ability to interact with other towns and cities, which in turn depends on its relative situation in the settlement systems (in terms of hierarchical level, specialization, accessibility)*" [22]. This is another research approach of simulation and observation of the urban dynamics in terms of economic growth/expansion, population rate changes or urban spatial and interacting dependencies driven by agent-based systems with visual outcomes.

3.1.4 Fran Castillo, Responsive Environments, Ecosophy City Model

Fran Castillo [23] is exploring various city properties and characteristics in his several computational models. His approaches of city simulations test spatial organizations of city patterns based on different configurations strategies or measured real-time data. By means of agent-based models and several urban-data visualisation he is able to produce different outcomes focusing more on a particular city scale and state or information characteristics.

His Ecosophy City model verifies a theoretical and philosophical approach of city complexities established by Felix Guatari (Three Ecologies concept). The city in this case is understood as a machine whereby the complexity is optimized by agent system through the concept of so called "ecosophy". It is defined by three systems of ecological meaning: social ecology, environmental ecology and ecology of mind. The agents are controlling the spatial division system taking into account several layers of city characteristics: green spaces, economy, public transport, services, social interactions or so called DIY infrastructure. The model has animated visual and spatial outcomes.

3.1.5 SynthCity simulation models: UrbanSim, UrbanCanvas, GeoCanvas

The group of three simulation platforms provided by SynthCity Company [24] includes analysis and visualisation tools in order to better engage within decision makers and architects community in terms of urban planning from macro to micro scale, analysis and design. The tools provide robust approach into the visualisation technology as well as evaluation and estimation of different urban scenarios with various inputs.

UrbanSim [24] is advanced ABM platform enabled to simulate advanced urban dynamics in various scales. The tool is mostly used as an analysis platform bringing insight into a wider urban performance in terms of demographic processes, long-term and short-term choices, land use regulation, transportation, real estate processes and economic conditions. With the integration of UrbanCanvas tool and global scale analysis with GeoCanvas one is allowed to enter into the robust analysis and urban estimation environment with different visual outputs. However, the tool does not provide wider spatial quality analysis of the environment in terms of urban activity graininess [47] and local bottom-up approach, but has a very strong potential to integrate different datasets into the simulation process for further consideration. As such, the simulation tool is definitely a powerful urban simulation and decision-making tool, but more focused on a top-down planning and scenario estimation.

3.1.6 Esri CityEngine | ABM Simulation Model by iA Chair of Information Architecture ETH Zurich, G. Aschwanden et al.

A well-known visualisation and modelling tool called CityEngine is based on procedural modelling process in order to achieve realistic model of city environment mostly used by game industries, movie companies or top-down urban planners. The tool provides integration with GIS data as well and by that way it is possible to publish developed model content online. The tool does not provide any nonlinear local-decision bottom-up modelling based on lower-level rules. However, it is possible to validate certain spatial configurations during the planning process in a very simple way without robust modelling process.

The ABM model used within the framework of the CityEngine application has been established by Gideon Aschwanden et al (2009) as a crowd simulation and occupant movement study whereby urban space was modelled procedurally. The method for populating generated 3D city model with crowd has been introduced in a simulation model of agent behavior. Such a model provides quantifying correlations of function of buildings, number of people and density fluctuation. In that manner the simulation model deals with the city space in order to identify e.g. possible problems for evacuation scenarios, accessibility or stress of the pedestrians. The agents are very precisely specified in the model with wider set of their characteristics. The simulation provided is definitely useful for the analytics, decision-making and urban design purposes as a decision making tool and as a communicative tool for stakeholders. However, the model does not provide changes in the urban patterns according to the needs of participants based on local decisions. The introduced simulation is specific in terms of procedural modelling, but the automatization of the urban form and space is not dependent on the crowd source's requirements. Nevertheless, the simulation provided is one of the cutting-edge platforms where it is possible to observe urban space based on the crowd behavior represented by agents with specific properties.

3.1.7 City Modelling By Michael Batty, CASA London, UCL Bartlett, London

Michael Batty (2007) [7] has been engaged with simulations and configuration of cities based on bottom-up paradigm for a long time. Batty recognizes the structure of a city as a cellular system of modules (cellular automata) that interact and influence each other. His theory is based on the theory of complexity, from which a city transformations are being emerged in certain time horizons. Models divide the urban landscape into abstracted smaller cells. The cells from which the construction spreads have strong interrelations between themselves and form the developing processes within the city under the rules of lower degree. They offer a variety of urban figures of development that can be specifically identified.

Forms lead to the fractal shapes of varying degrees of density and accessibility. This is essential when considering on what shape the city could be more appropriate in future than those that we identify today and also what tools are needed to achieve these equable forms.

Batty besides CA operates with agent-based systems as well in order to affect the fixed cellular structure. In this context he defines the need of using so-called mobile cell in order to be more accurate to urban dynamics. A mobile cell called agent can move between cells. These are objects that have no fixed position, but interact with other agents and with the environment where they operate. He examines the movement of agents and their arrangement in a simulated urban structure, looks for distribution position and geometric arrangement of pedestrians, the shortest distances to city potentials, migratory movements in the country, the behavior of pedestrians at the street level and in an idealized shopping mall, all this in a variety of agent-density populations with different parameters. CASA UCL is representing these developed city models within Unity3D game engine environment.

3.1.8 Models by Simulation Platform - Future Cities Laboratory SEC ETH Centre / SENSEable City Laboratory MIT / MIT SMART Laboratory, Singapore

Future Cities Laboratory Phase I and Phase II [25] established by Singapore ETH Centre for Sustainability and NRF in Singapore is a cutting-edge institution in the field of research in terms of urban design, big data urban simulations modelling, observation and evaluation cities behavior from different point of views, city sustainability and city density topics and other relevant fields regarding the future development of cities, mostly focusing onto the issues of Asian urban environments. Experts from several scientific fields cooperate in order to obtain multi-disciplinary approach of understanding of the city behavior and to develop better strategies, attitudes, concepts and decision-making tools for architects, stakeholders or government institutions.

Several various scaled models have been established by researcher Eva Fridrich [26] dealing with agent-based simulation in order to study and explore possible pathway networking, traffic accessibility and walkability, user space vision within the selected urban areas and adaptability of the urban fabric based on agent and user interaction in a lower level (Space-driven pedestrian flow analysis model and Singapore traffic accessibility model). Together with Dr. Matthias Berger, Prof. Dr. Gerhard Schmitt and Prof. Dr. Stefan Müller Arisona, Eva developed also an energy consumption model of Ethiopia (Addis 2050) [26] in order to explore energy supply for Ethiopia with various energy sources. In an interactive way, a user is allowed to edit the supply network and obtain a real-time numeric feedback on the state of supply and demand.

Similarly the SMART platform founded by MIT in Singapore has been involving within the urban simulation field from several horizons for a longer time. It has developed a simulation platform LIVE! Singapore [27] whereby it is possible to explore in a real time processes in an eye-catching visual animation outcome several city behaviours just running in Singapore: citizen phone talks, energy distribution, urban heat accumulation, public traffic systems - taxi, public transport, urban mobility within the city as well as with Singapore connection with whole world by planes and ships, citizens movements during cultural events in the city using certain simplified visual diagrams. The model deals with big datasets provided by national statistical agencies from public and private sectors. The model serves as an information and visual platform for further consideration and explanation of how the city space can be perceived and read.

3.1.9 KAISERSROT Model

The software tool Kaisersrot [28] developed by Chair of CAAD group at the ETH in Zurich is based on bottom-up approach within the urban design and planning operating with ABM methodology, evolutionary algorithms with robust set of parameters. It is focused on every urban scale and the tool provides different outcomes taking into account user-defined conditions. The tool has interactive 2D and 3D environment based on various spatial parameters. It deals with a collective control of parameters in order to fulfil the demands and requirements of the future participants of the environment. The outcome is an urban plotting and area zoning whilst it tests various scenarios in a new urban structure. It does not operate with the urban reconfiguration of an existing area. However, the tool is very powerful in terms of bottom-up simulation and as a generative design platform is often used by architects worldwide.

3.1.10 Tom Verebes, OCEAN CN Platform: Parametric Pearl River Delta Computational Model Interfaces and 4D City

Architect Tom Verebes and his consultation platform Ocean CN [29] concentrates onto various urban scales whereby his proposed urban models are not defined as a definitive single ideal solution but offer multi-layered verification with several options and possible outcomes that respond to fast-changing environmental conditions. Verebes (2014) understands city as a never-ending and unfinished fluid network with different pretensions in time and taking into account these facts he is able to produce variable design outcomes rather than one finite design solution. The questions comming from his research agenda are mostly: Is it possible to design emergent urbanism and how is it possible to model and simulate it? How to capture and articulate emergent phenomena of a city in order to better understand the city behaviour? Is a city adaptable according to its environmental and internal conditions?

The Ocean CN platform established a series of parametrical computational city model for the Hong-Kong - Shenzhen Bi-City 2009 Biennale as user model interfaces. The spatial characteristics of the 11 Pearl River delta cities have been involved into computational models and users were allowed to design their own city space within graphical user interface. These series of coded computational models can serve as a parametric platform in order to find various spatial city models driven by scripted internal conditions taking into account diverse initial massing topologies, densities, proximities and accumulation of massing within the rapid urbanization issue of the Pearl River Delta area in Asia.

The 4D City project is established as a collaboration between dotA studio and the Ocean CN. It deals with the urban layout of 25 sq km brownfield site, 50 km south of Beijing. The masterplan is defined as a multiple and not singular outcome. The model operates with different programmatic mixes and their associated typologies. In that manner the landscape consists of various blocks with differentiated height, footprint and typologies in order to observe novel urban patterns taking into account programmatic variations of urban environment.

3.1.11 MATSim

Another analytical tool MATSim [30] developed by ETH Zurich and TU Berlin is a powerful agent-based simulation platform for large-scale traffic modelling purposes. An open-source JAVA-based code is capable to be enhanced by implementing different user-defined modules in order to gain insight into the wider aspects of the traffic analysis. MATSim is able to simulate fast agent-based traffic mobility scenarios within the urban interactive environment defined in 2D space. In provided different tool modules one can simulate demand-dependent characteristics of the urban environment. The tool is very specific in terms of traffic simulations and does not provide any insight into the urban pattern spatial development or spatial reconfiguration scenarios.

3.1.12 Simulation Models by Jakub Vorel, FACTU Prague

Associate professor Jakub Vorel (2010) from the Department of Spatial Planning at the Faculty of Architecture CTU in Prague conducts several case studies based on agent-based simulation models and investigates selected urban environments in a wider urban scale in terms of land-use and urban pattern evolution. He introduces computer simulations as applications in educational and research activities (2010) in urban design, spatial planning and economics.

At his research he is mostly focused on bottom-up simulations in terms of agent-based models and 2D cellular automata representations in an entire city scale taking into account complex systems theory, i. e. local interactions between particular urban actors. At his experimental urban simulation model of micro-region Tábor he explores residential land-use changes and tries to identify the spatial factors which have the most significant influence onto urban changes. He simulates in a 75m x 75m cells grid the spontaneous and dependent land-use change dynamics based on several factors such as accessibility of public infrastructure, attractivness, physical characteristics of the land and externalities between neighbouring land uses (2010) in the first step and other demographics factors in the second step. Despite the fact he takes into account various urban dynamics and provides a probabilistic urban simulation model in a precise way and in various scenarios of urban processes, the results are still in a wider city scale and visually and graphically represents the 2D maps only. However, his smiluation models yield various benefits in research, study and education. Vorel argues the agent-based bottom-up approach is very suitable for the study of various urban processes on a local level based on local externalities and preferences. The further investigation in a model provided in this thesis will be concentrated onto a local neighbourhood scale and will be more focused on spatiality of the urban environment.

3.2 Speculative Emergencies

Several research agendas taking into account emergence phenomenon are trying to explore boundaries of architecture and urban design in terms of looking for novel tectonics, unpredictable development of urban patterns or unusual spatial scenarios built by new or now even unknown technological possibilities such as Taron or Zomparelli et al. in Achten et al. (2012). Research in this context means speculation outside the usual architectural or urban articulation of the form and content. The theoretical approaches dealing with speculative realism and object-oriented ontology thought patterns reflect different understanding of the world, relations and matter within the reality and virtuality. In various scales, architectural and urban design are experiencing this philosophical and technological shift in the contemporary post-digital architectural discourse.

3.2.1 Kokkugia research, Roland Snooks, Robert Stuart-Smith

Studio Kokkugia [31] is focusing on computational approaches in order to develop speculative design model platforms which deal with complex and self-organized geometries or selected behavioural strategies which reflect social, material or biological properties of the investigated environment. The London and Melbourne-based research studio operates with generative design methodologies exploring possible future urban environments or architectural objects. Experiments with the phenomenon of emergence represent the primal objective, which is deeply integrated into the design processes based on behavioural matter with uncertain and unpredictable principle. Agent-system models help to achieve this kind of design strategy. The autonomous agency is able to generate a sophisticated and complex environment by means of simple local interactions of agents in order to form a self-organized collective-designed pattern.

Kokkugia established several speculative models e.g. based on Swarming behavior strategy dealing with different scales from urban to architectural objects.

3.2.2 Biothing | Continuum, Alisa Andrasek

Research of Alisa Andrasek [32] is dedicated mostly on exploration of generative methodologies used in experimental architectural design approaches by means of computational and advanced scripting techniques in an open source platform. She accumulates various computational techniques which drive the urban, architectural or material formations. Patterns emerge by means of behavioral and sophisticated geometric arrangements within expressed simulation models. By such a principle, the designer can be considered as a code writer who works within various scales and production constrains. The accumulated techniques are stored as a toolset library which can be provided as a multi-strategic platform dedicated to groups of experts sharing their collective knowledge and creating relational infrastructure.

3.2.3 New Territories , (n)Certainties, Ezio Blasetti | Francois Roche

Another approach dealing with emergence phenomenon is taught by Francois Roche and Ezio Blasetti as a thought pattern paradigm on various educational institutions, mostly GSAPP, RMIT, USC LA or Die Angewandte whereby in established studio courses students of architecture are exploring architectural and urban speculative constructs from micro to macro scales and operating with new materialities, construction methods, computational processes or robotic expertise in order to estimate and overpass boundaries of contemporary architecture and urban discipline also from a philosophical point of view. The concept (n)Certainties [33] is based on a shared library of computational processes by means of blog archives from each academic time period dedicated to various topics. The courses are supervised by Ezio Blasetti and Francois Roche as well as other experts from the field.

Ezio Blasetti [35] is exploring new potentials in the architectural and urban environments [34, 36, 38] by means of computer coding and generative procedures. He is searching for novel methods of fabrication and manufacturing. He is focusing mainly onto micro scale of new standards of materialisation in order to implement the logic of coding into the organizational process of spatial materiality. He has founded several research, practising and educational platforms.

Francois Roche is the principal of New-Territories [37] research and architectural studio platform seeking for articulation of fiction / real situations within wider architectural context in different geographic territories. He is mostly focusing on exploring the boundaries between speculation and real practise, between fiction and reality. His blog contains several approaches and theoretical ideas in order to provide different scenarios of thinking in the framework of architectural or urban attitudes.

3.2.4 Nonstandard studio, Daniel Bolojan

In the context of emergence paradigm Nonstandard studio [39, 40, 41] is one of the major research platforms as well dealing with agent-based computational models. Controlled agencies in different scales manifest the self-regulated and self-autonomous morphology of the internal rule-based behavior in order to achieve robust complex articulation of the investigated situation. The agents are controlling the space or pattern activation and interact with each other or with the agents' traces and influence lager urban processes taking into account organizational conditions and subdivisions of wider spatial urban and architectural structures.

3.2.5 Plethora-Project by Jose Sanchez, Block'Hood Urban Game

Jose Sanchez is an architect, researcher and game developer based in Los Angeles, California. As a long-term investigator of various computational strategies used in architecture and urban design he cooperated with several architectural experimental studios and teaches on universities worldwide. He established the Plethora-Project platform [5] as an e-learning basis and scritpting and tutorial library for architects and researches. He mainly focuses on the relations between architecture, video games and generative design.

Sanchez developed the computer urban game Block'Hood [51], where it is possible to built, observe and virtually inhabit the custom-made future city in a neighbourhood scale in a various configurations. Using the building blocks and several urban dynamic strategies, he provides an incredible insight into the emergent city behavior and explores how the city elements and city configurations can relate to each other. The system based on bottom-up stimuli shows the ecological and entropical aspects of the urban environment in a computer game and taking into account the urban needs that have to be fed, it is even possible to observe an urban decay, abandonmnet or destruction of the modelled neighbourhood.

For the purposes of the case study provided in this thesis (in the next chapters), the several computational agent-based strategies and Plethora library for Processing have been taken from the Plethora-Project platform as a principal base for the computational model. The game Block'Hood, announced online after the thesis model had been developed, it can serve as a reference basis for the future research of the developed computational model EmCity presented in the next few chapters. As a state-of-the-art reference would be crucial in the future work and investigation.

3.3 Chapter Conclusion

Several computational models have been introduced as well as various research agendas dealing with the emergence phenomenon in various architectural or urban scales. Most of the research content is free to explore online.

The chapter summarized research of architectural or urban design platforms and agendas which are taught as well on prestigious universities worldwide. Most of them are exploring computational methods based on agent-based modelling in order to discover novel tectonics in architecture, construction or uncertain and unpredictable processes of form finding and new principles of fabrication or building procedures.

On the other hand, the simulation computational ABM models introduced in the previous chapter part serve as information platforms for understanding the selected behavioural aspects within the city in visual and time-depending outcomes. In the contemporary post-digital era it will be necessary to articulate these aspects into the planning and design process in clearer way, which is one of new research programmes at the Future Cities Laboratory in Singapore ETH Centre. In that manner another research questions are established as similarly as Prof. Verebes (2014) is asking: How to deal with these information aspects within the urban design and within the real environmental conditions? Is it possible to shape or utilize an urban environment based on these wider information aspects?

3.3.1 Summary of the Accumulated State-of-the-art Knowledge and Meaning for the Particular Research Outcome

The thesis in the next chapter will be focused on finding the way how to answer the above mentioned questions. The selected computational approaches mentioned in previous part in terms of novel tectonics and unpredictable urban design strategies together with the measurable bottom-up characteristics of already existing areas are considered as a basis for a thesis study experiment in order to attempt answer research questions and verify the hypothesis provided in the first chapter.

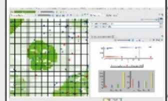
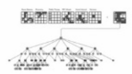
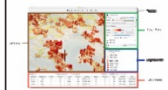
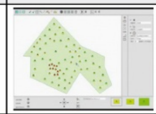
Shaping urban environments based on integration of wider set of information about city space and city behavior will be crucial in the future time horizons in order to capture or partially predict the city re-shaping and reconfiguration based on urban participants' demands or requirements as well as demands of developers, stakeholders or government authorities.

According to the idea of Batty's concept of agent and cellular automata simulations [7] that are based on complexity theory and the behavior of agents in the urban structure on a lower level, a research project has been established in this thesis as a case study in order to specify and observe selected dynamic phenomena in already existing city environments and to attempt to define its potentials or deficiencies. Taking into account different environmental conditions, the model has an ambition to be adapted to different scales or different urban situations as well.

The computational model in the case study will deal with dynamic variable system of urban cells taking into account distribution of agent flows within an environment where agents directly influence solid urban structure. Based on the mentioned simulation models and review of existing state-of-the-art projects and literature, the following objectives have been established in order to specify clearer details of the work outcomes. A comparison of the expected research results with mentioned models in the table determines the further characteristic direction in a particular case study.

By means of the table comparison between various above mentioned models (Tab. 1), one can consider the UrbanSim platform as the most powerful and appropriate simulation tool taking into account wider simulation aspects, nevertheless it is more focused on policy characteristics and top-down approach whilst the Kaisersrot tool has a very strong potential in terms of bottom-up approach implementation. Considering the emergent phenomena, the Kaisersrot model provides, simulates and generates the urban form more efficiently rather than UrbanSim, which is a rather analytical tool. In particular, the Kaisersrot model deals with urban formation as a design generative tool for urban design of the new developed areas. On the contrary, EmCity will be strongly focused more on a spatial qualitative representation of an existing urban patterns and reconfiguration in spatial structure based on emergent phenomena in terms of distance and diversity requirements. By means of its code organization based on a JAVA/Processing programming language [9] and an object-oriented architecture, it has better chance to implement a big data approach later on inside the simulation environment, despite this thesis does not consider this approach.

The comparison does not provide any classification about functionality which model is better for urban design, because each model represents different simulation attitude within urban design and decision process. Some of the models are more focused on economic and policy aspects, others on spatial configurations in urban structure without wider consideration of further characteristics about non-spatial urban dynamics. Urban designers and simulation experts nowadays still encounter the problem with the common urban dynamics simulation at one robust simulation or software application platform. It is still impossible to provide wide and overall insight into the city behavior from every single aspect. EmCity has not that ambition, though it will offer a spatial classification of an existing urban pattern with visual and 3D model outcomes in order to enhance urban designers' and architects' repertoire in their decision making processes during the early design stages.

ABM | GENERATIVE simulation models in urban context										
CAPACITIES / CRITERIA	G A M A	SIMPOP Family models	Ecoscopy City model	Sythcity UrbanSim	Sythcity GeoCanvas	Sythcity UrbanCanvas	CityEngine+ABM (iA Chair ETH Zurich) Aschwanden et al.	Kaisersrot (CAAD ETH Zurich)	MATSim	expected characteristics EmCity platform
										
ABM MODELING	O	O	O	O	x	x	O	O	O	O
LARGE SCALE MODELS	O	O	x	O	O	O	O	O	O	O
LOCAL SCALE MODELS	O	x	O	O	x	O	O	O	O	O
SOCIAL / MARKET SIMULATIONS / EXCHANGE	x	O	x	O	O	x	x	x	x	x
GIS DATA IMPLEMENTATION	O	O	x	O	O	O	O	O	O	O
MULTIPLE LEVELS OF AGENCY	O	O	x	O	x	x	O	O	O	O
SIMULATION BASED ON LOCAL DEMANDS	O	O	O	x	x	x	O	O	O	O
URBAN MOBILITY SIMULATION / TRANSPORTATION	O	O	x	O	x	x	x	x	O	x
SIMULATION OF DISASTER SCENARIOS	O	x	x	x	x	x	O	x	O	x
URBAN ACTIVITY GRAININES SIMULATION	x	x	x	x	x	x	O	O	x	O
MATH MODELS	O	O	x	O	O	x	x	x	O	x
NONLINEAR MODELLING	O	O	O	O	x	x	x	O	O	O
EMERGENT PHENOMENA IN URBAN PATTERNS	O	O	O	x	x	x	x	O	O	O
SPECIFIC SPATIAL ALGORITHMS USAGE	O	O	O	x	x	x	O	O	O	O
BIG DATA INTEGRATION POTENTIAL	O	x	O	O	O	x	x	x	O	O
SPATIAL SIMULATION IN URBAN STRUCTURE	x	x	O	x	x	O	O	O	x	O
URBAN RECONFIGURATION / CHANGES IN LOCAL SCALE	x	x	x	O	x	O	x	x	x	O
GENERATIVE PLATFORM FOR URBAN DESIGN	x	x	O	x	x	x	O	O	x	O
DECISION MAKING-TOOL FOR ARCHITECTS	x	x	O	O	x	O	O	O	O	O
OPEN SOURCE	x	x	x	O	x	x	x	x	O	O
GUI / 2D / 3D ENVIRONMENT	O	O	O	O	O	O	O	O	O	O
EXTENSIVE LANGUAGE / EXTENDABLE FOR OTHER APPLICATION	O	x	O	x	x	x	x	x	O	O
ADVACED VISUALISATION / RENDERING	O	x	O	O	O	O	O	O	x	O

Tab. 1. A comparison of the content of research outputs: ABM and generative simulation models and expected developed simulation model EmCity in a case study. The green cells represent crucial missing characteristics that EmCity application is trying to involve in.

IV. Simulation Model of the Environment Reconfiguration: Prague, South City

4. Case Study Prague South City: Simulation model based on Bottom-up Strategy

4.1 Computational Model of the South City Reconfiguration

Fig. 12 Selected part of the city for the case study: South City Prague.

This research aims to track and simulate the above mentioned urban dynamic processes using a case study of a particular selected and already existing site. The city part Prague - Jižní Město (South City) has been selected for its potential for further development and re-configuration in future time horizons (Fig. 12). It is an urban residential satellite characterized by overwhelmingly uniform living features with a population of 80,000 and the good traffic accessibility as well as public transport links to the city centre (Laskovský, 2011). The research in the case study focuses on the potential for further growth, re-configuration and transformation of the environment, targeting mainly at complementing and expansion of urban activities, additions and changes in infrastructure, communication and distribution flows to strengthen the dynamics of growth or thickening of the environment using parameters that express specific user requirements for their environment, respectively demands of investors and developers.

Research proceeding is as follows:

(a) Determining the lower-level simulation rules of reconfiguration within the existing bottom-up strategy;

(b) Application of the rules of reconfiguration to the existing urban situations using relevant algorithmic methods utilizing scripting techniques, and development of the simulation model;

(c) Testing the simulation model of the existing environment, complementing selected parameters;

(d) Evaluation, estimation, on-line publication of the simulation model.

4.1.1 Environment Participants´ Demands

The examined city urban structure is composed of communication traffic flows, block and solitary buildings, in which housing is the predominant function, while the built-up area also consists of urban services, administrative activities, environment and public spaces for leisure and rest activities.

For the purposes of determining simulation rules of reconfiguration it is necessary to define which aspect needs to be reconfigured, based on the needs of participants-users. In the first step, it shall be the walking distance to sites of respective activities and hence the reconfiguration of the communication flows. The next step will be to monitor the changes in positions of respective activities, their strengthening, growth and changes of structures in their shape and volume. This monitoring will be based on the interaction of agent-based system representing the needs of participants seeking sites of their activities with respective elements of urban structure. One of these aspects or combination thereof may cause the reconfiguration and re-modelling of the existing environment.

Selected requirements and objectives of the participants (sufficient walkable distance to various places of interests) were available on the basis of online questionnaire [16] and the public inquiry research South City-a place for Life provided by The Municipality of South City, Prague 11 [17], [18].

4.1.2 The Aims of the Simulation

The main objective of the reconfiguration simulation of the existing environment is to gain insight into the possibility of developing a diverse urban structure with an emphasis on increasing the quality of residential and public urban environments. The current state of the environment has certain inadequacies that reduce the environmental quality. These are in particular: strong uniformity of post-totalitarian urban environment, the lack of available and city-creating public spaces, approach distances to places of public activities are insufficient in some parts, the environment has a large blank areas that are unrelated and separated by barriers of highways.

The aims of the simulation are mainly:

• Verification of the importance of selected places in the model and their prospective intensification with new urban activities.

• Strengthening the environment diversity, i.e. eliminating the spatial and visual uniformity of the areas.

• Verification of approach distances to urban activities (maximum 10 minutes of walking time, about 700-800 meters or even less).

• Strengthening and possible reconfiguration of communication (distribution) flows.

•Distribution and incorporation of surrounding green areas - forest parks in the environment of existing buildings - land overgrowth into the city.

• Extension of public and private activities with relevant spatial structures with different typological form (new volumes), i.e. completion within the framework of undeveloped land without habitable scale.

The diversity of the environment defines its habitation quality in several levels: diversity of used typologies, densities, the differentiation of the urban meaning (centre, middle, verticals, core meanings, significant characters) and spatial levels (landscape, city and detail), diversity of building types (Norberg-Schultz, 1979) and the diversity of population groups with different areas of interest.

4.1.3 Input Parameters of the Simulation

The input of participants' requirements in the simulation model includes the minimum approach walkable distance into the positions of targeted activities and defined specific targets-attractors within a certain extent representing the objectives of the participants. The agents have a predefined initialization position (multiple locations in the model) according to the local real conditions (metro station, strategic transport nodes). The group of the agents will seek existing activities and areas (e.g. habitation). Further input parameters (variables) are the values of the speed movement of the agents, the level of attraction according to the selected targets, the value of maximum approach distance, the number of agents in the population, the way of agents' movement within the environment (several values of agents' behavior based on existing communication flows, parameters of spatial configuration based on swarming behavior, stigmergy, path following and free space distribution) [1], [2], [3], [4], [8]. The model is fully costumized, extendable, and model inputs can vary.

4.2 Methodology

4.2.1 Workflow of the Overall Process

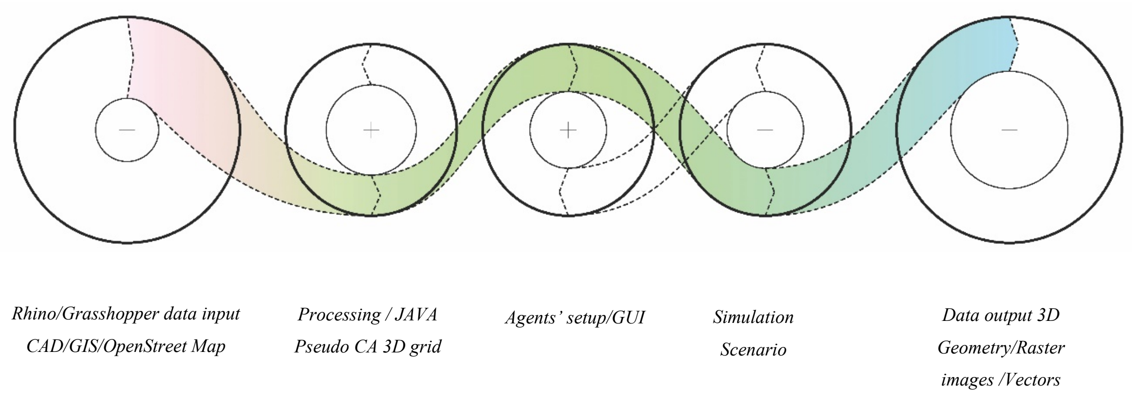


Fig. 13 Diagrams of the workflow according to the data preparation and further steps. The processes between agents' set-up and simulation scenarios are based on a feedback loop, i.e. it is possible to change the parameter inputs during the simulation.

The overall workflow is represented in Fig. 13. It was necessary to edit the data in a common CAD 3D modelling program (in this case the Rhinoceros / Grasshopper application was used) in order to prepare them for the Processing import. The CAD/GIS data have been provided by © the Institute of Planning and Development of the Capital City of Prague. For the simulation purposes data can be used from the OpenStreet Map platform as well. The CAD data are considered as a geometric basis for the simulation model which is imported via text string into the Processing environment [9].

4.2.2 Technological Description of the Simulation Model

For the development of the simulation model and its graphical expression using the defined rules, several computational scripting techniques have been selected in the programming language Processing with the use of algorithms and relevant strategies (Fig. 14), in the field of Path following algorithm, partially flocking algorithm (Swarming behavior [1], [4], [8], [10], [11] with separation, cohesion and alignment characteristics in order to define spatial conditions - spacing distances between elements), attraction (seeking targets) and pheromone path following – stigmergy [3], [15] (simulation of motion and communication distribution flows, accumulation of activities at the site).

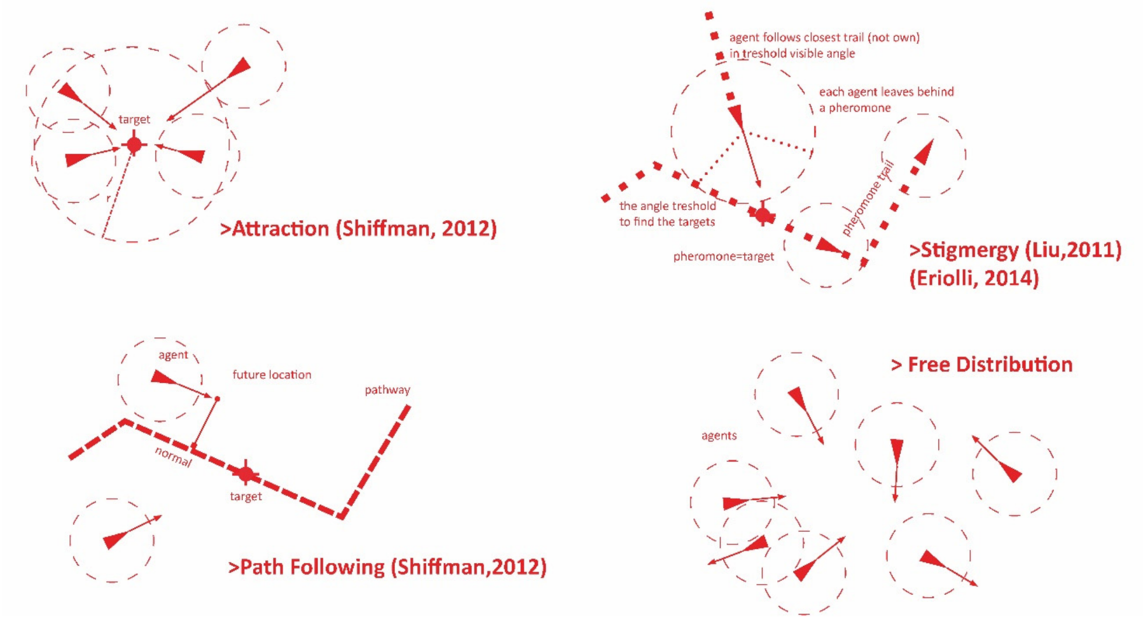


Fig. 14 Diagrams of the basic agent-based movement: Attraction, Path Following and Stigmergy processes implemented by means of the programming language Processing.

Algorithms of the above mentioned vector agent simulation approximate the most to the spatial expression of the dynamic processes that are taking place in an urban environment with communication and distribution flows that involve interaction of the particular inhabitant with the environment or the interaction of inhabitants between each other, or, respectively, the mutual influence of the elements of the environment. Simulation model operates with the agents' class from Plethora library [2], [5], [6].

The thesis operates with spatial agent movements under the defined rules in the simplified way in a simulation model platform established as a case study in order to observe spatial emergent phenomena within the urban structure [12].

4.2.3 Environment Transcription into the Model

In the first phase it was necessary to interpret the vector GIS data of the current site into the Processing environment for the simulation needs into two layers: the vector flow and the cell grid. The cell grid layer represents existing activities and volumes of the urban structure, which consists of the cell clusters (Batty 2007, 2011) [7]. The dynamic processes in the urban environment are interpreted by the vector flow (Fig. 15).

Fig. 15 Transcription of the environment into the agent-based model. The diagram contains GIS data, the 3D grid layer for the pseudo cellular automata and the vector agent flows layer.

The agents will respond to attributes of the environment such as physical barriers or infrastructure by adopting their behavior to the features of the modelled environment. Both layers are in mutual interaction.

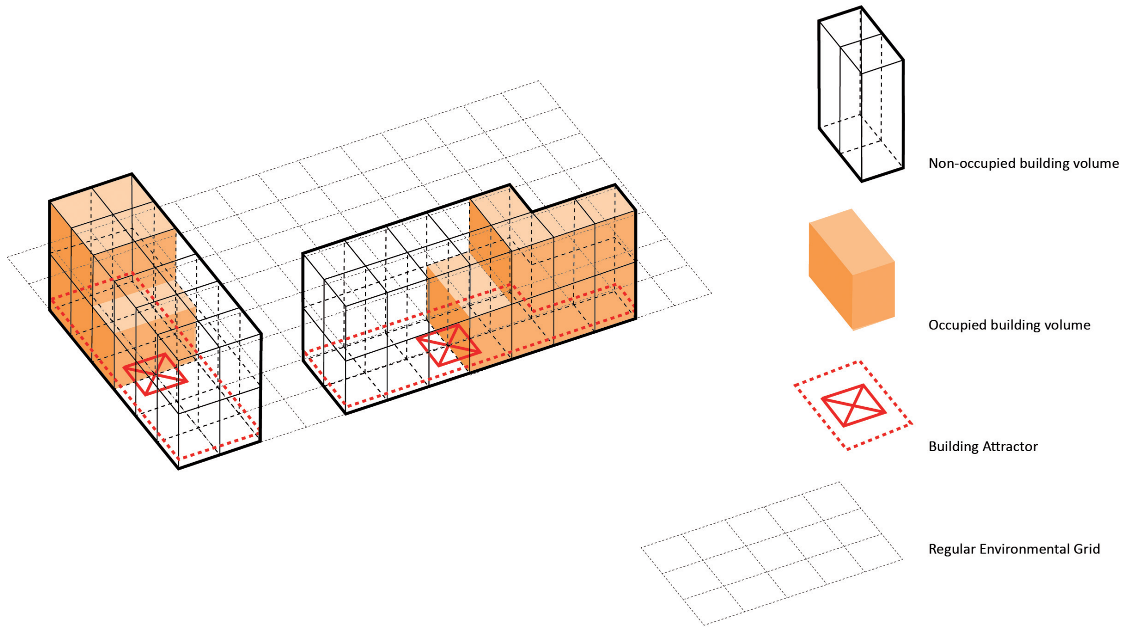


Fig. 16 The existing building structure is defined by cell cluster. Cluster operates with occupied mass capacity-it receives specific number of occupying activating agents.

There are urban activities defined as attractors and initial positions of agents in the cell grid and these attractors influence behavior of agents in the flow layer. The cell grid is apposite to the geometric characteristics of the area and contains certain information about the structure (position, height map, characteristic number of agents received into the positions). The territory will operate with a predefined capacity of the environment for the selected number of agents, while the population of agents is characterized by its objectives for a specific boundary number of places for colonization or area reconfiguration (DeLanda 2011). The environment defined by the cell clusters will operate with proper basic capacity (current statement of the building, i.e. how many agents the building is able to accept) and extended capacity in the case of adding new extensions and volumes (Fig. 16).

4.2.4 Simulation Rules of the Colonial Growth and Reconfiguration

The colonization of the area will be conducted by searching of activities within defined approach distances and within unpopulated environment using initial groups of agents - colonizers and then by adding new geometric volumes within a predefined grid through a predetermined rule. The capacity of the agents' population and the environment capacity for a given number of agents are user-defined in the graphical user interface. The environment is able to embrace a predefined number of colonizers that inhabit the territory. The territory is supplemented and thickened with new areas defined on the basis of various capacities of agent population and environment. The simulation rules according to colonial growth will be as follows (Fig. 19):

• From the initial positions in a situation (defined centres of individual environment parts, subway stations, Fig. 17) defined number of agents are released. Agents are representing in a simplified way defined number of users (participants in the environment). It is necessary to find level of resolution of the agents (Leach 2009b).

Fig. 17 Agents' initial positions in the site represent key junctions in the pedestrian or traffic flows.

• The agents seek private urban activities in a specific time period within approach distance and fill the cluster to its unused capacity.

• If agents reach the private urban activities, their initial position and nature will change. Agents alter the target of interest and begin to seek public urban activities and continue to colonize the environment from different initial positions represented by already colonized private clusters.

• In case the basic capacity of the cluster is saturated by the agents, a new extended volume appears. The cluster attraction is removed from the original position and located to a new extension until it is saturated and subsequently it disappears.

• In case the agent fails to reach the activity within the approach distance, a new volume is established.

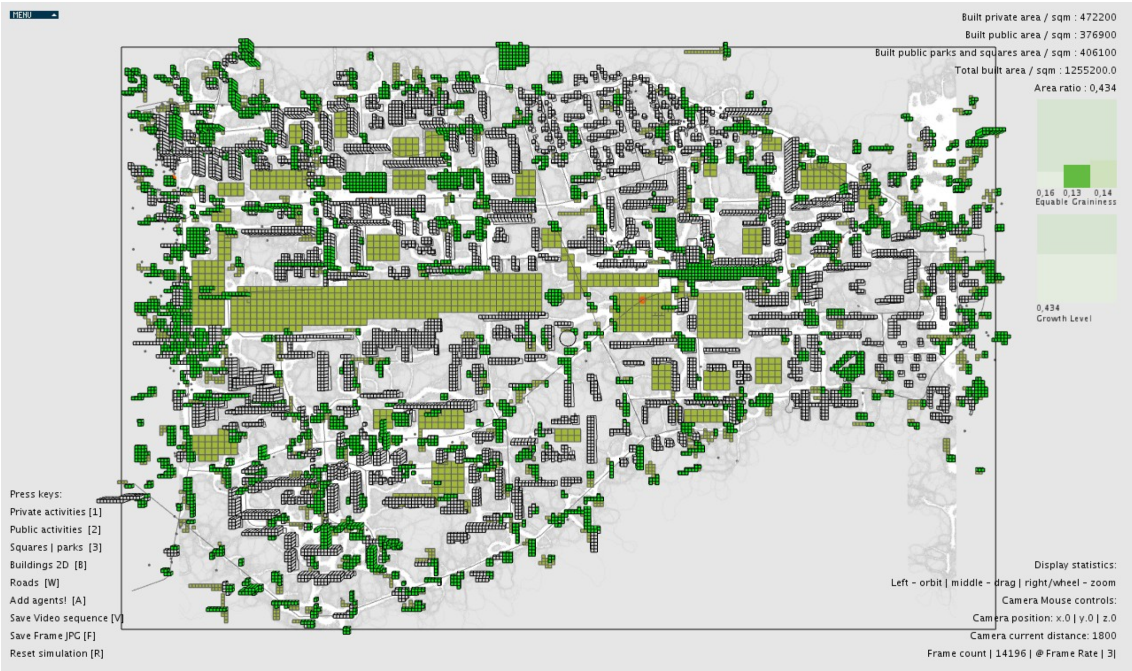


Fig. 18 Simulation model application in 3D environment with Graphical User Interface.

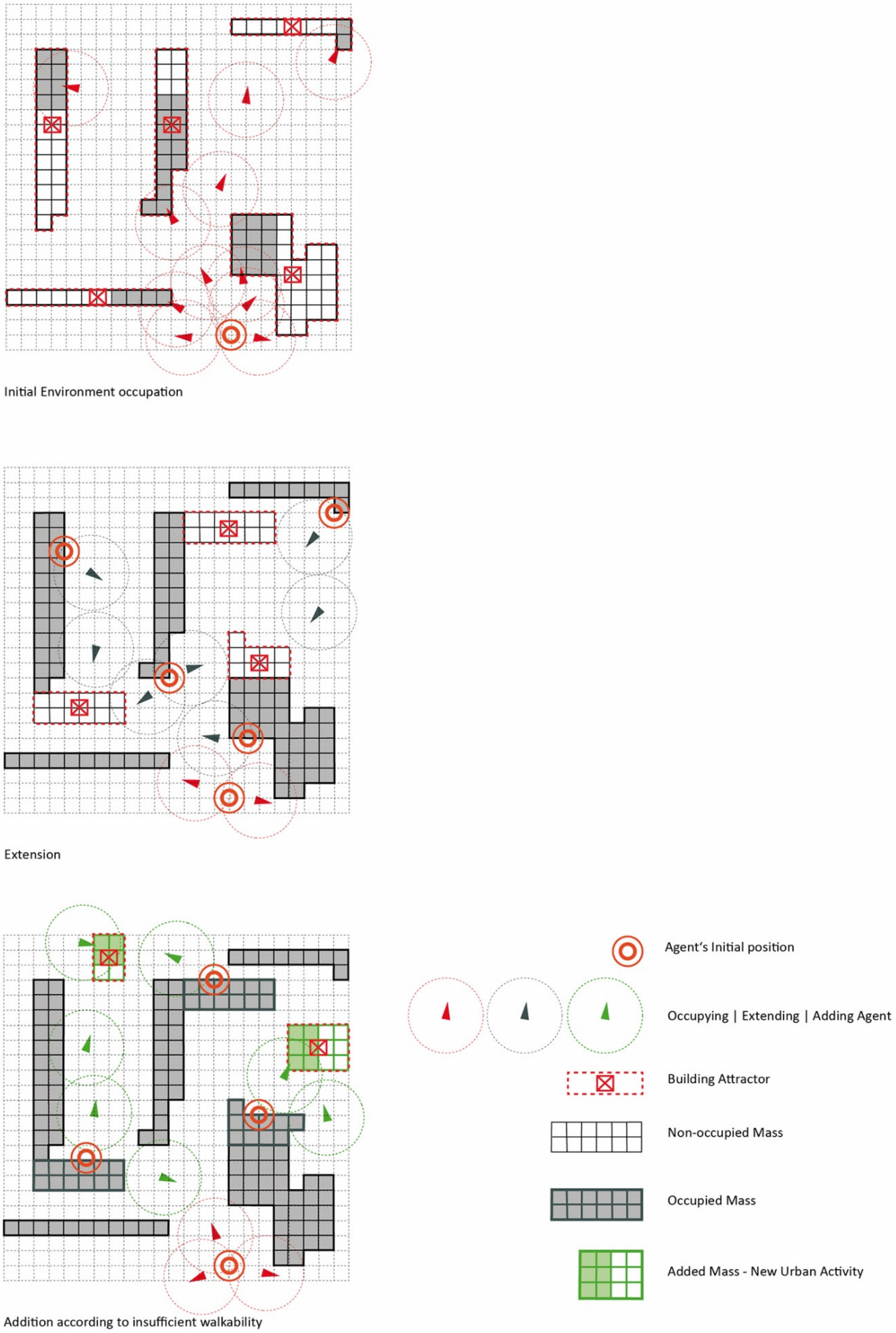


Fig. 19 Simulation rules of the colonial growth with initial positions and activated cluster capacities.

4.3 Graphical User Interface

The graphical user interface of EmCity has been proposed within the simulation model as a set of parameter sliders, buttons in hidden menu available on a mouseClick() function, statistical information about the content, charts and display information statistics (Fig. 18, 20). The interface is still extendable by other features and parameters according to the user needs.

4.3.1 Description of the Particular Features in the Graphical User Interface

Fig. 20 Graphical User Interface with features involved in the user menu.

Descritpion of the features:

Menu Pop up menu on / off.

Stigmergy Stigmergy algorithm on / off.

Scatter The spread of the agents when Stigmergy is ON.

Decay The intensity of the agents' pathway in a white colour.

Nsamples The accuracy of the stigmergy behavior.

Att_Distance / Show	Attraction distance factor to other agents / if Show is ON, the graphical representation of the attraction distance will appear.
Att_Angle	The vision angle during attraction.
Att_Factor to Buildings	The Attraction intesity factor to buildings.
Stigmergy Strength	The factor of stigmergy strength.
Attract	Attraction on / off to roads. If it is ON, the path following algorithm is running.
Path Following Factor	The intensity of the attraction to roads during path following behavior.
Swarming On/Off	The Craig Reynolds' Swarming behavior algorithm on/off.
Cohesion	The intensity of the agents' cohesion.
Alignment	The intensity of the agents' alignment.
Separation	The intensity of the agents' separation.

Generate Volumes	Generation of the urban mass according to approach walkable distance.
Approach_Distance	Walkable distance value (accesibility distance)
Show Trails	On / Off agents' trails in red colour.
Direction	On / Off agents' future location in 15/30 frames representing by red line.
Export PDF	Export of the current screen in the PDF file (vector graphics).
Export OBJ	Export of the current 3D model scene into OBJ mesh file. (3D mesh).
Private Activities[1]	On/Off Private buildings.
Public Activities[2]	On/Off Public buildings.

Squares | Parks[3]	On/Off Public parks and squares.
Buildings 2D	On/Off Building footprints – GIS | CAD data.
Roads	On/Off Traffic scheme.
Save Video Sequence	Save sequence of the images of the current scene appearance (raster graphics).
Save Frame JPG	Save single image of the current scene (raster graphics).
Reset Simulation [R]	Reset whole scene and strat simulation from the beginning from initial positions of agents.
Built private area / sqm	Value in sqm according to the scene status.
Built public area / sqm	Value in sqm according to the scene status.
Built public parks and squares	
area / sqm	Value in sqm according to the scene status.
Total built area / sqm	Value in sqm according to the scene status of the whole built area.
Equable Graininess chart	Graphical representation of each area ratio as a urban graininess [47]. Once the charts are in the same positions, the urban graininess is equable.
Growth Level chart	Information about the growth in the scene.
Display statistics:	
Left-orbit | middle-drag|	Mouse controls.
right/wheel-zoom	
Camera Mouse controls:	
Camera position: x|y|z	Statistics about camera position.
Camera current distance:	Statistics about camera distance from the origin point.
Frame count||Frame Rate||	Statistics about frame count and frame rate.

4.4 Emergent Behavior in the Simulation – Testing and Observation

It is essential to test a diverse number of transmitted agents of a particular type (public, private), the measure of approach distances and the measures of the population capacities influencing the volume sizes and environment capacity as well and observe the differences in structure and compare them. The simulation shall be tested with the same general inputs and parameters several times. It is also essential to compare models with different input settings to see whether the structure will develop differently or in the same way. By executing this computer based model several times, with different initial settings, one may discern patterns and regularities that recur in the results (Holland 1998). Architects can verify several spatial scenarios of the environment development by observing the differences between the results of simulation and look for appropriate structure, which creates a habitable or liveable environment and captures a sufficient volume required facilities.

4.4.1 Scenario 1: Basic agent movement: Free Distribution, Path Following, Stigmergy with Attraction Combinations

The developed simulation model has been tested with several different input parameters and user-defined set-up interactively during the simulation in order to control agent movement using different flow algorithms (Path following, Stigmergy, Free Distribution flow, Attraction yielding Urban Growth) and their combinations (Shiffmann, 2012). Four simulation cases have been tested in the first scenario in order to observe basic agent movements driven by algorithm control used with varied number of agents within 200-2000 iterations (Fig. 21, 22, 23, 24). The observation has been executed without urban activities graininess [47] in the first simulation scenario in order to consider the urban mass only, as results show.

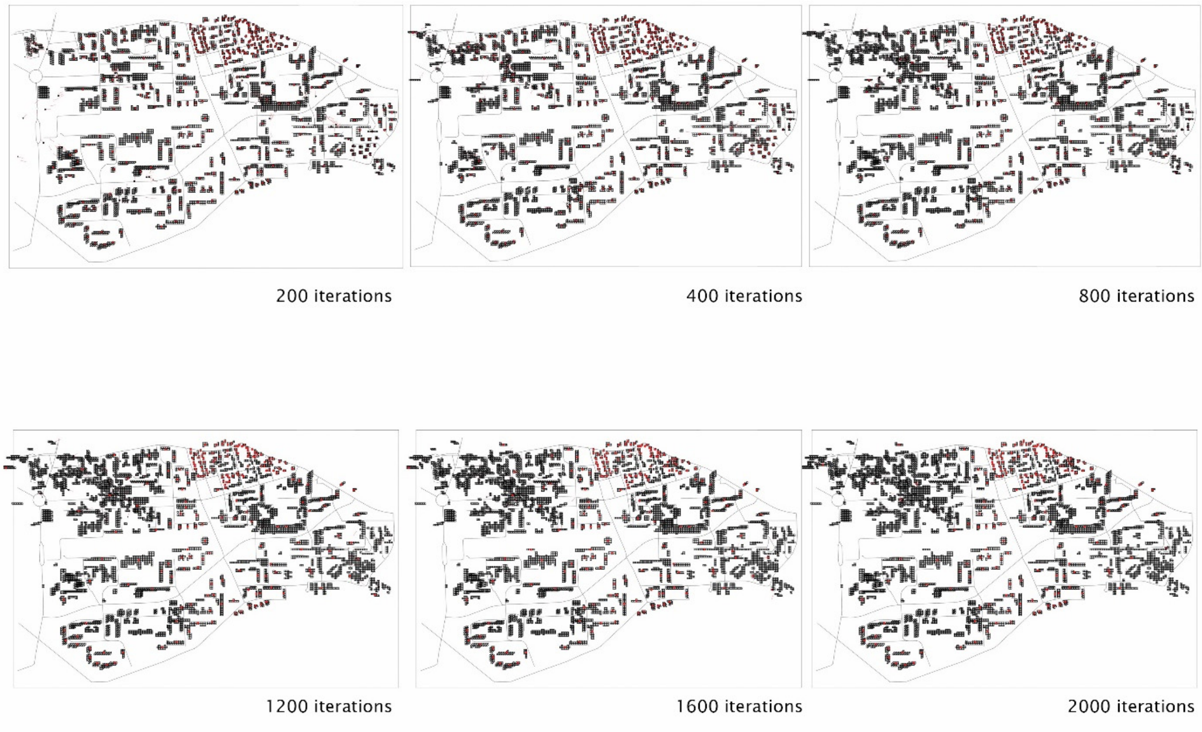


Fig. 21 An observation with 150 colonizers. Free Distribution Flow algorithm.

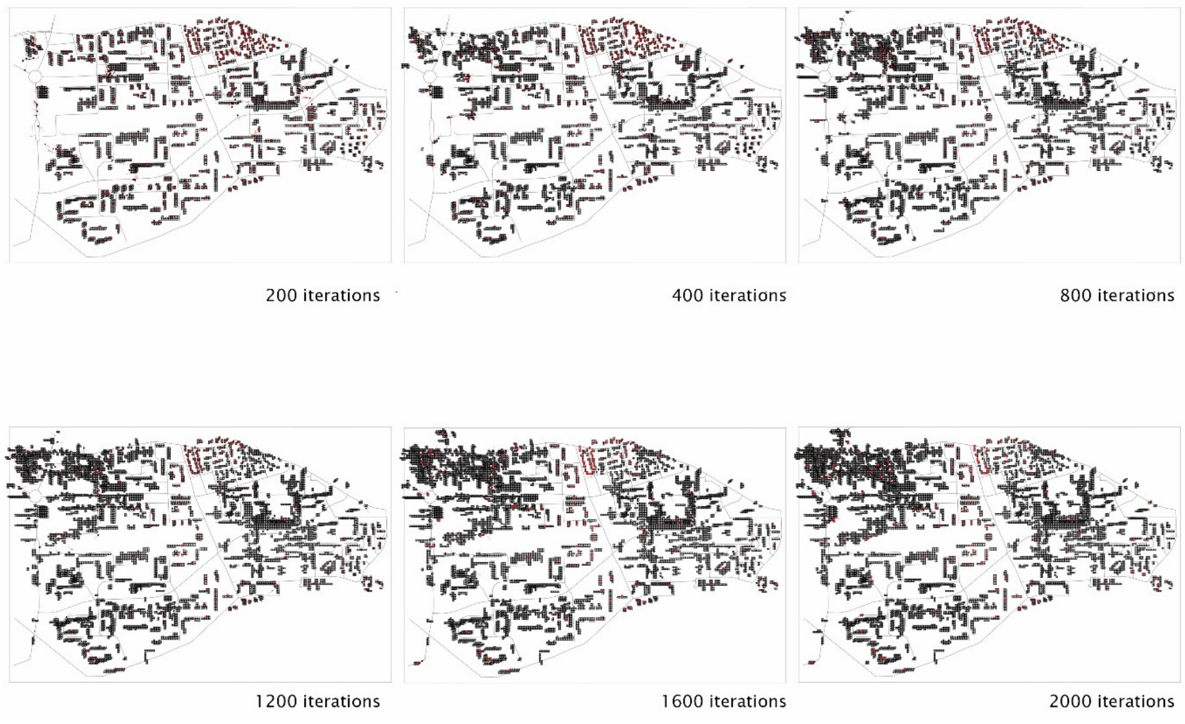


Fig. 22 An observation with 300 colonizers. Path Following algorithm.

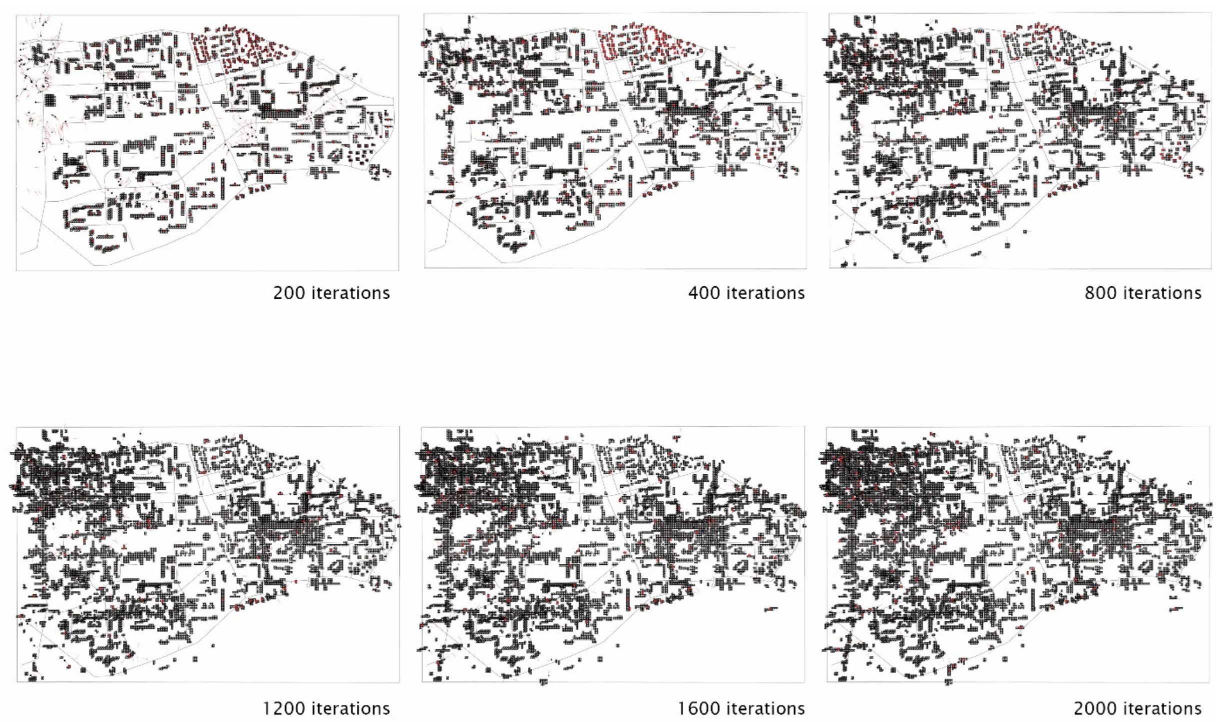


Fig. 23 An observation with 510 colonizers. Stigmergy and Path Following algorithm.

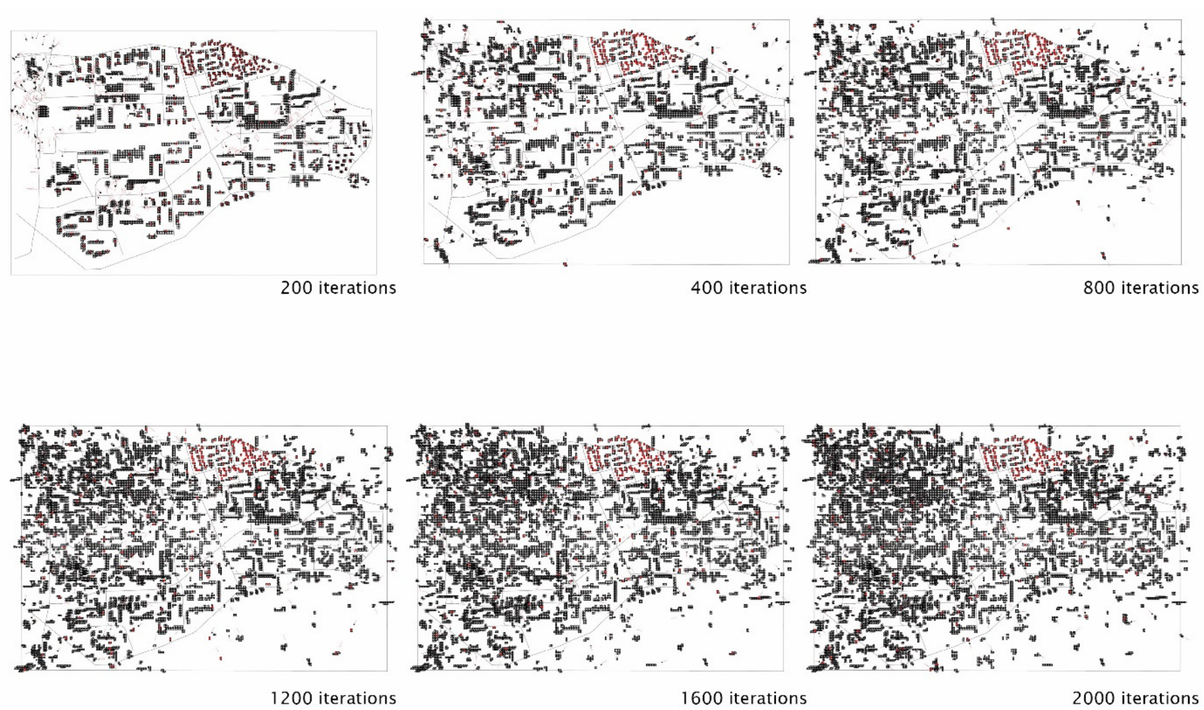


Fig. 24 An observation with 510 colonizers, high level of Attraction algorithm which leads to decay of urban structure. Extreme development of the patterns.

The simulated situations in the first scenario must be interpreted and assessed in terms of compliance or non-compliance of the objectives of the simulation mentioned in the previous chapter. For the visual evaluation it is necessary to assess the observations separately according to the selected point scale 1-5 (1 - worst rating, 5 - best rating) for each stated objective (i.e. the objectives of the simulations are the evaluation criteria) and within each iteration (200, 400, 800, 1200, 1600, 2000). The environment score is averaged into a single value for each simulated case. The rating is interpreted in the graph (Fig. 25) where the curves relate to the time evolution of the model in relation with the observed characteristics in terms of compliance of the simulation aims of the generated urban fabric. However, spatial quality of the urban space is impossible to validate from the overall point of view, the chart represents an aspect of the reached simulation aims that has been considered by the author. It is impossible to compare generated spatial structure with real future urban reconfigurations (we are not capable to know how the urban structure will be developed in the future decades) and atmospheres within the real urban qualities and conditions. Thus, it is possible to consider the generated urban patterns and their spatial configurations only visually, graphically and artistically by the graphic

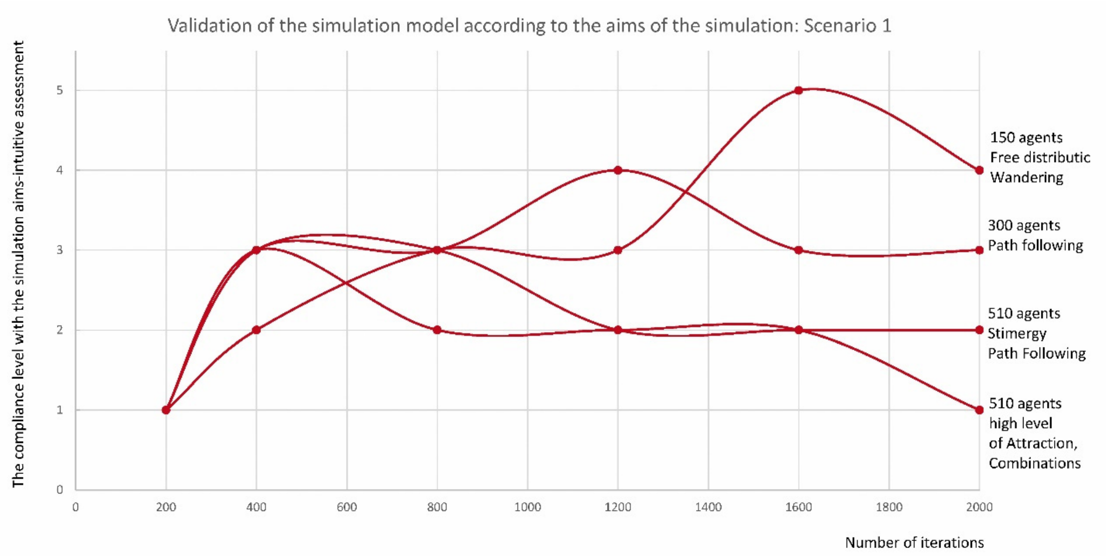


Fig. 25 Preliminary qualitative evaluation of the simulation results according to the spatial configurations of the generated urban environment in the first scenario. Mutual comparison of particular simulation cases. The evaluation takes into account the compliance of the simulation aims mentioned above. The intuitive visual and graphical observation of the urban patterns is done by the author. Extreme values are added into the complex information about the possible development of the pattern formation and has speculative characteristics. Spatial quality of the urban space is impossible to validate from the overall point of view. The graphical representations show a speculative image of the urban district and its possible development in time.

representation in the model from artistic and design point of view. The observation of the extreme development of the structure, which would be not acceptable in terms of urban planning or re-planning purposes has its own visual information value that offers further wider insight into the overall process.

4.4.2 Scenario 2: 3-times Run Simulation with the Same Inputs

The simulation of the urban growth has been run three times (Fig. 26, 27, 28) with the same parameter inputs in order to observe emergent behavior of the pattern in each run. The assumption had been declared before the simulation processes: if the process is not developed in the same way and it has various and different results as the previous simulation process, then the model can be considered as a platform which shows unpredictable emergent phenomena. The uncertain results in this case can be validated as an average of several runs of the simulation. And finally in the fourth run the number of agents' population has been changed. The observation brings different results in each run, but the nature and character of the first three runs is similar. The built area ratio aspect yields similar values as well as the urban graininess is more or at the same level of the spread of urban activities.

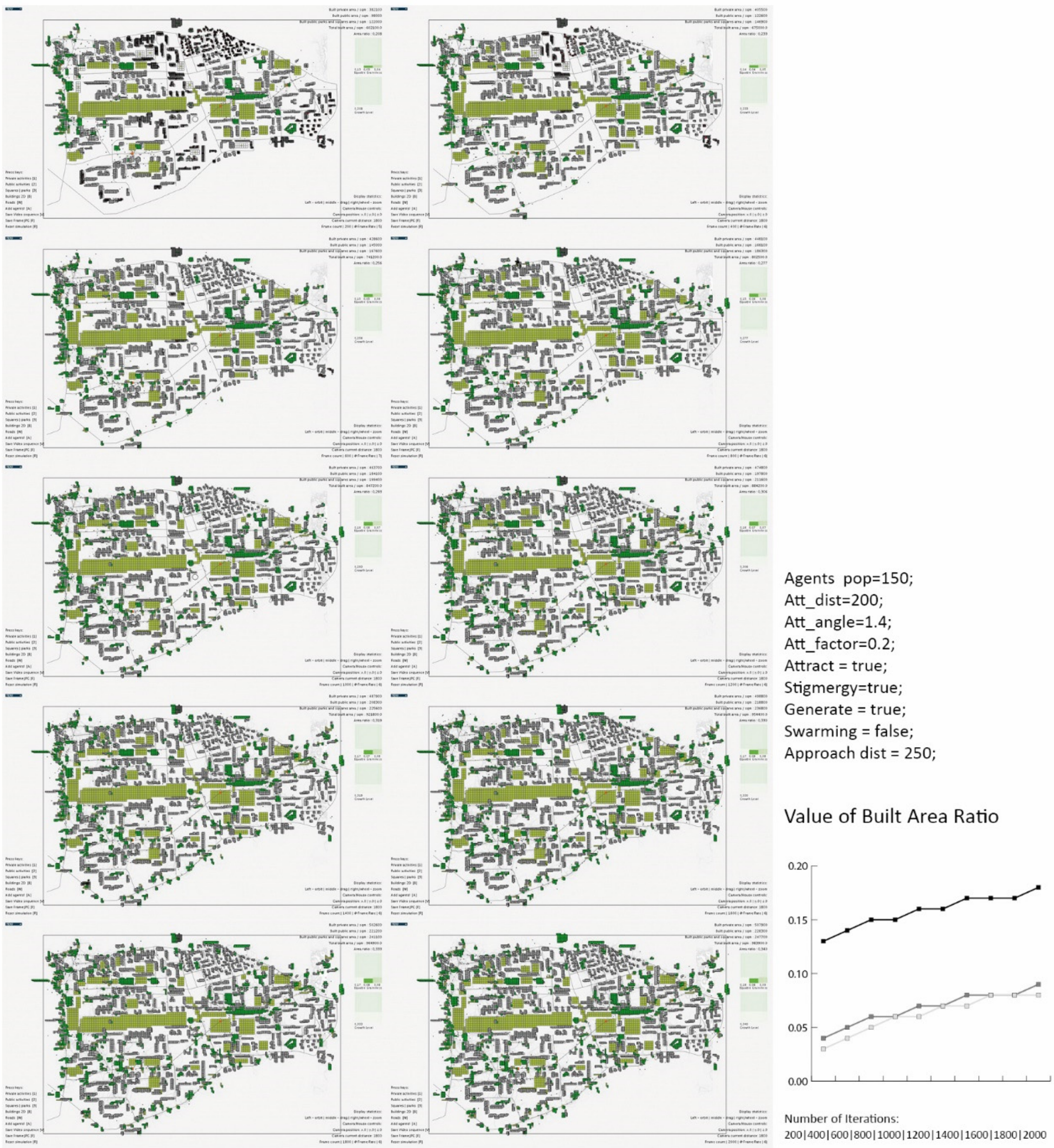


Fig. 26 First run of the simulation. The results show urban growth in each time iteration.

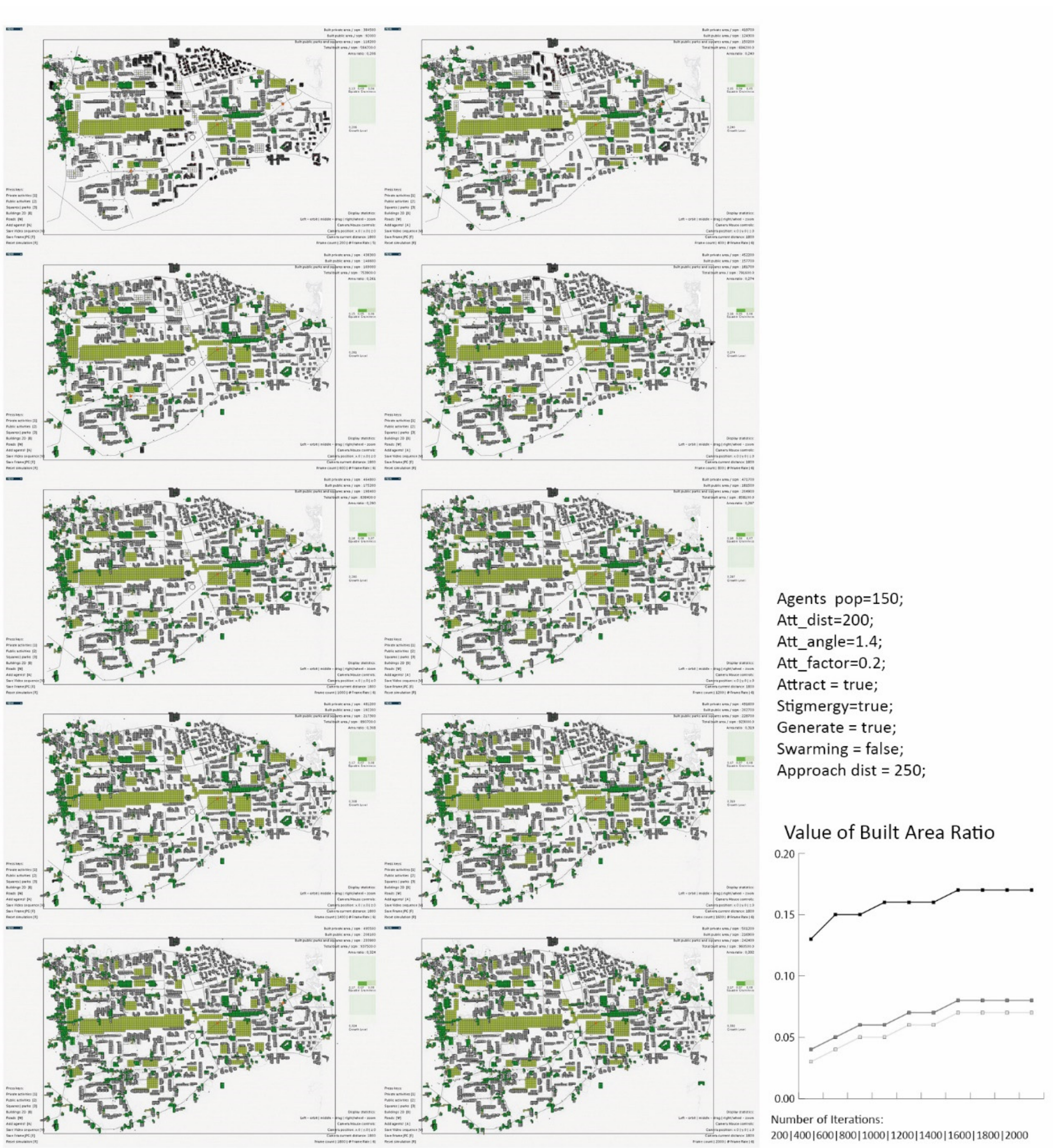


Fig. 27 Second run of the simulation. The results show urban growth in each time iteration, the differences of the built area ratio are obvious in certain iterations.

Agents pop=150;
Att_dist=200;
Att_angle=1.4;
Att_factor=0.2;
Attract = true;
Stigmergy=true;
Generate = true;
Swarming = false;
Approach dist = 250;

Value of Built Area Ratio

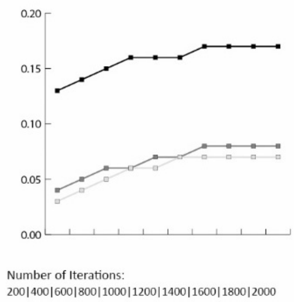


Fig. 28 Third run of the simulation. The results show urban growth in each time iteration, the differences of the built area ratio are apparent.

4.4.3 Scenario 3: Agents' User-defined Initial Positions

In the next scenario the two differents model inputs have been considered. The first model is based on the same agents' initial positions as the previous scenario. (Fig. 29). But with the different number of agents' population, in this case 300 agents have been released from the initial places in the site. The second model contains randomly distributed agents' initial positions (Fig. 30). The compared results from both simulations formulate the statement that randomly distributed agents lead to more randomly distributed urban activities and the urban graininess [47] is then more equal. Even more randomly distributed agency yields higher demand for the built environment.

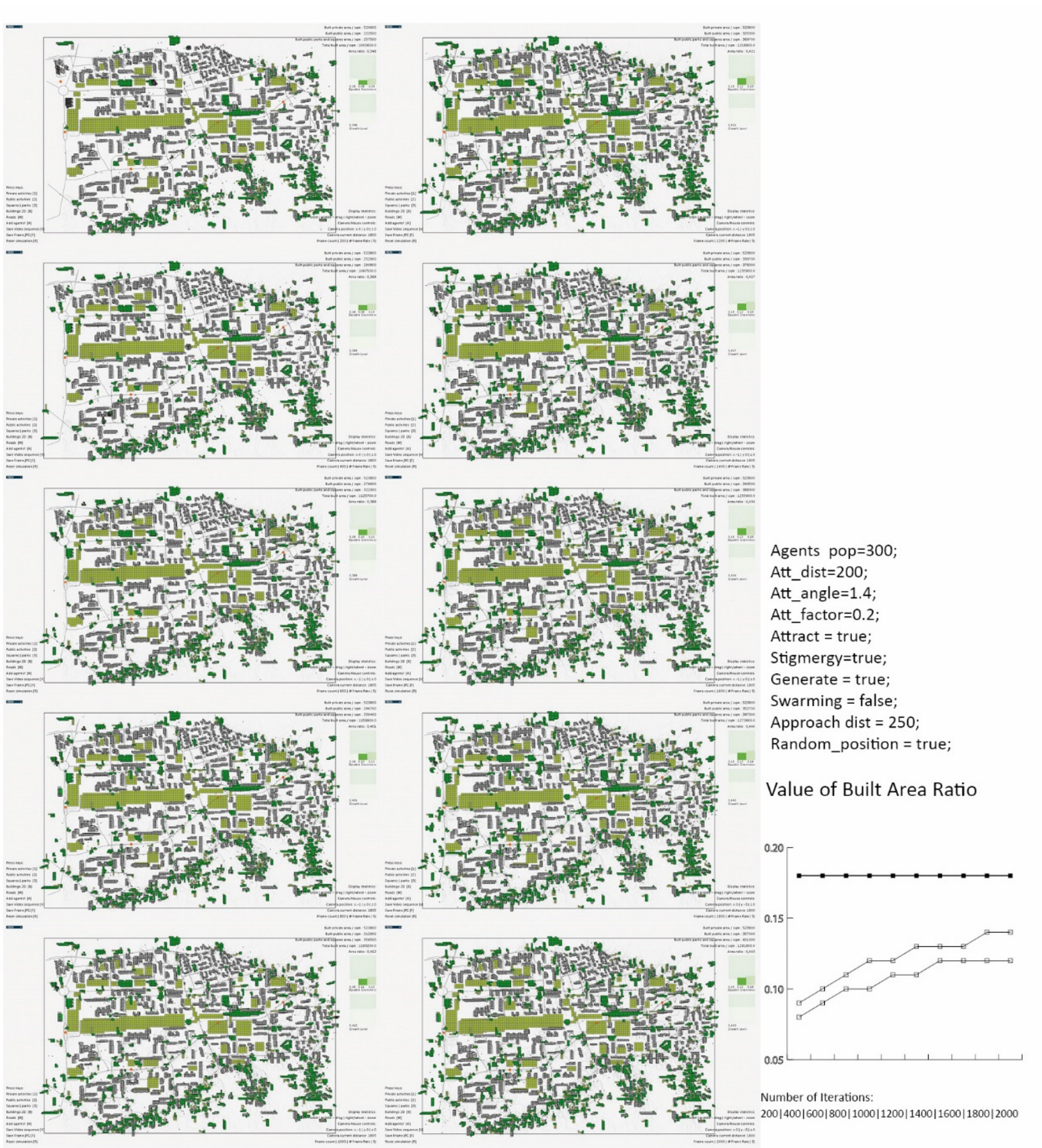


Fig. 29 The simulation model with the higher number of the agent population.The initial positions are as the same as the previous scenario.

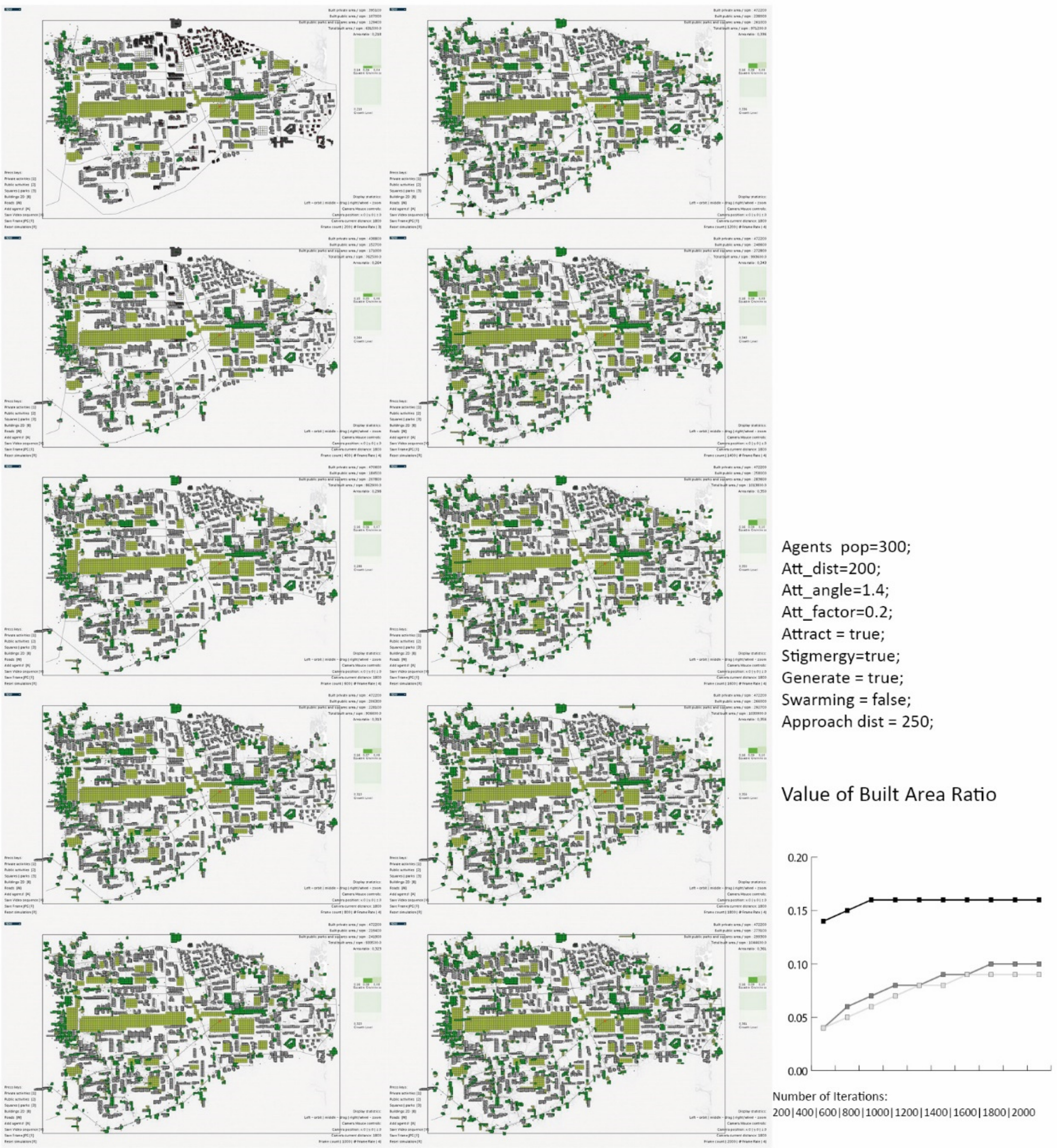


Fig. 30 The results with the different initial agents' positions (random) and a higher number of the agent population. The pattern formation is more spread and the urban pattern and activities graininess is more equal.

4.4.4 Scenario 4: Different Spatial and Shape Urban Typologies and User-defined Top-down Interaction – Extreme High Density Study

Typology volumes and configurations of urban growth figures can vary within a predefined pattern formation by specified standoff distances and heights of the buildings. The stand-off distances between urban elements can be defined during the simulation process as well using the Swarming behavior algorithm in the Separation, Alignment and Cohesion parameters.

For the addition and extension of the spatial urban mass a user-defined building footprint can be used as well as various spatial typologies or formations. The 2D footprint of the building outlines and their prospective mutual positions in the plan are written into the TXT or CSV data structure with XYZ coordinates for each point. In that manner, the road network or path for the agents can be considered as an external geometric source from the different CAD applications (e.g. Rhinoceros / Grasshopper, AutoCAD, Maya, etc.).

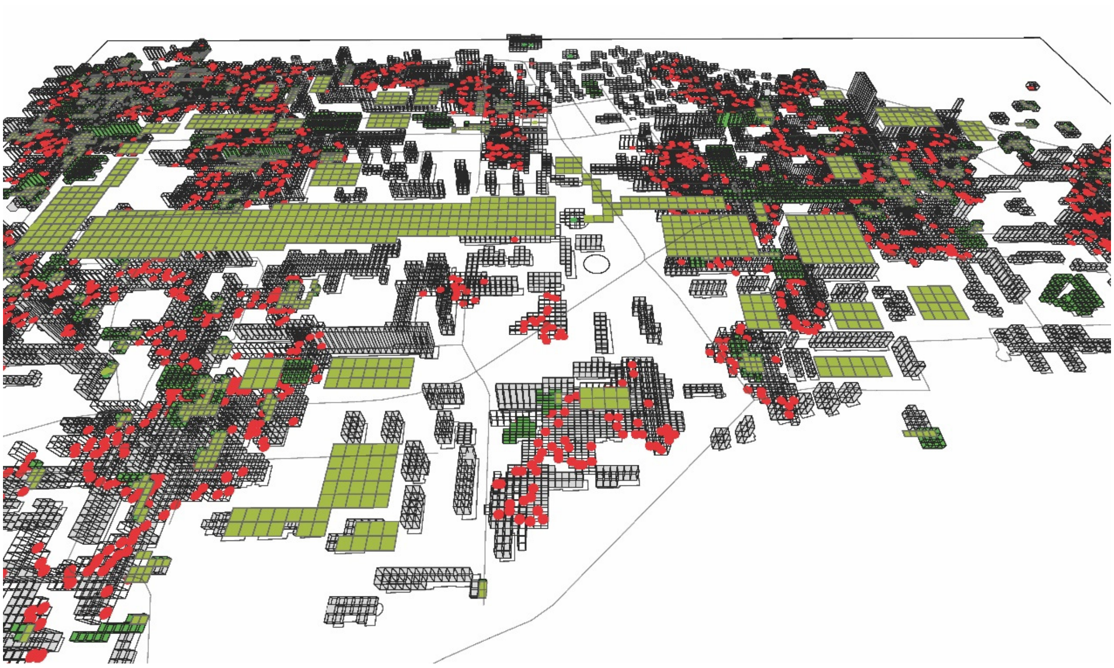


Fig. 31 Extreme high density study in the 4th scenario.

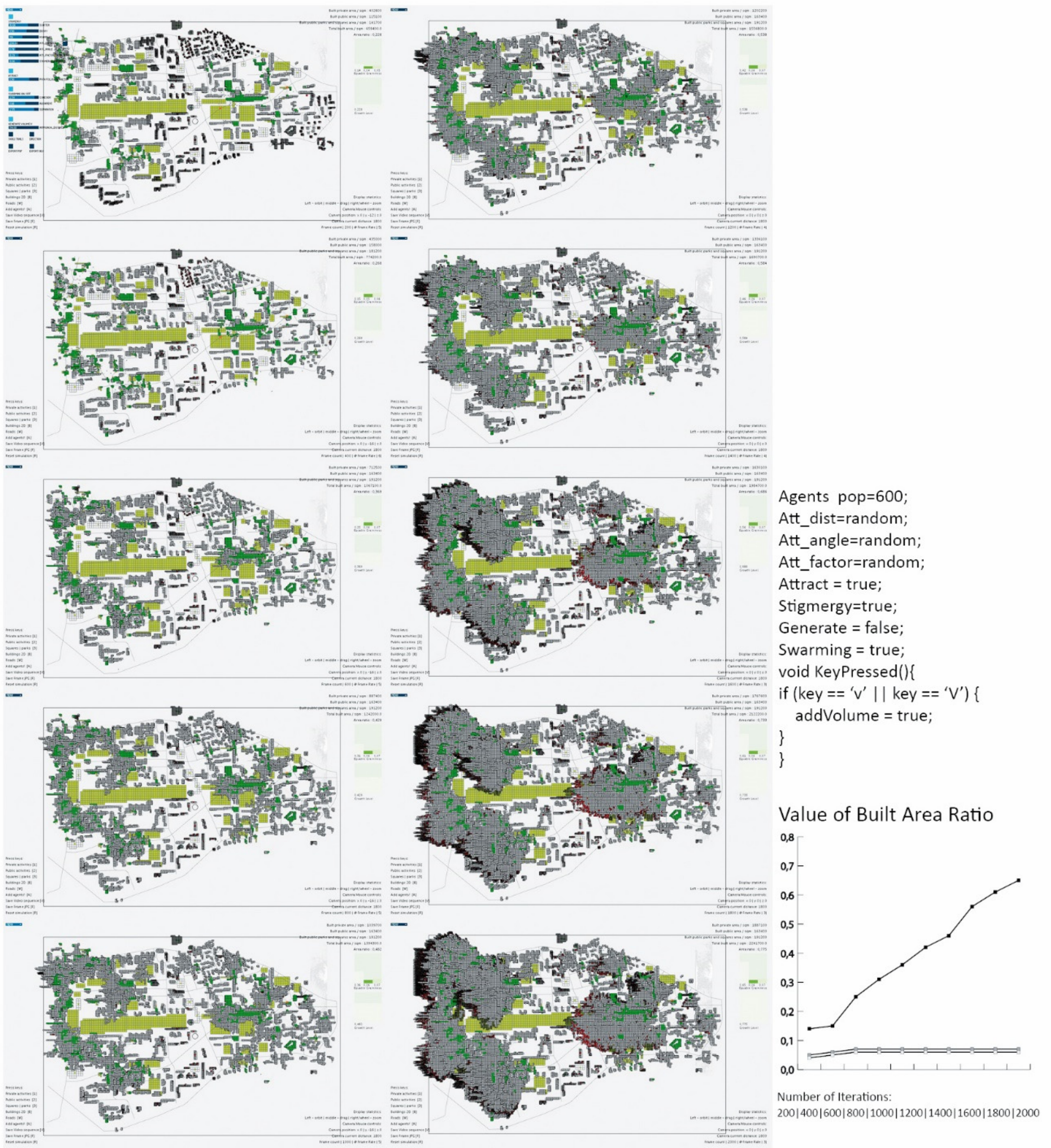


Fig. 32 The pattern formation based on a high number of urban agency and user-defined generation of an urban growth and combination of several agents' movement strategies including the swarming behavior.

In the following study the different parameter inputs have been used. The simulation brings extreme results in terms of urban density with high value of the built area ratio. According to the user-defined interaction during the simulation process in a specified iteration steps (Fig. 31, 32), the model is capable to generate extreme high-density patterns in certain places, mostly nearby the agents' initial positions. User can add the agents on the stage and expect more dense urban fabric.

By means of user-defined initial footprints, the architect can control several aspects of urban development in terms of spatial pattern formations. The selected several agents' movement strategies and their combination bring a very rich repertoaire of the spatial configurations. (Fig. 33, 34, 35, 36).

Fig. 33 Study of the agents' movement patterns during the simulation process.

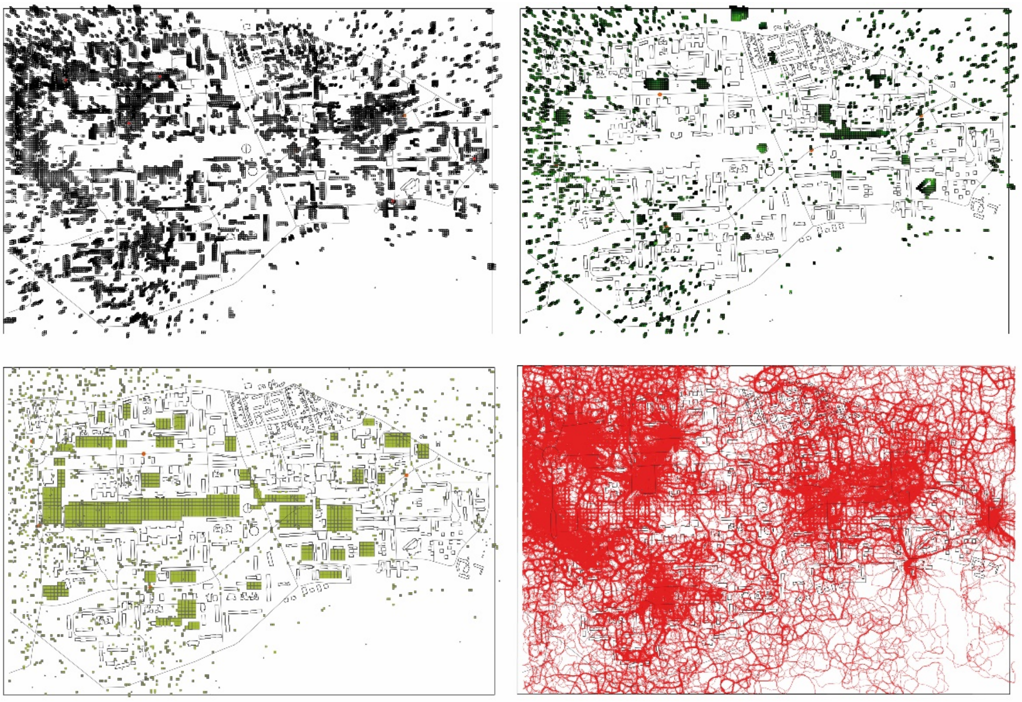


Fig. 34 The wider spread of the urban pattern emerged by different typology input into the computational model. The structure is represented by three urban activities: Private, Public and Parks/Squares. The red pattern represents the agents' movement. By that way it is possible to specify new emergent pathways or traffic distribution flows.

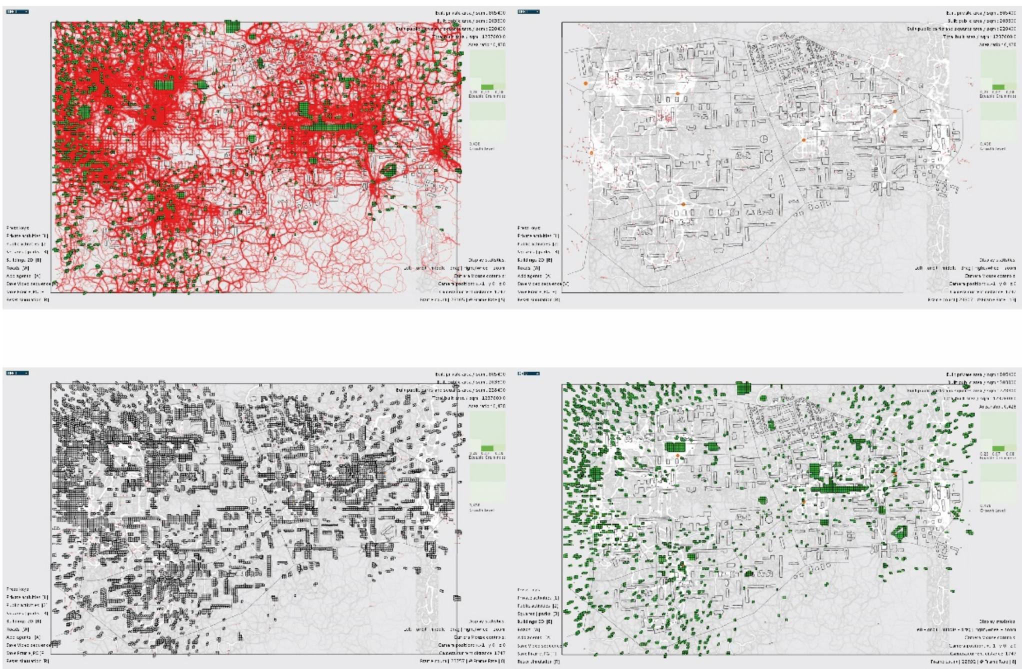


Fig. 35 The emergence of patterns according to the Stigmergy and Attraction algorithms and its formation around the places with strong potential of the urban growth. For better understanding the particular urban activites are divided into separated image representations which are possible to switch in GUI.

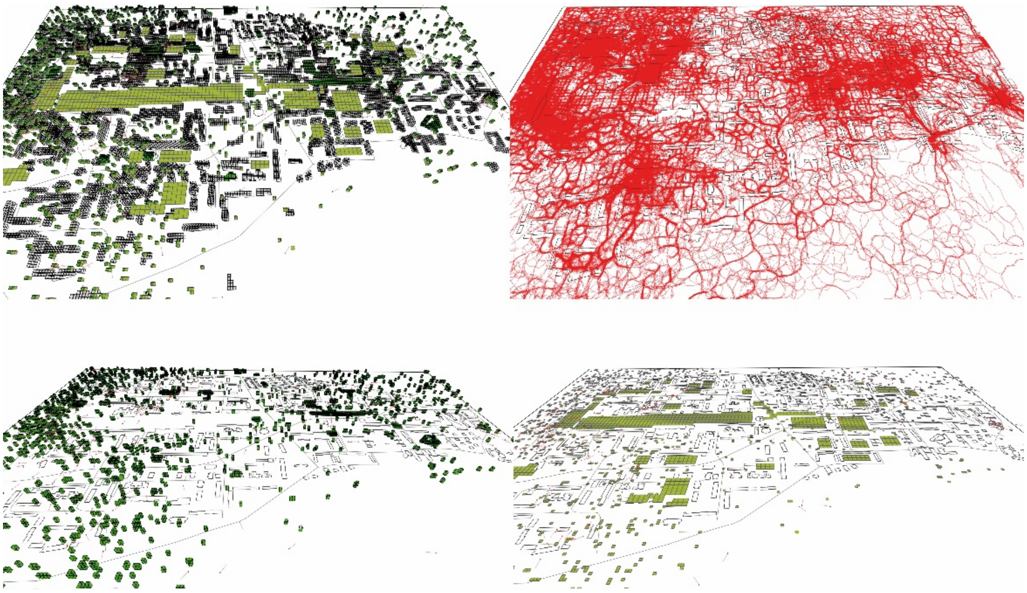


Fig. 36 Despite the fact that model uses different typology formation, the evidence of new focal points in the South City is legible also in comparison with previous observations.

4.5 Evaluation of the Observed Results

4.5.1 Interpretation of the Results

By means of the computational model EmCity and its capability to generate a big amount of different results one can assume that this kind of model and its usefulness can be hardly interpreted in terms of discovering one proper and final solution for a particular urban situation or scenario. As the results in the second scenario seem to be similar and the spatial conditions are the same, it is still apparent that final configuration is different for each simulation run. The model generates a lot of spatial configurations and it is not possible to specify which outcome is the best. We can interpret the observed results as a variety of spatial possibilities that can be considered during the modelling and planning process. According to the fluid and dynamic processes in an urban environment, the urban designer can modify and specify various input parameters and consider them into the model. As David Jason Gerber in Verebes (2014) declares the urban planning is nowadays more based on a multidisciplinary approach *where it is no longer adequate to provide the top-down plan* […] and *conversely, we cannot apply no rules at all to the growth of urban form.*[…] *While we can attest to our technological capability and an increase in our ability to manage complexity, what needs to be further theoretized, experimented upon, validated, and tuned is in fact the mix of top-down and bottom-up design processes.* In that manner the computational model EmCity provides a combination of top-down and bottom-up approaches that can yield emergent urban configurations in a geometric model based on spatial relational properties.

Despite the fact the EmCity platform is not a simulation model of a real world with all complex conditions and urban dynamics, it offers a speculative insight into the development process of particular spatial urban relations in terms of walkability, density and spatial adaptability. By means of such a model one can simulate and investigate different levels of urban densities, graininess and spatial qualitative relations in an urban structure in a variety of results. In this case it is possible to observe an unpredictable behaviour of the urban growth in the pattern by taking into account the accessibility and the spread of urban activities. The places with higher concentration of an urban mass in a simulation can be considered as places with strong development potential in the future. At the same time particular places show certain deficiency that can be improved in next time periods of urban development. The selected part of a city is re-configured based on user-defined spatial conditions. The outcomes can be interpreted visually, qualitatively - in terms of their spatial characteristics and can be compared with existing emergent or vernacular urban patterns (Rudofsky 1964).

4.5.2 Visual Qualitative Comparison with Existing Emergent Patterns

For the visual qualitative comparison the selected existing urban patterns have been considered which emerged based on the bottom-up development in the past (Fig. 37, 38, 39, 40). The aim of the comparison is to specify mutual visual and spatial similarities in the pattern and therefore to better comprehend the spatial and hierarchical overview of the urban environment in the solid mass. By these comparison results one can declare that EmCity as a tool for spatial urban modelling in a local scale can enhance the repertoire of the urban modelling and simulation tools that are based on bottom-up rules and at the same time the tool can be used for modelling and simulation of the urban growth in terms of bottom-up spatial stimuli.

Many historical structures emerged in the past by local bottom-up negotiations without any higher order or urban planning. As Bernard Rudofsky (1964) declares this kind of anonymous architecture was always developed in the context of the environmental conditions and *builders demonstrate an admirable talent for fitting their buildings in the natural surroundings.* It brings an assumption that bottom-up development has still to deal with the context and it needs to take into account the topography and natural sources of the environment. Thus, an anonymously built architecture or a city is not built by accident. The low-level rules based on spatial characteristics, basic human demands, negotiations, industrial and technological shift and the environmental and cultural context always play a crucial role in the urban growth or city development as well as the maturity of the participants and their heritage legacy throught the generations. The emergent architecture in that manner is recognizable by its *humaneness*.

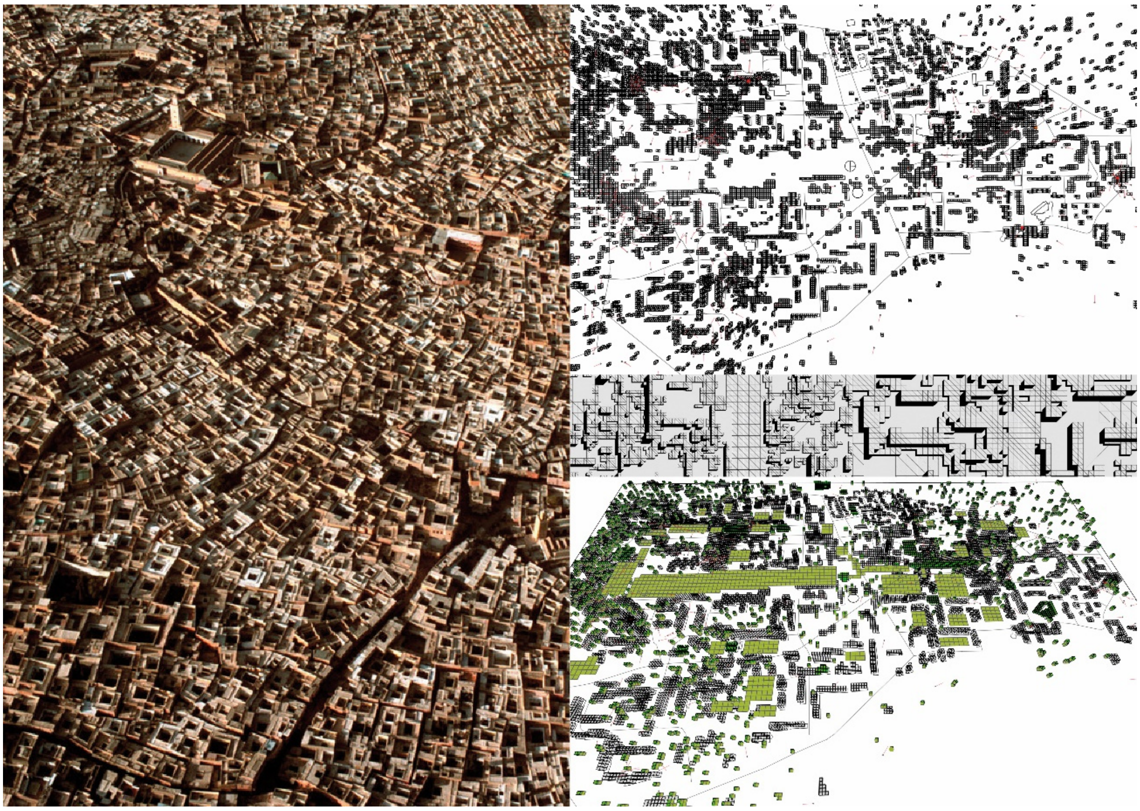


Fig. 37 The visual comparison of the generated urban pattern from EmCity and the existing pattern in Marrakech. Despite the cultural difference is not considered into the comparison it is possible to observe certain geometrical and spatial similarities between the structures. The final formation is different (EmCity does not use the courtyards in the typology) but the mass is similar in the accumulation of the fabric. EmCity deals with the orthogonal formations within the precise grid 10 x 10 x 10 m.

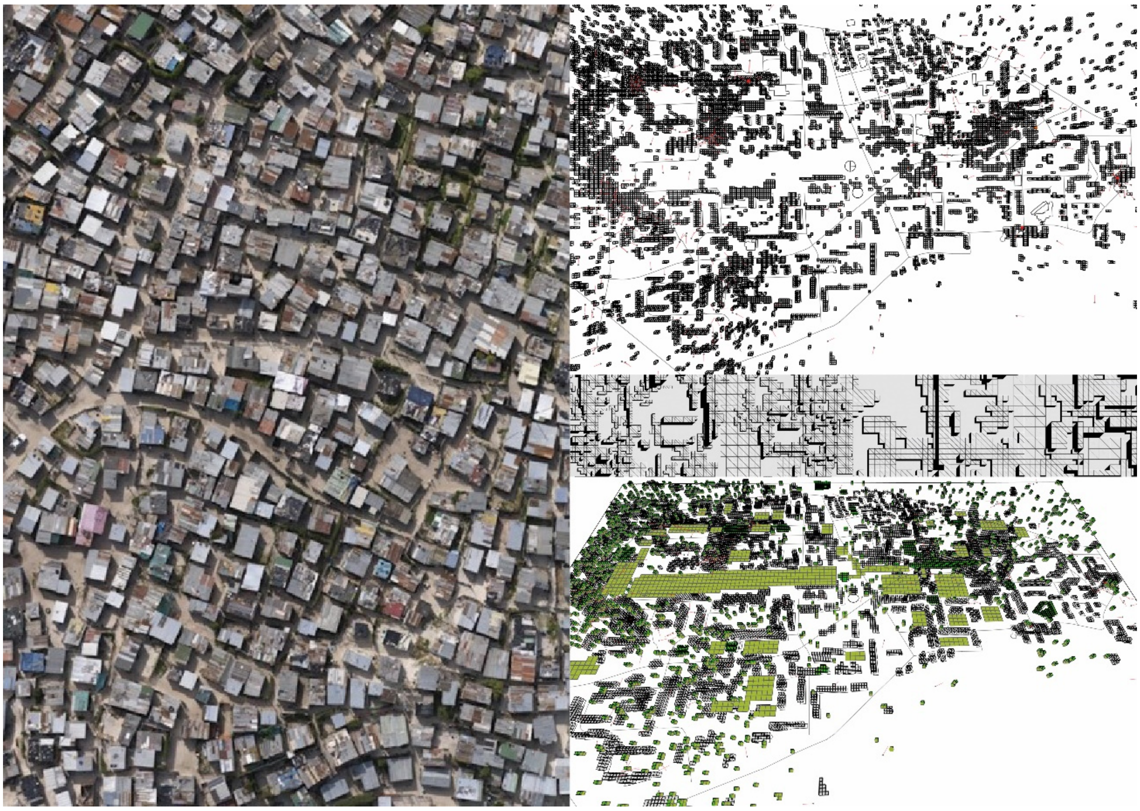


Fig. 38 Another selected structure from the Seville in Spain [48]. The patterns are very similar, the only difference is in ortogonality in the framework of the EmCity application. The comparison yields the statement that the EmCity application is a tool for modelling emergent urban patterns.

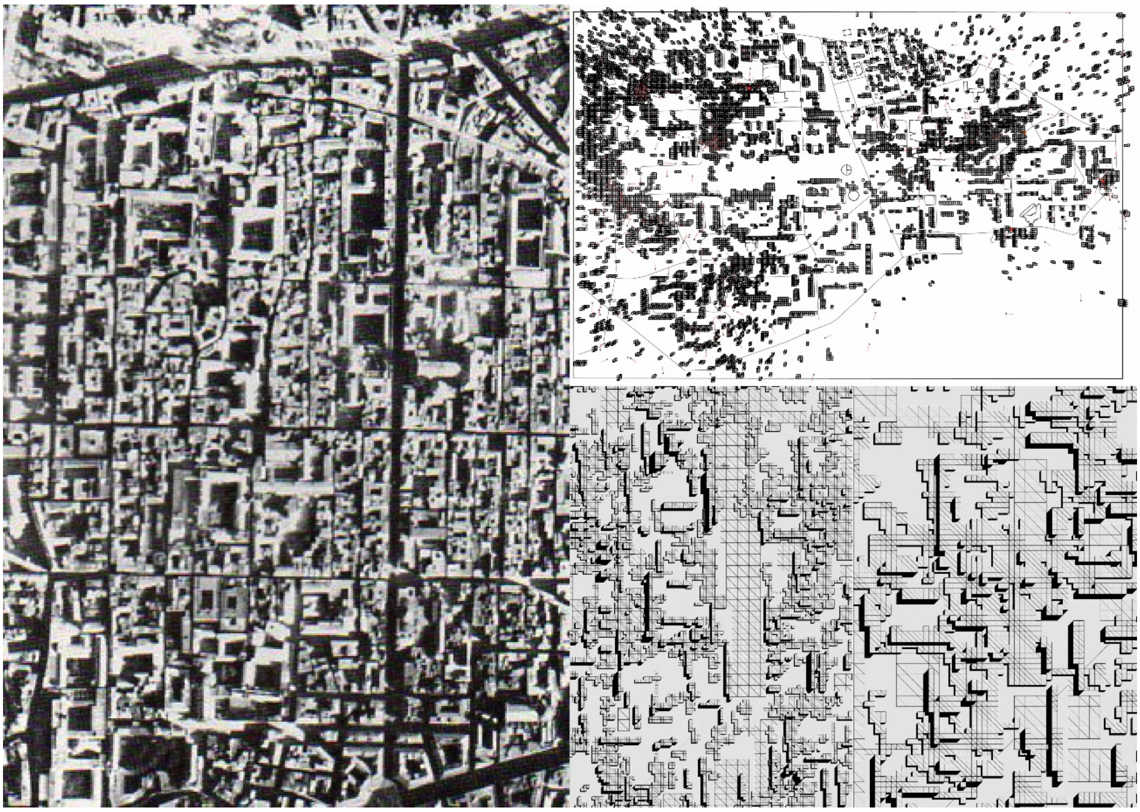


Fig. 39 The structure in Logone-Birni in Africa. The formation is similar as well. The pattern in Logone-Birni is divided into separated blocks in a certain regular formation. The South City structure is more organic in this case, with open public spaces.

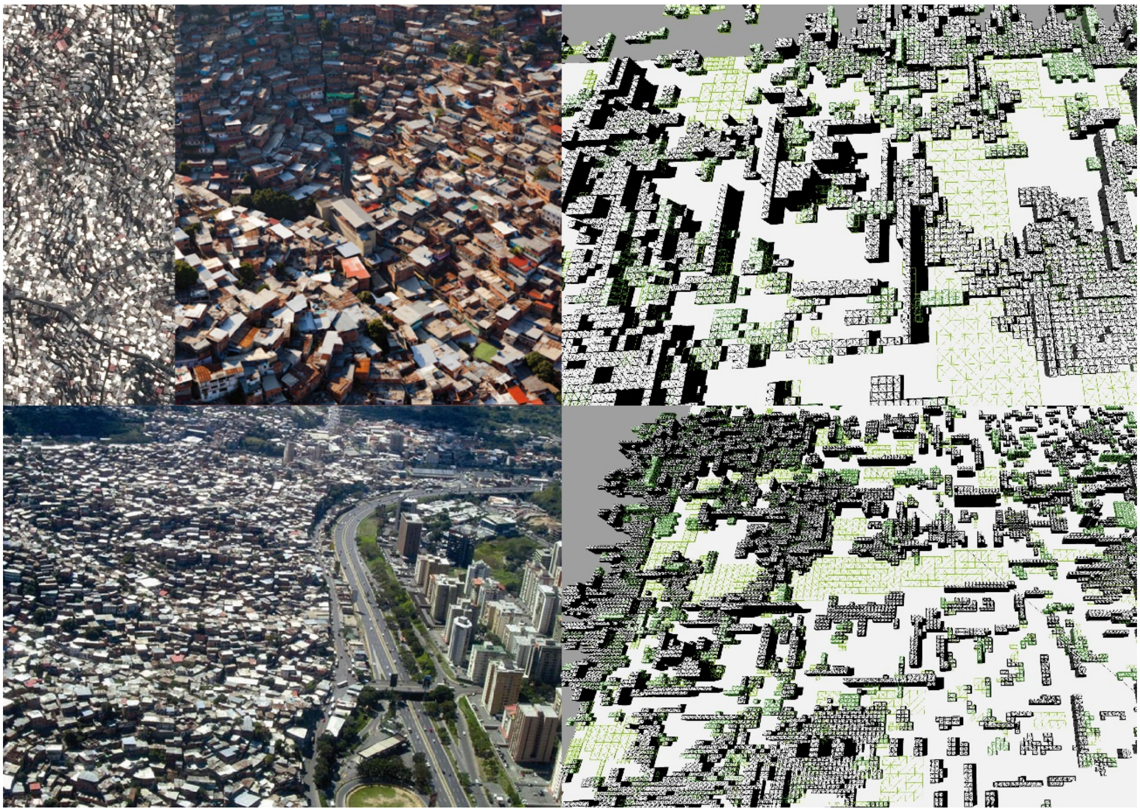


Fig. 40 The formation of the organic bottom-up structure in Barios district in Caracas. The slums are built completely without any precise regular rules, it is based on natural and spatial conditions in the environment. The clustering of the organic pattern is partialy similar with the South City structure after higher number of growth iterations.The South City is flattened, the terrain conditions are not complex in comparison with Caracas.

If we take into account the previous results from the computational model in different scenarios as well as with different typology formations and algorithm usage we can observe the places within the site which shows certain deficiencies. In each scenario they are basically at the same places where the urban mass is denser and acitivies are accumulated. These places where the urban mass is more concentrated can be considered as places with strong future potential to become new focal points or district centers. They are accessible in terms of spatial relations with surrounding neighbourhoods in a proper approach distance. In that manner where the mass formation after growth simulation is denser, the urban planners should focus more on these places as key strategic distinguished points in further planning or design process. (Fig. 49). The routing network pattern which emerges in the site based on Stigmergy algorithm shows evidence that these places would be developed in the future in order to establish proper urban structure in terms of appropriate spatial and walkable relations (Fig. 33, 34, 35).

4.5.3 Quantitative Comparison of the Selected Scenario Results with Existing Structures – The Structural Index of Similarity (SSIM)

The simulation outcomes have been evaluated and compared with the existing emergent patterns of vernacular urban settlements (Fig. 41) in terms of the image feature detection[1] as well. The aim is to discover the similarities from the image essence and consider possible emergent qualities from the generated outcomes together with already existing patterns in a quantifiable way. As such, it is possible to specify the similarity index between compared images. Despite the respective method shows similarity index as a number between 0 to 1 (0 - no similarity, 1 - images are the same) it is assumed that various obtained number with various input conditions does not objectively show the same similarity and this method actually does not establish the objective final rules which can be implemented to other scenarios. The algorithmic method of a computer comparison will be always different from very complex visual human comparison in a human brain. However, the method provides the measurement of similarity in a very simplified way and can help to enhance the original visual comparison method from another point of view.

---

[1] "*In computer vision and image processing the concept of feature detection refers to methods that aim at computing abstractions of image information and making local decisions at every image point whether there is an image feature of a given type at that point or not. The resulting features will be subsets of the image domain, often in the form of isolated points, continuous curves or connected regions. In computer vision and image processing the concept of feature detection refers to methods that aim at computing abstractions of image information and making local decisions at every image point whether there is an image feature of a given type at that point or not. The resulting features will be subsets of the image domain, often in the form of isolated points, continuous curves or connected regions.*"[42].

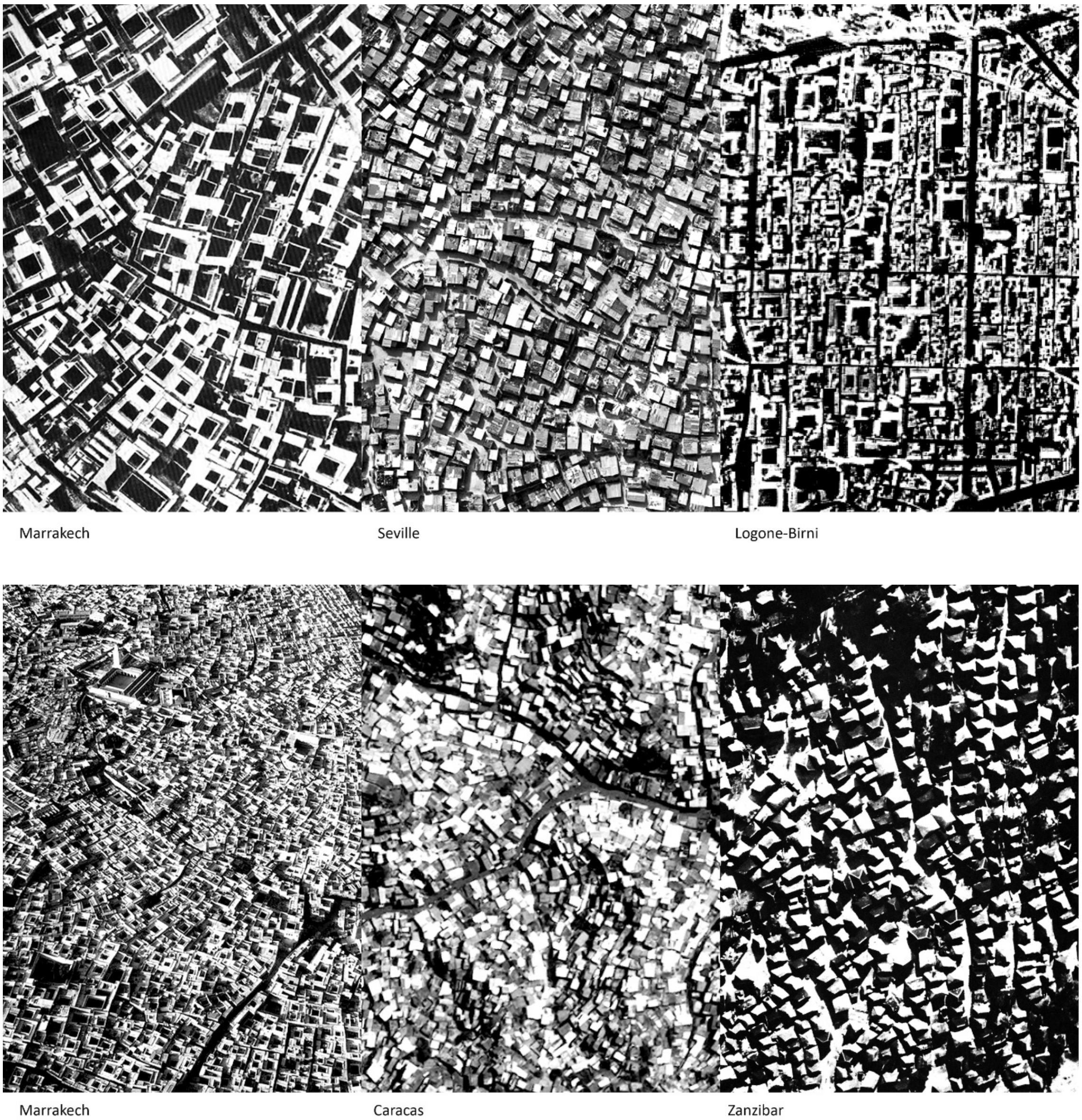


Fig. 41 *Selected vernacular and existing urban textures based on complete bottom-up formation . The grayscale images serve as a visual base for the structural similarity comparison with generated outcomes from the EmCity model.*

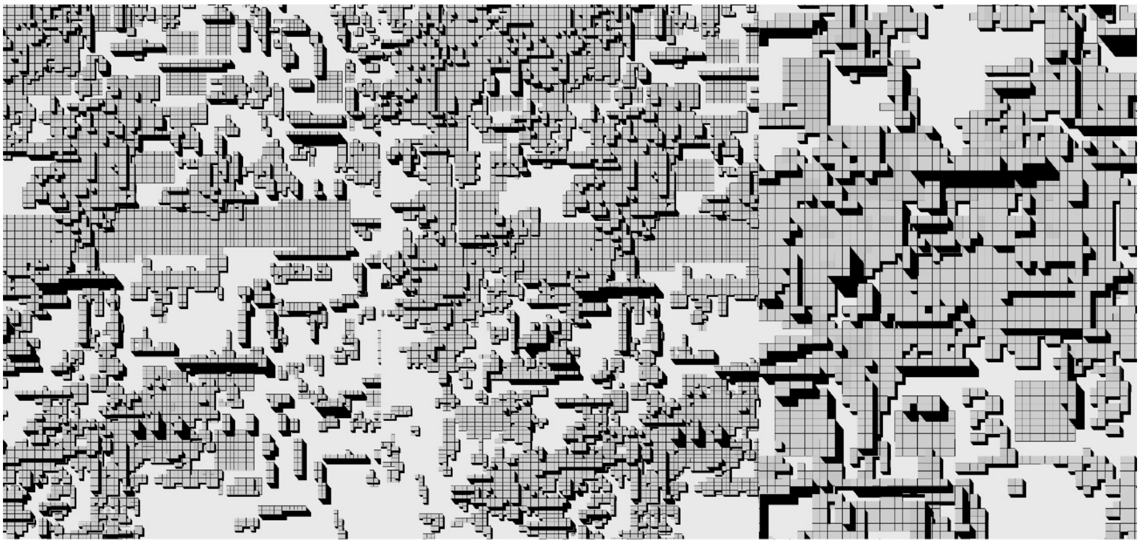


Fig. 42 Selected urban patterns from the EmCity model as a base for the structural similarity comparison in various scales.

The established workflow is as follows:

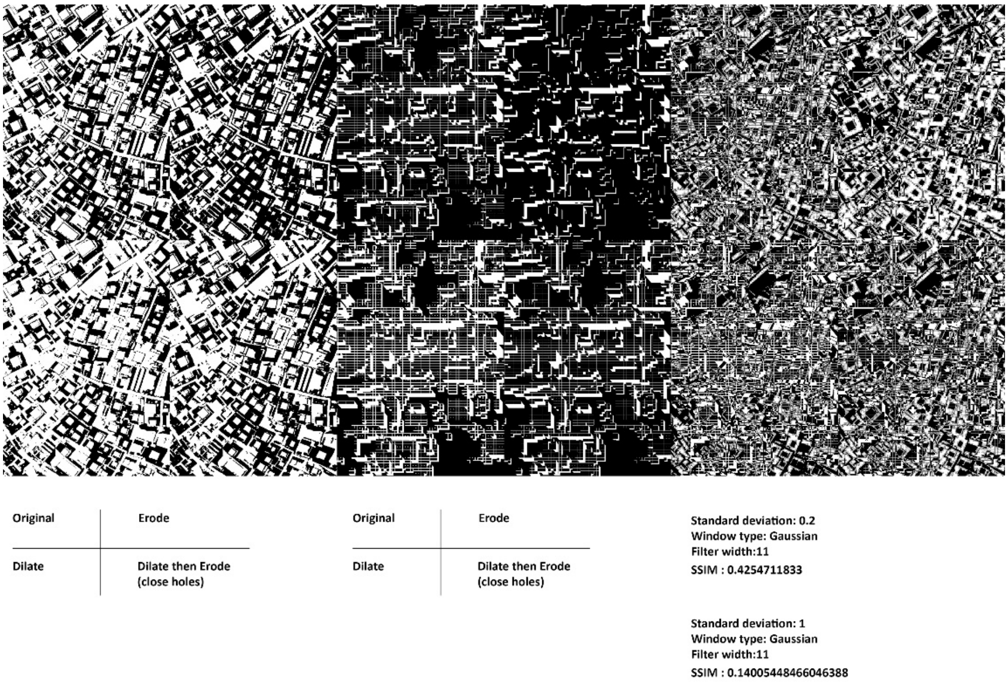
1. The image selection for the comparison of existing patterns (Fig. 41) and selected frames from the EmCity model (Fig. 42)[2].

2. Grayscale conversion of images.

3. Image classification method (computer vision) for dilatation and erosion / graphical simplification of the image content by means of usage the OpenCV library [49, 50]. In that manner we can establish the graphical representation of a simplified essence of the investigated image. (Fig. 43, 44, 45).

4. The SSIM - The structural similarity index (Zhou et al. 2004) based on perceptual image quality measurement. The SSIM measurement method is originally intended to comparison between images where one of them has poorer quality. The index declares the quality level (from 0 to 1) of the image in comparison with original image with the higher quality (Zhou et al. 2004) [43, 44]. By that way it is possible to measure the divergence of the image similarity. In a graphical simplified way, where the image abstraction has been simplified into outline representation (dilate and erode analysis using OpenCV library [50]), one can measure the structural similarity between two images.

[2] The image selection is individual and subjective, based on author's subjective decision.



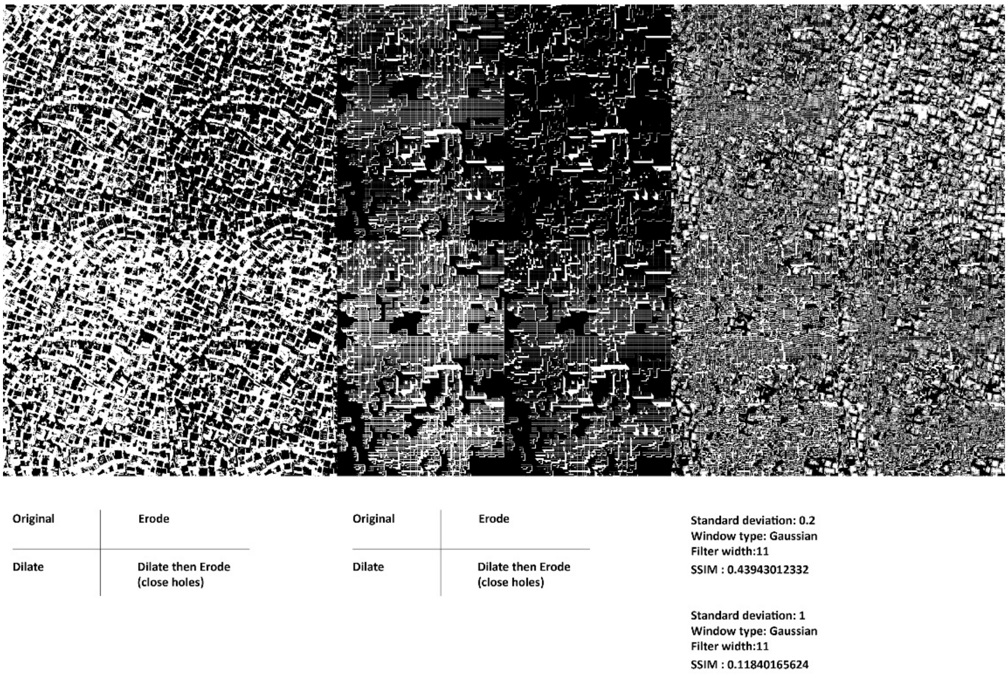


Fig. 43 The image essence simplification into eroded and dilated textures and their structural image similarity comparison with different input values in terms of pixel comparison (Zhou et al. 2004). The structural similarity comparison is based on perceptual image quality measurement with SSIM index as an outcome. The SSIM map is combination of both compared images whilst SSIM index declares the measure of the overlapped pixels with the attributes in terms of luminance and contrast measurement. Marrakech and Seville comparison with the selected various-scaled models from the 4th EmCity model scenario.

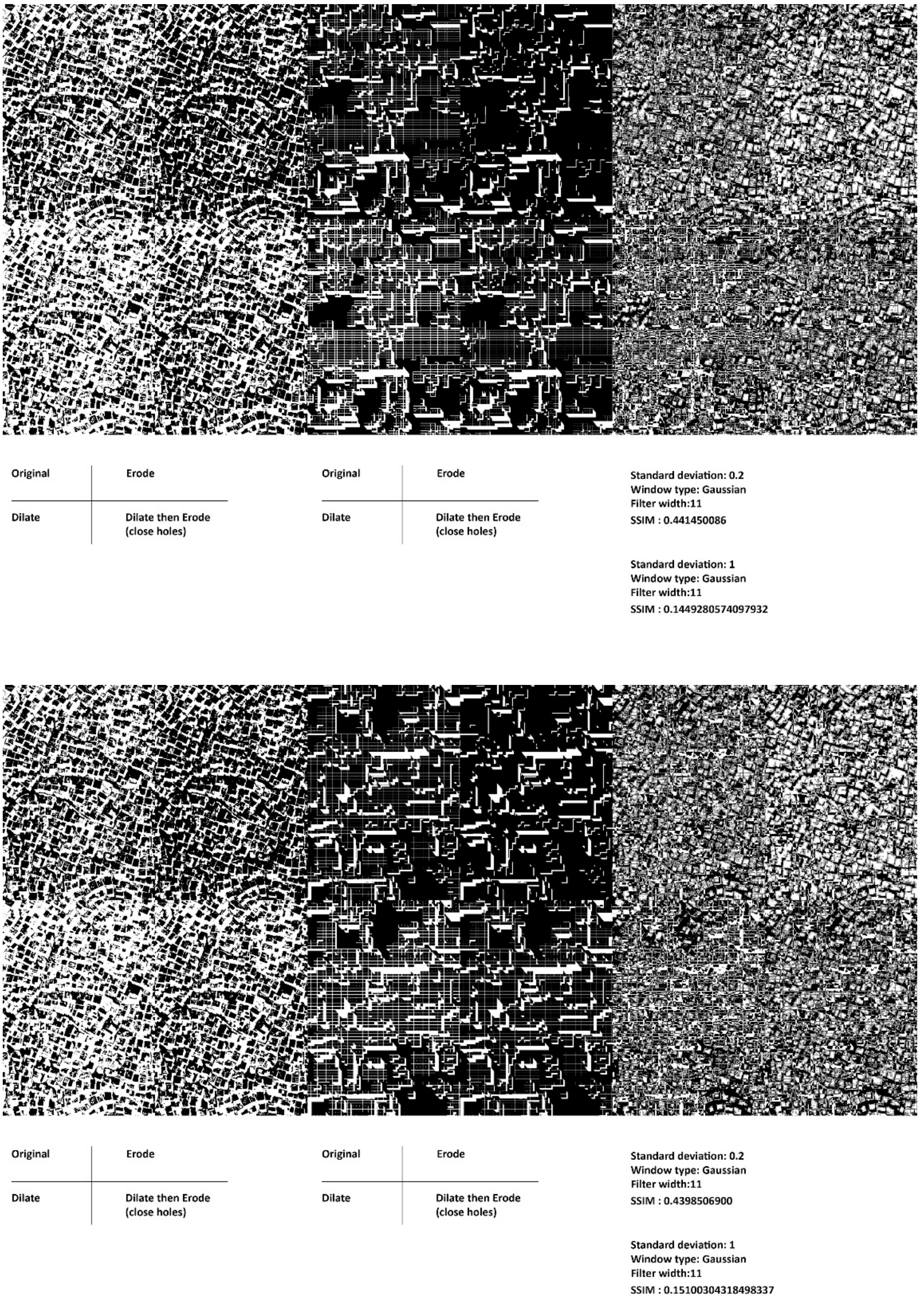


Fig. 44 The image essence simplification into erodedand dilated textures and their structural image similarity comparison with different input values in terms of pixel comparison (Zhou et al. 2004). The structural similarity comparison is based on perceptual image quality measurement with SSIM index as an outcome. The SSIM map is combination of both compared images whilst SSIM index declares the measure of the overlapped pixels with their attributes in terms of luminance and contrast measurement. Seville comparison with the 4th EmCity model scenario.

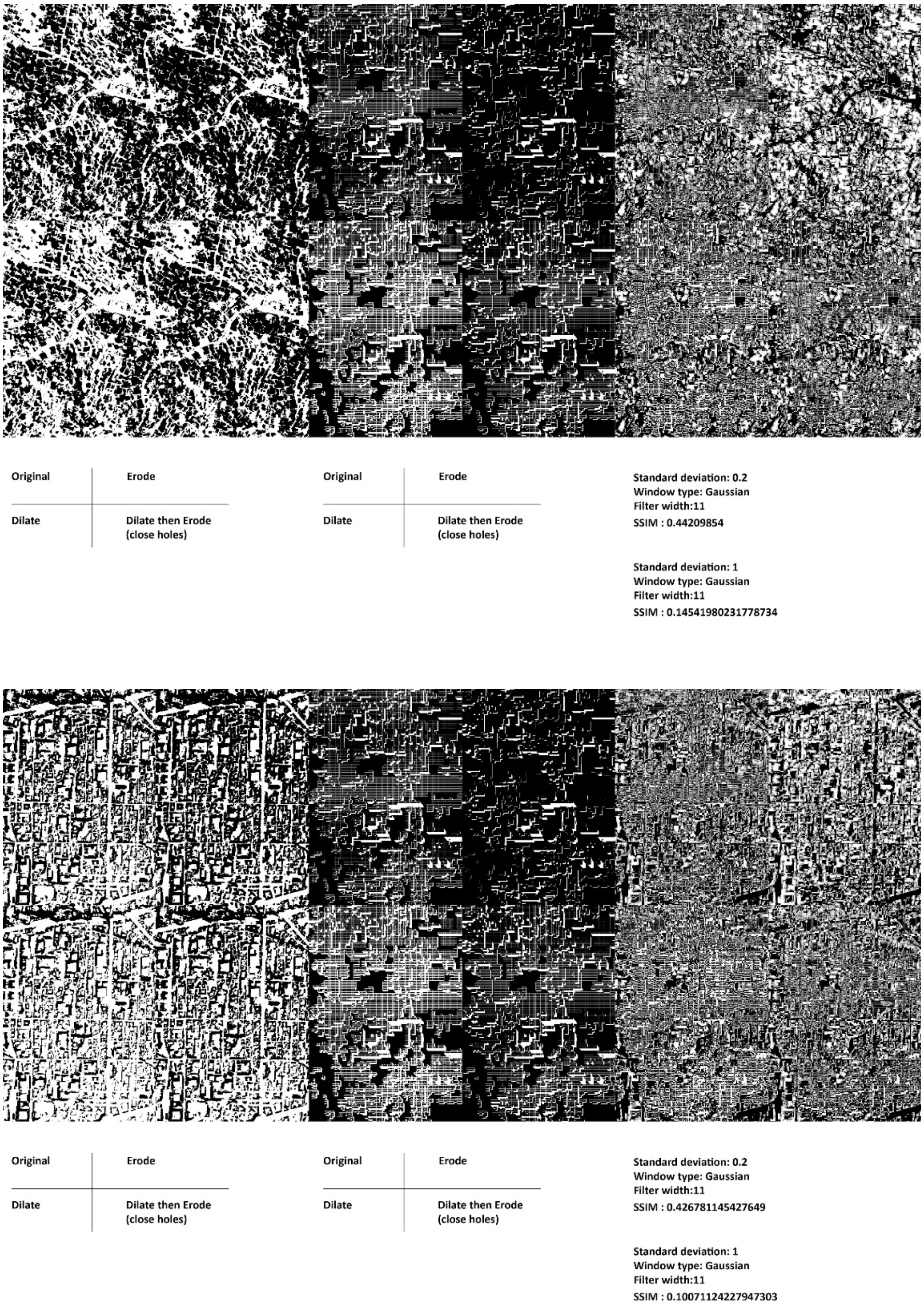


Fig. 45 The image essence simplification into eroded and dilated textures and their structural image similarity comparison with different input values in terms of pixel comparison (Zhou et al. 2004). The structural similarity comparison is based on perceptual image quality measurement with SSIM index as an outcome. The SSIM map is combination of both compared images whilst SSIM index declares the

measure of the overlapped pixels with the attributes in terms of luminance and contrast measurement. Caracas and Logone-Birni with comparison of selected part of the model from the 4th EmCity scenario.

The comparison provides different similarity index in all compared scenarios with different original existing patterns by means of JAVA SSIM plugin for ImageJ application [45]. Despite the fact images are not exactly the same and they are not too similar in a visual manner, it is still possible to declare and argue that EmCity outcomes are similar to existing emergent patterns in terms of shape or pattern formation when compared using pixel-by-pixel structural SSIM analysis. Certain shape similarities are still recognizable. Therefore the pattern structures in various outcomes from the EmCity model are complex and emergent, based on simple rules yielding more complex behavior in an urban pattern formation. Concluding these facts it is possible to declare that emergent spatial urban pattern formation can be modelled by means of computational model in laboratory conditions.

4.5.4 Visual and Spatial Qualitative Evaluation in UNREAL Engine from the 1st Person's Position

For the time being the generated urban structure has been observed, compared and evaluated in terms of top plan or a bird perspective. But for better understanding and observing the spatial relations in the model results the game engine system UNREAL has been selected for the spatial observation of the pattern in a virtual world from the first person perspective as similar as the computer games. The game engines systems such as UNREAL, Unity3D or Crysis nowadays are the new platforms that architects and designers use for the spatial evaluation of their design proposals or for the real-time visualisation purposes in a virtual observation. Using the available virtual reality equipment such as the Oculus Rift headset or the 3D Cave one can enhance the modelling possibilities with new potentials basically into one to one scale. The gaming hardware and software together with the Kinect setup into one interactive virtual space environment will be a new observation and visualisation tool in the future time horizonts available in architectural or urban design studios. The interactivity as an inextricable part of an architectural presentation and visualisation will be crucial in the forthcoming years. The research institutions such as Future Cities Laboratory in Singapore with the Value Lab Asia environment, CASA London or Seanseable City Lab MIT have stared exploring the potentials of such virtual interactive tools and environments. The geometric result of the model from the scenario 4 has been imported into the UNREAL system and edited as one virtual spatial scene where the user is capable to explore the environment from the first person's perspective (Fig. 46)[3].

The observed results show diverse spatial environment qualities with open public spaces and parks with diverse urban mass size and density. The space thickened and sorted into the smaller parts is more legible and better identified. From the urban design point of view the accessible space with spread of different urban activities (as results show) and equable urban graininess is more convenient in terms of walkability, liveability and sustainability. By that way the experimental South City case study in a computational model EmCity shows that denser urban space is more liveable and offers better user identification with the urban environment. The structure in that way is more adaptable according to the users' demands and offers diverse spatial qualities. The urban scale of the environment is more understandable, friendly and habitable. It is presumed that the South City in Prague has apparently strong potential to become liveable place for occupying the environment with the equable spread of urban activities within the space.

The spatial character of the reconfigured diverse structure based on the emergent spatial bottom-up phenomenon and the specified simulation aims have been fulfilled when we are evaluating the model in terms of its spatial characteristics.

[3] The EmCity First person's position 3D virtual model using Unreal engine is a part of this thesis on the attached CD.

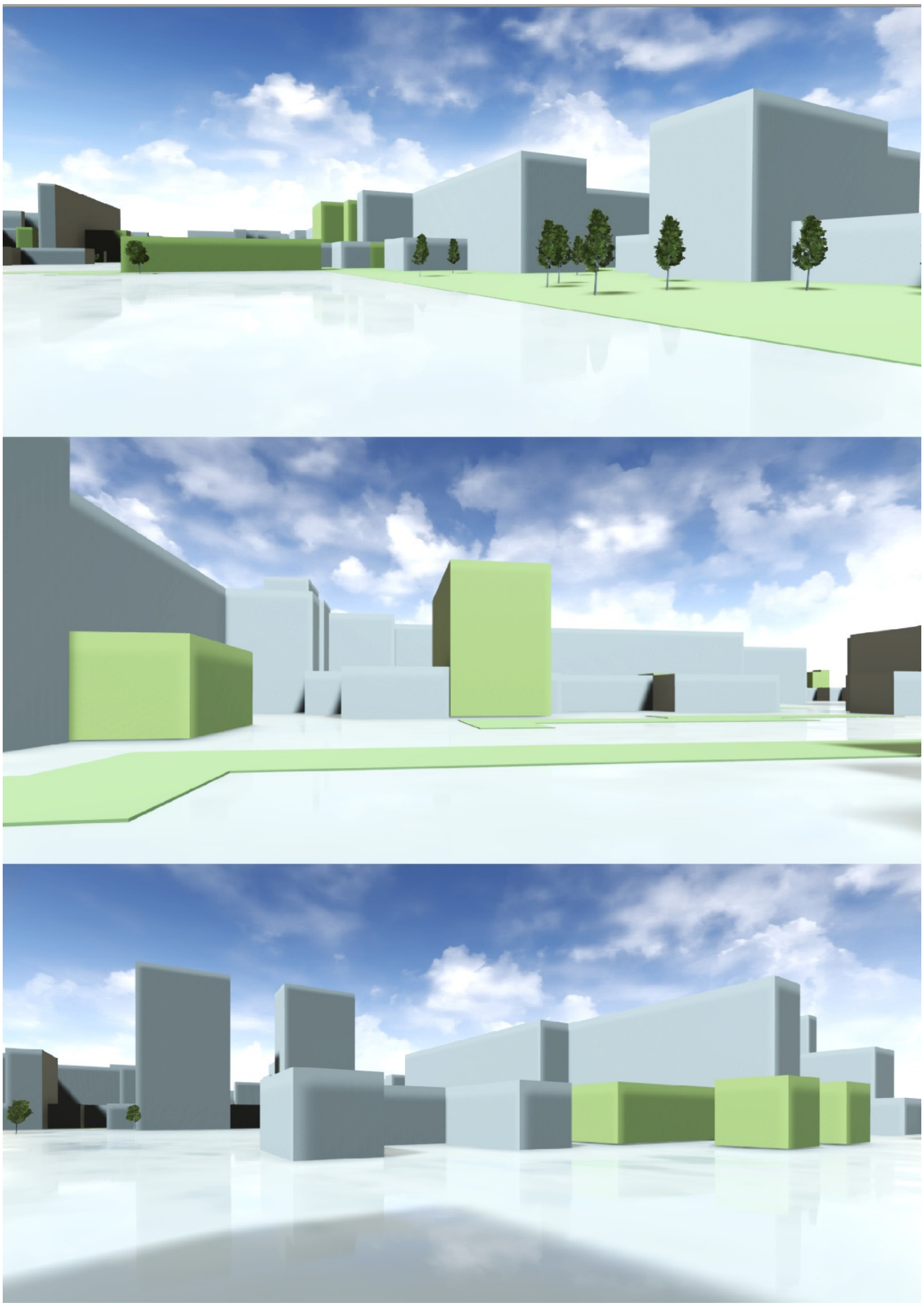


Fig. 46 The urban pattern observed by means of UNREAL game engine environment. It is obvious that denser urban mass with diverse typology and various building scale and changing character of the horizon silhouette is more suitable for habitation, spending time in public environments and user identification with the urban space. The aims of the simulation have been fulfilled. Emergent strategy (in this case also with certain top-down intervention - manipulating with the controls during the simulation,

controlling the agents' movement and position) is more convenient as a method for urban planning as a traditional and conventional top-down approach.

4.5.5 Qualitative Comparison of the Scenario Results in Terms of Potentials and Deficiencies of Urban Pattern

For the qualitative comparison of the scenario results in terms of their potentials and deficiencies of the urban pattern the selected captured frame 1600 has been considered from each simulation scenario as a pattern base of graphical representation of the urban structure. The aim is to find the similarities or strong differences between the patterns from each scenario in order to specify the potentials for further consideration in planning processes or define the deficiencies within the urban pattern that can be improved later on during early design phases. The amount of the captured frames from each simulation serves as a rich outcome base for the qualitative comparison. By means of captured outcomes one can evaluate the generated patterns in terms of their relational spatiality, diversity and overall character.

The visual comparison can be done by one's naked eye or by deep pixel analysis using the software tool. For the comparison a common software tool Adobe Photoshop has been used in order to specify the differences between several outcomes in terms of graphical shape similarities or differences. The character and overall nature of the selected scenario outcomes seems to be very similar by visual consideration made by naked eye. An indepth analysis based on a pixel comparison method with the software tool points to various differences, as following images show (Fig. 47, 48, 49).

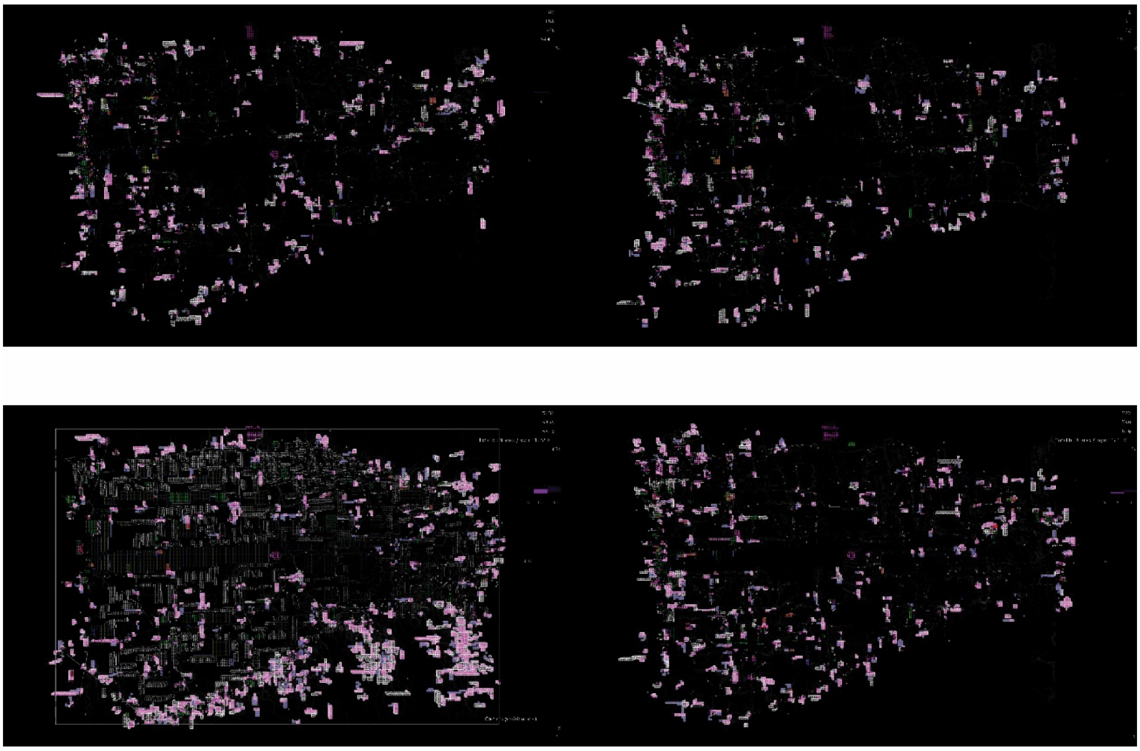


Fig. 47 The comparison of the selected frame 1600 in each scenario. The scenarios are muttualy compared in order to specify the differencies or similarities in the urban pattern. The above image shows differences, which are highlighted.

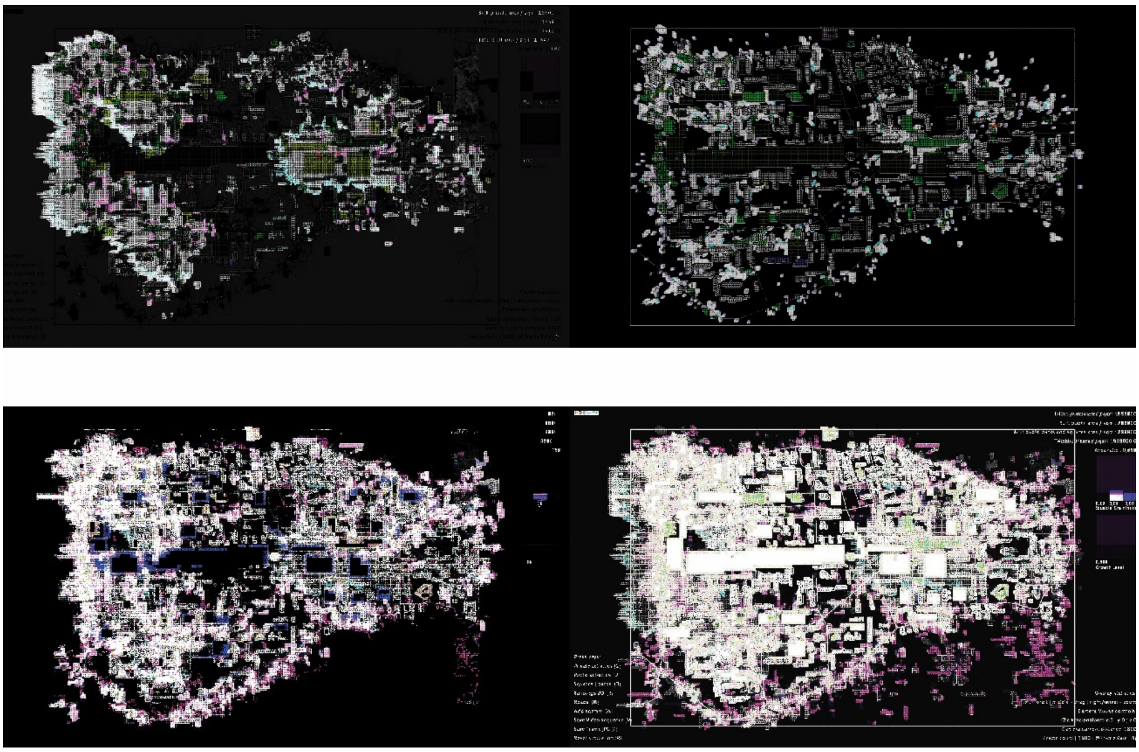


Fig. 48 The high-densities scenarios and mutual comparisons and combinations of all differences in one image.

Each scenario has been compared as an embedded layer above the previous one, i.e. each scenario has been compared in the context of the same three-run simulation with the different initial agents' positions, user-defined position and high density scenarios with the different typology input respectively.

The results of the comparison by means of visual outcomes yield selected areas in the urban pattern that can be considered as areas with strong potential for the future development. They can be assumed as future potential new centres within the urban structure where individuals would spend their time in all urban activities, as result shows (Fig. 49).

The deficiencies in the urban structure in terms of spatial relation and walkable distances can be defined as places where the urban pattern emerged. Once the walkable distance is insufficient, the new urban mass appears according to needed urban activity. The computational model basically points to certain places that should be considered as places with inadequacies in an initial urban situation and at the same time several of them would have a strong potential in the future time horizons to become new highlighted city spaces with spatial diversity that can bring the city bigger liveability and attractivity.

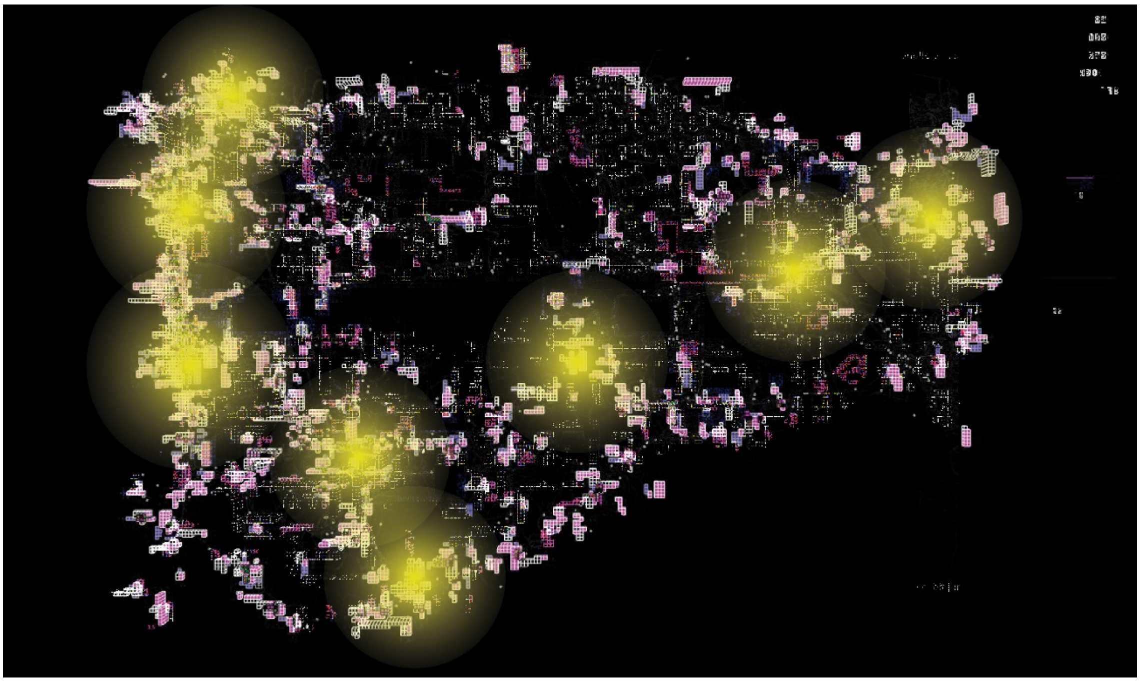


Fig. 49 The combination of the differences of the same input 3-run simulation.. The results point to selected places in the pattern that can be considered as places with very strong potential for further development and growth. Urban planners or designers should consider these places in the design process.

4.5.6 Evaluation from the Technological Aspect

From a technological point of view, the model is an open-source platform[4] that can be extended and scaled by additional parameters and algorithms that will complement its technological potential. The emergence of the cellular grid layer and vector dynamic flow layer is relevant for future work with the system in order to generate solid structure in the grid. Such a system simulates the movements and selected distribution flows in the urban environment in a simplified model. The method of GIS geometry transcription by using the developed algorithm has a major importance for its application for different environments and spatial case studies using any GIS data or OpenStreet map data. 3D grid layer allows architects to work with varied scales and typologies. The transcript can be executable by using any other GIS documents with diverse geometrical character.

4.5.7 Discussion: Novelty of the EmCity and Contribution for Contemporary Urban Planning

EmCity is a computational modelling tool for nonlinear urban modelling based on spatial relational qualities (walkability, equal spread of urban activities) in a local scale and serves as a decision-making software application for architects and urban planners in the early stages of urban design. The tool also serves as a qualitative visual analytical tool for setting-up and considering the accessibility in a local scale within the urban environment in requested distance in a 3D space. The EmCity brings explorative approach into the investigation of the urban textures in order to better understand the configurations within the urban mass when the urban environment is thickening. The tool visually shows tendencies how the urban structure can be adapted based on spatial relational properties related to the bottom-up demands and by means of top-down decisions as well. The basis of the application allows user to adapt it to different urban environments. The flexible and open architecture of the application core is capable to integrate a lot of algorithmic approaches that can enrich and enhance the capability of the modelling tool.

The crucial characteristics of this tool lies in a combination of two attitudes of the urban planning processes in one visual computational modelling platform: the bottom-up approach based on the spatial relations between the urban pattern and an urban agency (measurable walkable distance and equable spread of urban functions within the modelling area)

[4] The source code with EmCity executable file is a part of this thesis on the attached CD as well as on the webpage <http://archa3d.com/emcity/EmCity_64bit_Win.zip> [46].

and the top-down approach based on the input controls of the agent initial positions, movement strategy (various agents' movement controls and set-ups of their mutual interaction, setting-up initial positions of the urban agency in an iterative modelling process, the levels of importance-attractions of urban mass or connections) and essential input typology pattern (basically the infinite number of top-down configurations can be used) which brings a variety of urban solutions with many urban configurations and density values. As it is a nonlinear and modelling tool with unpredictable results, the novelty of this modelling process leans basically upon an interminable amount of urban solutions based on combination of bottom-up and top-down approach within one platform. The urban planner is capable to select appropriate solution for further evaluation, consideration or discussion with the stakeholders, clients and participants. The variety of aspects can be set up as input properties in order to produce diverse number of configurations which can be extremely different or slightly similar one to the other. The parametrization of these urban characteristics can inform traditional urban planning processes with the robust investigative point of view with diverse explorations of possible solutions and test probes of the urban textures and spatial configurations rather than yielding one final urban solution. This modelling attitude takes into account adaptive characteristics of the environment as well as spatial demands of the participants. In that manner the urban planner or architect has better control of the entire design process and he is able to implement various characteristics into the model by means of diverse number of spatial parameters as well as the behavior of the urban agency taking into account his own individual input characteristics.

The difference from the traditional planning is based on this amount of variation of the possible solutions which fits not only the framework of the architect's demands but spatial bottom-up stimuli as well as one robust investigative approach which leads to more flexible and adaptable decision-making framework. As such, this tool reflects contemporary context with fast changes and dynamic relational characteristics within the never-ending changes in the city entirety.

As Prof. Tom Verebes declares (2014) in his edited title Masterplanning the Adaptive City: Computational Urbanism in the Twenty-first Century: "*conventional techniques of masterplanning as we have seen, are inflexible in the face of changing requirements and limited in their adaptability to new contextual criteria, and therefore less intelligent than ought to be. [...] And it is an oversimplification to set top-down design in opposition to bottom-up growth and developments of urbanism - both approaches understand and project the city as a coherent whole.*"

" The opposition of formal, planed cities and informal, unplanned urbanism is set against the notion of the unplanned city begin shaped by small-scale, bottom-up interventions, and the idea of masterplanning as the domain of large-scale hierarchical actions is challenged as romantic. A masterplan can benefit from contamination by the mechanisms of informal urbanizations, which operate at multiple spatial scales and speeds, never finished, nor pretending the completeness. [...]."

Therefore the combination of bottom-up stimuli together with controlled interventions as a top-down approach which EmCity allows in a certain way is more efficient rather than conventional and traditional insight into the planning process in the early stages of urban design. The flexibility which computational model offers is crucial in the context of the contemporary dynamic post-digital era. As David Jason Gerber argues in Verebes (2014) "*it is no longer adequate simply to provide the top-down plan and expect to see the city emerge as intended. Conversely we cannot apply no rules at all to the growth of urban form*" The urban model should provide openness for various urban scenarios and allow urban designer to distinguish several solution possibilities which are adaptable for new conditions. The EmCity application offers such a solution in terms of infinite number of spatial configurations based on bottom-up spatial requirements taking into account architects' ideas at the same time.

The planner is able to modify and capture a lot of urban scenarios in a design loop process with direct visual and spatial feedback from the computational model. Then he/she would be capable to compare different versions of possible solutions or configurations and decide to implement selected scenario for further planning process. This way of nonlinear modelling better reflects the uncertainty of the behavior of a complex phenomenon as the city is. Despite the fact that the modelling probes and spatial model tests are not simulated in the framework of the real city conditions with entire urban dynamics (Vorel 2010), the EmCity serves as a testing normative model platform for variety of result in terms of their spatiality and adaptability in very fast computational system with graphical and 3D spatial model representation.

EmCity as a nonlinear modelling system is able to produce a huge amount of unpredictable outcomes which fit well the initial design phase in the framework of entire urban planning process and can be implemented as the model test probes in the initial design phases. By that way the traditional top-down planning process with one single urban solution can be enriched by a variety of different urban solutions from several points of view. The idea of combination of the top-down approach together with the selected bottom-up development yields more realistic urban scenarios how the city can involve various urban spatial conditions into one adaptable entirety which shows emergent complex properties.

From the workflow point of view the big advantage is that the system is capable to recognize the imported CAD | GIS footprint and the spatial grid layer can be adapted according to imported situation. In that way the tool is suitable for usage in already existing urban scenarios which can be modified, reconfigured and adapted according to the new spatial conditions and inputs.

By means of the computational model the user is allowed to model equable urban graininess (the convenient spread of urban activities within the modelled site) according to the appropriate walkable distance in a reachable distance radius.

4.5.8 Structured Summary of New Features of EmCity Application and its Limitations

Thus, the new features of the EmCity application can be summarized as follows:

- Spatial simulation based on accessibility in the already existing environment modelled in 3D space by means of computational model.
- Demanded walkable distances lead to the instantaneous reconfiguration of an urban mass based on additions and extensions.
- Generative platform for urban design.
- Model shows tendencies of changes in urban pattern based on spatial bottom-up stimuli.
- Model yields a great number of possible configurations.
- Model combines bottom-up and top-down approach.
- Tendencies showing places with urban potential.
- Model takes into account an equable spread of urban activities (private buildings, public buildings, and public open spaces) in the site.
- Customized modelling algorithms are open to be edited, extended, or scaled.

Therefore it is possible to specify the possibilities of the EmCity computational model as such:

- Spatial urban nonlinear modelling based on bottom-up stimuli with selected top-down control in a local scale.
- Modelling of urban thickening (growth of the built-up areas).
- Modelling of urban reconfiguration (extensions, addition of urban patterns).
- Exploration of formation tendencies within the urban pattern in a modelled area based on bottom-up approach.

- Finding the deficiencies in a spatial configuration of the initial pattern according to the specified reachability and spread of urban activities (urban graininess).
- Capturing the graphical and 3D model outcomes into variety of 2D and 3D formats.

However, the EmCity still has limitations in terms of:

- Precise reconfiguration based on all real urban dynamics and its prediction in the specified time horizons.
- Prediction of the decay of the urban mass based on real conditions (e.g. disaster scenarios or decay in long-term time periods). The decay algorithm is possibly applicable.
- Modelling of complete and real urban dynamics with all mutual dependencies.
- Economic modelling and prediction of markets, costs and properties.
- Large scale urban modelling in more detail.

4.6 Chapter Conclusion

There has been established a spatial non-linear simulation platform of reconfiguration of urban structure *EmCity* using a combination of several computational strategies that lead to a simulation of the colonial growth and thickening of the urban pattern in the South City District in Prague as a case study of examining the behavior of the urban structure in a local scale. The model has been evaluated from several points of view in terms of various input parameters, spatial differences between various scenarios, various typological simulation formations which bring a variety of results. It is necessary to continue with the simulation of reconfiguration of entire urban activities and observe the results of emergent behavior in the model in further simulation runs in order to explore wider and more robust solutions. Its development can be interactively influenced according to user input requirements, features and requirements of the agents that represent certain number of participants in urban spatial flows. It is vital to determine the evaluation criteria for such a model from multiple perspectives. One of them is the issue of a real-life application. Simulation model definitely does not simulate all the complex dynamic phenomena in urban environments simultaneously, however, it is offering a certain systematic solution where individual dynamic phenomena of the environment can be interpreted according to needs representing, in a particular way, respective solutions that can be used by architects or serve as a preliminary predicative tool in the design process in terms of spatiality and spatial relations in the urban environment. Through different values of the individual features of the agents (communication flow speed and agent population measures, distribution rate and degree of attraction and connectivity) it is possible to change the nature of the environment and thereby reach diverse predictions in urban structure configurations.

Another criterion might be the quality of the built environment which can be assessed in terms of architectural and urban perspective (habitability, spatial quality, diversity of the environment, aesthetic requirements, etc.), however it is impossible to validate systematically the quality of the urban space from the overall point of view. As an evaluation of the model in the first person position shows diverse qualitative characteristics of the spatial configurations, it is hardly possible to declare which model scenario is the best or which is better than the other. The above computational model has provided an insight that can be characterized in terms of the real and exact application to some extent speculative. Anyway, it is a platform that explores the behavioral and spatial relationships of participants in the observed environment in a local scale and therefore it tends to approximate to the real selected demands of population of the urban environment in measurable bottom-up characteristics in terms of walkability, spatial diversity and urban activity graininess. The model can be used also for other spatial case studies, mostly in the urban environments with high urban mass density.

The agent-based methodology in the existing urban environment in terms of creation and reconfiguration of the built environment is applicable within the real urban context. It will be useful in a particular observation of the selected bottom-up participants´ stimuli. It is assumed that the multilevel scenario development of the existing environment would be readable, receivable and intelligible. This assertion is necessary to be verified by extended functional simulation model of the area, i.e. with other analytical information such as Space Syntax information or Isovist simulation in the next layer. Utilizing the emergence phenomenon as a paradigm of the design and reconfiguration environment in the existing urban context, it is presumed and characterized as speculative in certain way, but offers a legitimate insight and a possibility for another understanding of social, spatial and environmental interactivity in terms of urban design thought using the agent-based methodology.

The agent-based model does not represent a model of the reality we know. It is rather an instrumental platform for architects who explore the potentials and tendencies of the spatial emergent bottom-up approaches based on spatial relations between urban units, agents and urban networks within the city environment. The result is a speculative image of the urban district South City in Prague and does not establish one proper re-design solution or one potential reconfiguration design where the above mentioned aims of the simulation were accomplished. Emergence paradigm offers dozens, even hundreds of urban spatial solutions. In that manner an urban space can be configured based on adaptive spatial conditions. The model has a strong potential to become a generative tool for exploring the rapid urban growth, heterogeneity and urban graininess in the existing high-dense urban areas, especially in Asia according to the well-known contemporary conditions. The research so far has been concentrated onto the developing an analytical and generative tool for architects in the early phases of urban design and synthetizes accumulated computational advancements based on the agent-oriented approach. The computational framework has been established as an extendable and scalable system and as an open-source platform.

The computational model EmCity published online [46] and its source code in a JAVA/Processing language as an open-source application will offer a possibility to enhance the code by means of new suggestions or algorithmic procedures in a wide community of Java and Processing developers and architects as an open live system. It will be possible to add new features of the simulation in order to enhance the definition of the model validity. By that way the model will offer a diverse range of its application in the context of planning, education or architectural design. The structure of the application is easily expandable, scalable and adaptable to the particular users' exploitation.

V. Future Work

• The city can be understood as a self-maintaining organism with internal self-sufficient metabolism. Considering the city as an adaptive never-ending formation process which can be self-driven, self-organized and self-produced, the further research shall continue in focusing on these aspects. Another research question emerges in that manner: How to simulate and model such a behavior using information technologies ?

The further research should recognize a paradigm shift from the buildings, streets, blocks and infrastructure into networks, negotiations, and interconnections within interactive relations. Can a city be considered as an invisible representation of the virtual and digital existence? These new research questions might lead into a speculative design research. A lot of observation of the rapid urban growth and urban decay in various spatial case studies should be built, modelled, simulated, observed and validated. In that manner the city can be perceived as a self-referencing autopoietic system.

• The other field of the research is connected with the real–world data implementation, big-data informed urban design as an interdisciplinary approach that can shape the city space and influence the city behavior based on wide properties and characteristics, even in real time processes. This is a robust approach which needs wider interdisciplinary and transdisciplinary cooperation with the proper hardware support.

• These two above mentioned approaches would be considered and involved in a qualitative validation of the computational models based on a different technological or hardware equipment used during the visual observations such as Oculus Rift, 3D Cave or wider responsive augmented virtual environments in order to explore visual and spatial potentialities of the models in a virtual reality together with augmented reality and responsiveness. The very strong potential lies in interactivity with the computational models that can be used in urban design and planning as a new methodological design approach.

VI. Overall Conclusion

1. The developed simulation platform represents the nonlinear evolution of the urban structure based on the needs of participants - walkable approach distances to the places of interests and volume expansion.

2. ABM methodology is useful and applicable as a modelling technique for partial spatial emergent behavior of urban structures in the city environment that simulates growth of urban mass, reconfiguration and dynamic flow distributions that can affect the urban pattern formations.

3. The simulation has identified deficiencies in the urban structure (insufficient walkable distances, lack of urban activities) and outlined possible scenarios development environment in mass structure in many variations.

4. Simulation offers alternative spatial solutions and delivers fast results. Parametrically user-defined input conditions and values allow user to observe various options of the urban development. **The hypothesis of the research has been confirmed.**

5. The simulation model can enhance the decision-making and design tools in the early conceptual design phases during the design process or considering the urban environments in a particular planning process.

6. The model would be available as an educational tool at the universities and may be useful in practice as a partial validation tool in a setting-up of the strategic documents of further urban development or policy making processes.

7. Open-source model enables future work to extend the algorithmic procedures operating with the emergent approach of the agent system and it is extendable and scalable system with additional rules, which affect the configuration and re-organization of the urban structure. The

system has a potential to integrate a big data approach as a convenient tool based on a Java / Processing programming language.

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B. Web Pages

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C. Table of Figures

D. Curriculum Vitae

PERSONAL INFORMATION

Peter Buš, Mgr. Art.

Tolsteho 522/11, 10100 Prague 10 Vrsovice, Czech Republic

+420 608 806 760

buspeter@fa.cvut.cz, peterbus@archa3d.com

http://www.archa3d.com

Sex Male | Date of birth 28/08/1978 | Nationality Slovak

WORK EXPERIENCE

2015-present

Research Assistant | Architect

Simulation Platform - Module IX , Future Cities Laboratory, Singapore ETH Centre, Singapore, 1 Create Way, Create Tower #06-01, 138602 Singapore. http://www.fcl.ethz.ch/module/simulation-platform/

- research in the field of Urban Studies in terms of advanced urban simulations
- development of the simulation model of selected urban dynamic phenomena
- advanced algorithmic 3D modelling, visual programming
- writing the appropriate conference papers, publishing, presenting

Business or sector Research, Urban simulations, Visual Programming, Advanced 3D Parametric Modelling.

2010-2015

PhD candidate / Design Studio Professor Assistant

The Cabinet of Architectural Modelling MOLAB | The Department of Architectural Design I,
Faculty of Architecture, Czech Technical University in Prague, Czech Republic, Thakurova 9, Prague 6 Dejvice,
Tel.: (00420) 224 356 207,

contact person-research: Associate Professor Dr. Henri H. Achten, e-mail: achten@fa.cvut.cz http://fa.cvut.cz
contact person-teaching: Associate Professor Arch. Miroslav Cikán,
e-mail: cikanmir@fa.cvut.cz http://fa-atc.blogspot.sg/

PhD Thesis: Emergence in Urban Environments: Agent-oriented Simulation of Environment Reconfiguration.
Responsibilities include:

- doctoral research in the field of Architecture and Urban studies in terms of emergent urban strategies
- development of the computational model of selected urban dynamic phenomena based on bottom-up stimuli
- writing the conference papers, publishing, lecturing, presenting
- leading and organizing workshops in the field of computational design
- tutoring in the architectural design studio

Business or sector Research, Education, Architecture, Urban Design, Computational Design, CAAD

2011-present

Project Architect

Self-run architectural practice ARCHA Peter Buš Architecture | Computational Design
Project Architect and Planner, 3D graphic / Visualisation / CAAD specialist, http://archa3d.com

2008-2011

Project Architect

Architectural studio DaM Ltd., Prague, Czech Republic,
full time employed Project Architect and Planner, 3D graphic / Visualisation / CAAD specialist
Na Dolinach 6, Prague 4, Czech republic, http://www.dam.cz

2006-2008

Design Architect

Architectural studio MCA atelier Ltd., Prague, Czech Republic,
full time employed Design Architect and Planner, 3D graphic / Visualisation / CAAD specialist
Dykova 1, Prague 10, Czech republic, http://www.mca-atelier.com

Business or sector Architecture, Urban Design, 3D modelling, CAAD

EDUCATION AND TRAINING

2010-present

PhD – Thesis Title: " Emergence in Urban Environments: Agent-oriented simulation of environment reconfiguration"

Expected EQF 8

The Cabinet of Architectural modelling MOLAB, Faculty of Architecture, Czech Technical University in Prague, Czech Republic

- City planning, computational design strategies, spatial planning, bottom-up simulation, urban modelling

1998-2004

Master of Arts in Architecture (Mgr. Art.)

EQF 7

Department of Architecture, Academy of Fine Arts and Design in Bratislava, Slovakia, www.afad.sk

Bachelor of Arts in Architecture (Bc.)

Department of Architecture, Academy of Fine Arts and Design in Bratislava, Slovakia, www.afad.sk

- Architectural and Urban Design, Visual arts and architecture disciplines, History of Visual arts and Architecture, Technical disciplines, Computational Design, Building Construction, Visualisation, Architecture and Urban 3D Modeling

PERSONAL SKILLS

Mother tongues: Slovak, Czech

Other language

	UNDERSTANDING		SPEAKING		WRITING
	Listening	Reading	Spoken interaction	Spoken production	
English	C2	C1	C1	C1	C1

Levels: A1/2: Basic user - B1/2: Independent user - C1/2 Proficient user
Common European Framework of Reference for Languages

Communication skills

- Excellent communication skills gained through my experience as an architect, assistant professor / tutor and PhD candidate.

Organisational / managerial skills

- leadership / tutoring / organisation in the design studio, faculty workshop participating
- I was responsible for a team of 25 students in the design studio at the faculty
- as an project architect I was responsible for organisation and leading the project team

Computer skills

- Rhinoceros - expert
- Adobe Creative Cloud - expert
- Grasshopper - expert
- Processing / Java - advanced
- Maya - advanced
- V-ray render platform - expert
- Autodesk 3D Studio Max, Design, Autocad, Architecture - expert
- Game engines Unity3D | Unreal - advanced

Other skills

- visual arts: painting, drawing
- music: guitar

ADDITIONAL INFORMATION

Selected architectural / urban projects

- The revitalisation of the Slovak National Gallery in Bratislava, competition entry, 2003
- Revitalisation of the main town square in Nitra, architectural competition entry, Slovakia, 2009
- The new city centre Zamostie Trencin, 2nd Prize, arch. competition entry, Slovakia, 2010
- Reconstruction of two historical residential houses from 19th century on Janackovo nabrezi 53/55, Prague, Czech republic, project 2006-2007, realisation 2008-2011
- Main Point Karlin, Prague, administrative block, 2010

Conferences and publications

- 30th eCAADe International Conference in Prague, Czech Republic, Digital Physicality / Physical Digitality, "*Emergence as a Design Strategy in Urban Development*".
- 31st eCAADe International Conference in Delft, Netherlands, Computation and Performance, "*Emergent Urban strategies-Rules of City Reconfiguration*".
- 32nd eCAADe International Conference in Newcastle, UK, Fusion: Data integration at its best, "*Emergent articulation field in existing urban context-Computational typologies with emergent matter*".
- M. Berger, P. Buš, V. Cristie, A. Kumar, Simulation platform module IX, Future Cities Laboratory Singapore ETH Centre, *"CAD integrated workflow with urban simulation-design loop process"*. Sustainable City 2015, 10th International Conference on Urban Regeneration and Sustainability, Medellin, Colombia, 2015.
- M. Berger, P. Buš, V. Cristie, A. Kumar, and J. Lauener, Simulation platform module IX, Future Cities Laboratory Singapore ETH Centre, *"Cooler Calmer Singapore: Towards comfortable tropical urban environments"*. FCL Magazine No. 4, special Issue, Simulation module IX, forthcoming, 2015, Singapore.

Research grants

- The Grant Agency of the Czech Technical University in Prague, grant No. SGS13/150/OHK1/2T/15, 2012-2014, "Emergent urban strategies-simulation model of environment reconfiguration".
- AKTION Programme Czech Republic–Austria, 2013 "Disruptive Eco-logics".

Workshops

- Research stay Disruptive Eco-logics, IOA, die Angewandte Vienna, 2013
- Upward: urban project workshop and responsible design Torino, Politecnico di Torino, Italy, 2012
- Iterative Protocols, Processing workshop Vienna, 2011
- Porous Formation and Virtuosity, Processing workshop Re.Co.de nature, Prague, 2013
- Pheromonics, Processing workshop Re.Co.de nature, Prague, 2014
- Generative Handmade, Processing workshop Re.co.de nature, Prague, 2014

Honours and awards

Grand Prix of the Society of Czech Architects, 2012,
1st Prize Revitalisation of the Crucifix Bastion- Horska, Prague 2, Czech Republic, - cooperation with MCA atelier Ltd.., competition entry 2007, realisation 2010-11

Memberships

- Certified architect / Slovak Chamber of Architects (AA SKA 1872), 2010
- Registered architect / Czech Chamber of Architects, 2012

ANNEXES

- Portfolio of computational design | advanced 3D modelling | architectural and urban design
  http://www.archa3d.com

E. Publication Summary

1. P. Buš*, Emergencia ako tvorivá stratégia - proces tvorby pomocou digitálnych parametrických nástrojov, Emergencia v architektúre – úvod do problematiky*, research poster, 1st PhD Students' Workshop, FA CTU, Prague, 2010. (100%)

2. P. Buš*, Emergencia ako tvorivá stratégia - proces tvorby pomocou digitálnych parametrických nástrojov, Simulácia chovania emergentných štruktúr pomocou agentovo-orientovaného modelovania*, research poster and oral presentation, 2nd PhD Students' Workshop, FA CTU, Prague, 2011. (100%)

3. P. Buš*, Emergencia v architektúre: definícia pojmu a úvod do problematiky*, article, magazine Stavba 1/2012. (100 %)

4. P. Buš*, Emergence as a design strategy in urban development, Using agent-oriented modelling in simulation of reconfiguration of the urban structure*, Digital Physicality, 2012, 30th International conference eCAADe, 2012, FA ČVUT Praha, article and paper presentation. (100%)

5. P. Buš, L. Kurilla, H. Achten*, Emergent Urban Strategies, Rules of city reconfiguration,* 31st International conference eCAADe, Computation and Performance, Faculty of Architecture, Delft University of technology, Delft, Netherlands, article and paper presentation, 2013.
(33,3%)

6. P. Buš, *Emergentné urbánne stratégie: Pravidlá rekonfigurácie mesta*, príspevok na konferencii TYPOLOGIE (N)OSTALGIE, FA VUT, Brno, 2013, proceedings TYPOLOGIE (N)OSTALGIE, edited by FA VUT Brno, article and paper presentation, 2013.
(100%)

7. P. Buš, H. Achten, *Simulovat nepředvídatelné*, research poster, exhibition Design Computation, MOLAB, foyer at the FA CTU Prague, 2013.
(90%, 10%)

8. P. Buš, *Emergent urban strategies*: *Simulation of environment reconfiguration*, 2nd Design Computing PhD workshop, OPPA III, FA CTU, 2014 visiting critic: Professor Peter Russell, TU Aachen, 2014. (100%)

9. P. Buš, L. Kurilla, H. Achten*, Emergent articulation field in existing Urban Context: Computational typologies with emergent matter*, 32nd International conference eCAADe, Fusion, Northumbria University, New Castle, UK, article and paper presentation, 2014. (33,3%)

10. Buš, P., *Emergencia v urbánnom prostredí: Agentovo-orientovaná simulácia rekonfigurácie prostredia,* Kolokvium FA ČVUT 2014 – Architektura a Urbanizmus v středoevropském prostoru, International conference, Prague, 2014. (100%)

11. P. Buš, L. Kurilla, H. Achten*, EmCity: Simulační model emergentního města*, autorizovaný software. [ONLINE], <http://archa3d.com/emcity/EmCity_64bit_Win.zip>. (45%, 45%, 10%)

12. M. Berger, P. Buš, V. Cristie, A. Kumar, Simulation platform modul IX, Future Cities Laboratory Singapore ETH Centre, *CAD integrated workflow with urban simulation-design loop process*: Sustainable City 2015, 10th International Conference on Urban Regeneration and Sustainability, 1-3 September, Medellin, Colombia, 2015. (25 %)

13. M. Berger, P. Buš, V. Cristie, A. Kumar, Simulation platform modul IX, Future Cities Laboratory Singapore ETH Centre, *CityHeat: Interactive visualisation system of simulated urban traffic heat propagation:* Siggraph Asia, Kobe, Japan, 2015 (forthcoming). (25 %)

14. M. Berger, P. Buš, V. Cristie, A. Kumar, and J. Lauener, Simulation platform module IX, Future Cities Laboratory Singapore ETH Centre, "Cooler Calmer Singapore: Towards comfortable tropical urban environments". FCL Magazine No. 4, special Issue, Simulation module IX, forthcoming, 2015, Singapore (forthcoming). (20 %)

F. Workshops, Research Stayings, Study Travels

1. *UPWARD Urban project workshop and responsible design* Torino 2012. Politecnico di Torino, Torino, Italy, 05/2012.
2. *Iterative protocols*, Processing workshop Co-De-It, Vienna, Austria, 11/ 2012.
3. *Porous Formation and Virtuosity*, Processing workshop, VŠUP, Fakulta architektury ČVUT, MOLAB, ReCoDenature.org, Praha, 2013.
4. *Disruptive eco-logics*, Die Angewandte, IoA, Urban Strategies Postgraduate Program, Vienna, 06-07/ 2013.
5. *Pheromonics,* Processing Workshop Co-De-It, ReCoDenature.org, VŠUP, Praha, 2014.
6. *Generative Hand-made,* Processing Workshop ReCoDenature.org a VŠUP, Praha, 2014.
7. *Cooler Calmer Singapore,* Simulation Platform Research Module IX ,
   Future Cities Laboratory ETH-Centre Singapore, iA Chair of Information Architecture ETH Zürich, Singapore, 01-08/2015.

G. Fundings, Grants

1. Own resources.
2. Grant SGS13/150/OHK1/2T/15, FIS 161-1611350E000, 2 years project
   "Emergentní urbánní strategie - simulační model rekonfigurace prostředí", FA ČTU, 2013-2014.
3. Grant Program Aktion ICM-2013-04516 Disruptive eco-logics, AKTION - programme of Austria –Cezch Republic cooperation-experimental development, study research stay at the IoA, University of Applied Arts in Vienna, Die Angewandte, Vienna, Austria, 2013.

H. Teaching

1. Assistant Professor at the ATC design studio, (Head of the studio Associate Professor arch. Miroslav Cikán): Department of Architectural Design I at the FA CTU in Prague, teaching in undergraduate and graduate programmes.
   2009-2014. <http://fa-atc.blogspot.cz/>.
2. Co-tutoring *Porous Formation and Virtuosity*, Processing workshop, VŠUP, FA CTU, MOLAB, ReCoDenature.org, Praha, 2013.