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URBAN AUTOPOIESIS

Towards Adaptive Future Cities

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Abstract. A city, defined as a unity of inhabitants with their environment and showing self-creating and self-maintaining properties, can be considered as an autopoietic system if we take into account its bottom-up processes with unpredictable behaviour of its components. Such a property can lead to self-creation of urban patterns. These processes are studied in well-known vernacular architectures and informal settlements around the world and they are able to adapt according to various conditions and forces. The main research objective is to establish a computational design-modelling framework for modelling autopoietic intricate characteristics of a city based on an adaptability, self-maintenance and self-generation of urban patterns with adequate visual representation. The paper introduces a modelling methodology that allows to combine planning tasks with inhabitants' interaction and data sources by using an interchange framework to model more complex urban dynamics. The research yields preliminary results tested in a simulation model of a redevelopment of Tanjong Pagar Waterfront, the container terminal in the city of Singapore being transformed into a new future centre as a conducted case study.

Keywords. Urban Metabolism; Urban Autopoiesis; Computational Interchange; Emergent Urban Strategies; Adaptive City.

1. Introduction

The research explores aspects of self-maintenance, adaptability and self-creation of urban patterns transformed into a domain of interacting urban community of inhabitants represented by urban agents together with its physical urban structure.

1.1. BACKGROUND AND RESEARCH QUESTIONS

In this particular research study, the concept of autopoiesis covers the way how the urban structure is created, transformed, distributed or redistributed, assembled, organised, reconfigured and proceeded. This implementation of the autopoiesis paradigm into urban systems aims to grasp more complex characteristics of the city within the contemporary urban design discourse, in particular, tendencies of patterns to grow or decay according to inhabitants' requirements, distribution flows of energy, costs, goods, services or city networks connectivity (virtual, physical or social) related to an entire urban metabolism.

In a long term perspective this investigation tries to identify and discuss internal dynamics in a selected part of the city of Singapore that can help experts to better position their decisions. In so doing, several research questions need to be addressed: Which kind of urban forms and systems are more convenient in terms of rapid changes (social, behavioural, spatial) in our contemporary cities? Which urban tectonics and morphologies are able to efficiently react to various forces in cities, such as population growth? What kind of urban activities are able to maintain themselves according to local and external interactions and relay of information? Is there a convenient way of visual understanding of unpredictable processes and unexpected features of our future cities that can inform experts?

Although the research questions relate to broader aspects of urban environments, the notion of the autopoiesis presented here is focused on significant properties of an urban system which actuate the urban patterns to grow and subsequently lead to new conditions of urban configurations that urban growth refers to. In particular, it covers internal spatial relations between particular interacting urban units (agents in relations with an urban mass) that make the system constantly self-referencing (Maturama & Varela 1980) and in a state of dynamic self-creation. The urban environment investigated in this research study is reduced in its complexity with respect to its spatial aspects (Luhmann 1975; 1982).

1.2. PROBLEM STATEMENT

Following these features of autopoiesis mentioned above, urban designers still facing the problem how to model and simulate various complex characteristics of urban environments in one robust and comprehensive simulation and at the same time. Moreover, these characteristics and dynamics are dependent on themselves and they are creating never ending intricate processes of continuous transformation, which makes a city environment *always in a state of flux, growing and decaying* (Verebes 2014).

Other aspect of the problem outlined here is the designer's intention and his contribution to an urban layout generation. To simplify the entire design process, it is necessary to proceed his or her design intervention into the modelling framework as interactively as possible and minimize the computational process within an entire system. More specifically, the designer would be able to manipulate with the system in an intuitive way.

1.3. RESEARCH OBJECTIVES

The paper aims to establish a modelling workflow which reflects the above mentioned facts and would allow urban designers and experts to deal with various sources of data, e.g. external big data sets, user interaction inputs from a different application in order to obtain one robust modelling environment incorporating more complex urban phenomena and dynamics. Thus, the main research objective in this particular research study is to provide a framework, a simulation platform for architects and urban designers which will combine designer's top-down design requirements and bottom-up inhabitants' community demands and their interactions into one system as a modelling application with an interactive visualisation.

1.4. SCOPE OF THE PAPER

The paper introduces a modelling methodology approach based on a connection of two different applications for urban designers interacting between themselves (Rhino/Grasshopper and Java/Processing agent-based model) and combined with the user's input and interaction in a real-time process. To test the performance and interactivity features of modelling more complex urban design scenario, we propose a custom-oriented computation interchange framework, namely the LUCI (Treyer 2016a). In particular, the Tanjong Pagar Waterfront in Singapore has been selected as a test site for the experiment. The modelling approach involves selected bottom-up spatial demands, such as accessibility distances defined by the user in the graphical interface, spacing distances between urban elements and equable spread of urban functions in order to obtain mixed-used urban environment.

As a resulting outcome of this research, the study provides several spatial scenarios with variants, for urban designers' consideration. These are introduced and explained in section 4. The paper does not provide final designs and overall modelling of all metabolic urban layers, such as its mobility, transformation capacity, energy and waste flows, however it outlines a base for a modelling framework, where these aspects can be incorporated later on from other applications via the interchange platform LUCI.

2. State-of-the-art Review

As Christine Boyer states (2015), a city, an autonomous entity expressed in a living metabolism, *is adaptable to many forces and dynamics*. The phenomena of an emergence in the framework of cities as complex systems are known from theories as from Michael Batty's work (2014) modelled by means of cellular automata and agent-based models or concepts of cities as metabolic networks, e.g. theory of "Netzstadt" (Baccini 2014). According to Varela (1979), the autopoietic system is structurally linked to its environment, adapts according to its local or external conditions and maintains its internal organisation within this environment. It is a *complex organisation in which information transmittal, reception and interruption proceed recursively through continual feedback and feed forward across multiple levels within the system* (Boyer 2015).

According to Spyropoulos (2013), it is necessary to understand today's contemporary context where architecture must be engaged with the *information-rich*

environments and continuously changing demands for *adaptive models for living*. His approach, as he claims, explores possibilities where *the interplay of local agency and environmental stimulus constructs collective order[...], governed through emerging collective interaction*.

To model such complex phenomena of a city, it is necessary to take into account mutual dependencies of particular urban aspects together with urban designer's intention which communicate between each other and exchange information. The conventional modelling applications do not provide communication functionalities related to multi-layered interwoven processes dependent of themselves. The advantage of our proposed communication interchange platform, apart from other communication platforms, e.g. gHowl components (Fraguada 2016) or Functional Mock-up Interface FMI (Junghanns 2016), is that it is capable to incorporate various urban data sources or connections with other interfaces or applications developed in different programming languages or models in different scales and different platforms in one more robust system. The workflow is not time-consuming and not demanding a higher computational power, offering an open source environment for other contributing developers (Treyer 2016b).

The simulation of urban growth with agents is done also in popular games like Sim City (Wright 2016 [1989]) or rule-set-based urban growth platform City Engine (Esri 2016). Although the game Sim City is not related to any urban design tasks, it can serve as a valuable information source how the urban growth rules are incorporated within the entire system. Therefore, an urban design modelling process with the game-like graphical user interface can be as similar as playing a game in an intuitive way.

3. Methodology

The proposed Lightweight Urban Computational Interchange system LUCI (Klein & Treyer 2016) serves as a communication and management distribution channel between modelled urban metabolic layers in general, and dynamic data sent from different modelling interfaces (e.g. Rhino/Grasshopper) represented by the designer's predefined urban patterns, later distributed into a dynamic generative model (figure 1).

3.1. LUCI - LIGHTWEIGHT URBAN COMPUTATION INTERCHANGE

More specifically, this paper investigates an urban growth based on an accessibility and spacing distances between particular urban elements. An imported data set is subsequently read by the agent-based generative simulation model and displayed as a simplified 3D environment. This particular layer, in this case the external geometrical data set from the Rhino CAD application, is transferred into a computational service within the LUCI interchange system and involving the designer's parametric geometrical modifications in Grasshopper each time it is modified or changed. As such, the modifications are read and sent by the LUCI and the simulation is fed in a real-time process.

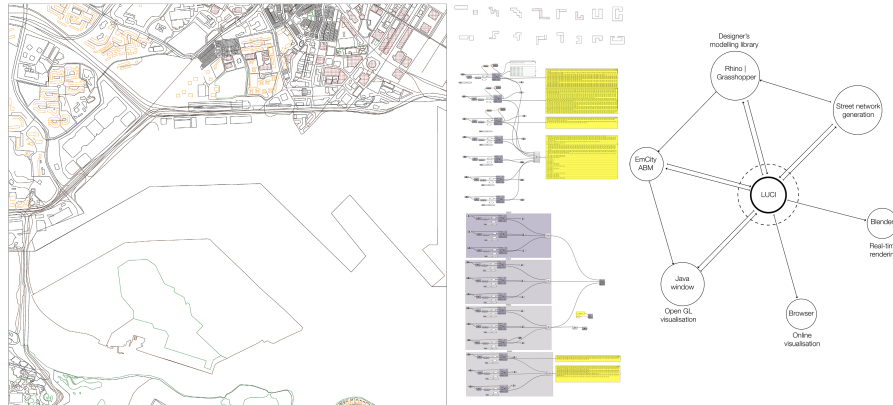


Figure 1. A designer's modelling framework containing a library of various predefined shapes transferred into an ABM simulation for a subsequent interaction with agents. The data are exchanged by the LUCI middleware. .

Rhino/Grasshopper is well known for serving as a integration platform for various applications within the realm of digital architectural production. It is possible to connect Rhino/Grasshopper through gHowl to a number of compatible applications through TCP and UDP networking protocols (Fraguada 2016). Yet, Rhino users ever again hit limits. Grasshopper is known for being rather slow, not able to handle enough geometry to be suitable for large urban planning and it is single-user centric. There are some startups, such as Flux or Shape Diver (2016), that aim to provide solutions to overcome this by bridging Rhino/GH to the Internet, to Excel, to Autodesk Revit. Still, these solutions focus on Rhino and heavily depend on Windows as their main platform. With LUCI we follow a slightly different approach. The aim is to provide a neutral, open source platform and programming language independent framework. It has a modular structure that allows interested developers to replace modules in case they favour to.

As a result, it will bring a comprehensive simulation and generative model depending on a real-time user's modification or other external data source that can be embedded, such as a vector position for various urban features, any quantified definition of many variables or pre-defined shapes of urban patterns for each of the used urban typology, in this case housing, public buildings or open public spaces.

3.2. ABM SIMULATION MODEL

The core of the generative simulation model introduced here is based on the EmCity platform (i.e. *Emergent City*), an agent-based simulation developed in previous phase of the research (Buš 2015). The agents try to achieve their demanded target (private or public building or a space) in a specific predefined accessible distance. If it is not achieved, the required urban unit or an activity appears, adapted to current distance requirements.

The model has been adapted to Tanjong Pagar site for this particular case study purpose and enhanced with interactivity features, where the user is allowed to mod-

ify the initial positions of agents in regard his or her preferences in the graphical user interface. As such, the observer controls the positions where agents are released from, in an interactive way and in a real-time process. Moreover, each initial position has been weighted with an user-defined number of released agents. In that manner the user specifies the level of importance for each particular initial position which reflects the real scenario more properly. The source code of the EmCity model is available as an open source platform under the GNU General public licence (Buš & Kurilla 2016; Treyer 2016a). The CAD data source regarding the Tanjong Pagar site as an initial geometrical input has been transferred into the model from the Open Street Map platform.

3.3. MODELLING PROCEDURE IN A CASE STUDY

In this section we aim at demonstrating LUCI's potential by showing how it can be used to interlink different applications on different machines with different operating systems. With this setup we want to provide multiple comparative views of the case study area. The principle step is the creation of urban geometry based on an agent simulation, which incrementally adds buildings to a scene corresponding to the behaviour of its agents that represent inhabitants in a simplified way. With every iteration the attached views will be updated. All views not only synchronise their geometry but also the camera angle at which the geometry is presented.

The geometry creation is implemented in a Java-based Processing Application. The typologies that are being placed in the scenario can be modified real-time in Rhino. The comparative views are provided by a Java application that uses OpenGL for display. Additional views are provided by Blender for ray-trace rendering as well as by a web viewer that theoretically allows to present views to any connected participant in the internet.

4. Generation of Urban Patterns in Tanjong Pagar Waterfront

The modelling and simulation framework has been set by connecting Rhinoceros/-Grasshopper designer's interface and the Java-based agent simulation model EmCity by means of the LUCI middleware platform.

4.1. RESULTS AND OBSERVATION

The user is allowed to observe growth of the urban area based on the designer's pre-defined spatial scenarios of various types of shapes and configurations (figure 2). Data are sent to the LUCI in real-time and displayed in the viewer. The geometry can be modified by the designer and it is updated in the display window. By using this methodology, the bottom-up growth of the city is simulated according to criteria of accessibility, spacing distances (density), spread of urban typologies and positions of agents and different spatial scenarios are built, visualised and stored. The LUCI stores and proceeds the data for further observation or rendering using other applications, such as Blender in a real-time process.

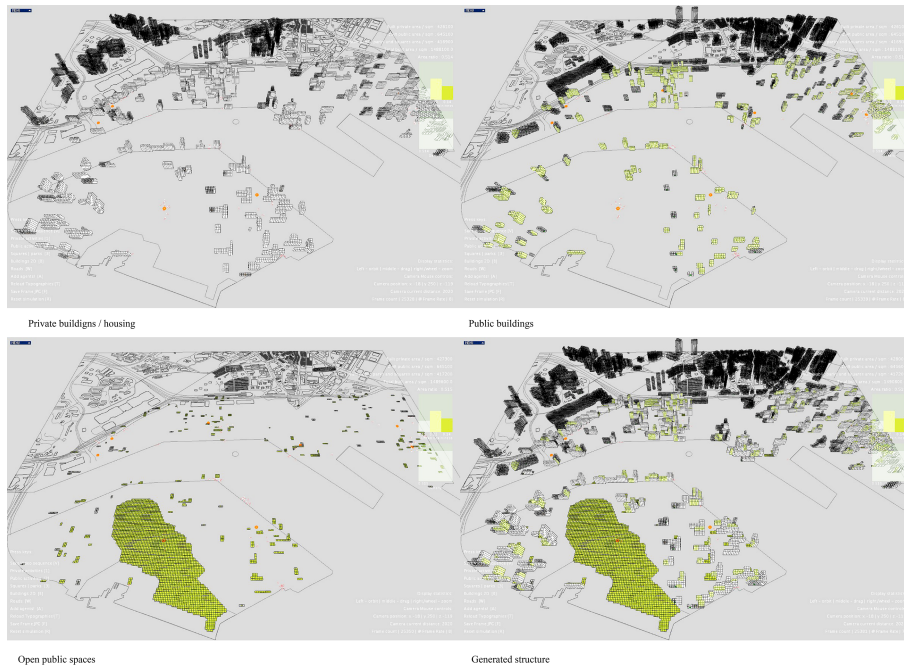


Figure 2. Combination of user-defined typologies in one urban layout. Different types have been sent from Rhino to the ABM model during the simulation process.

Thus, the framework allows to connect modelling software, rendering application, Java-based agent simulation and several display windows with the same or different camera positions, if necessary. In that manner, architects are able to gain and deal with big urban scenarios efficiently and from different perspectives, incorporating more complex and behavioural urban phenomena into a design process, displaying various aspects of the urban scenario at the same time.

The urban patterns, as it is observed from the agent-based simulation, grow and adapt according the user's preferences in terms of specification of agent's interactions, their initial positions and locations with weights combining with the formation process based on the designer's definition of the spatial scenario. A combination of bottom-up autopoietic growth together with the user inputs will allow to model more complex urban features considering the intuition of the designer. This cognitive approach of design computing, involving human's interaction with the machine, can yield more appropriate design scenarios related to real demands and bottom-up requirements, but still taking into account the designer's inputs and contribution.

The volumes of urban mass are generated in the ABM model. They are located according to random positions following the locations of agents themselves, their spacing distances and the accessible distances to particular buildings. The growth of the new added volumes proceeds based on demanding accessible distance set by the designer in the graphical user interface. The heights of the buildings can

vary in accordance with the user's parameter inputs in Rhino. Each input yields different results. Although the character of the layout is comparable and similar for each investigated scenario (figure 3), the outcomes are always different (figure 4).

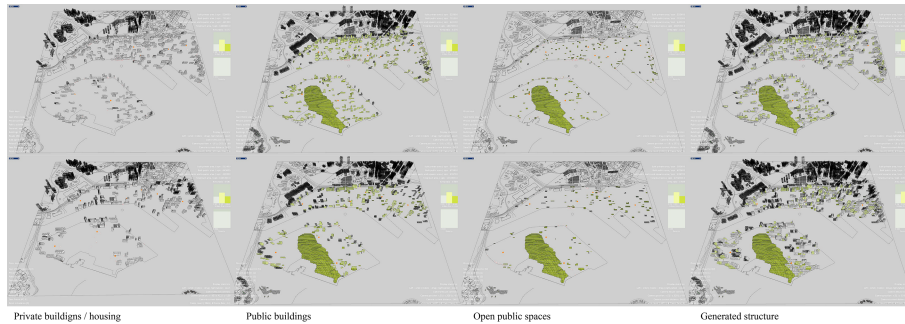


Figure 3. Various types of pre-defined urban configurations from Rhino appeared in the ABM model. The user is allowed to explore each urban activity separately.

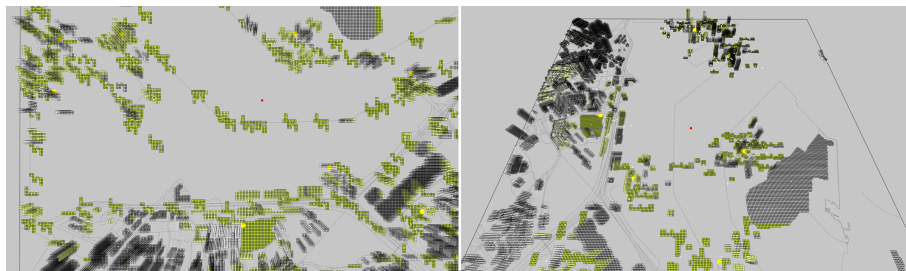


Figure 4. Generation of new buildings based on agents' flows and user-defined accessibility distances.

5. Conclusions

The proposed modelling framework allows the user to connect various applications (CAD, ABM model, visualisation window) by employing the middleware system LUCI which serves as a communication and data exchange platform.

5.1. DISCUSSION

For the time being, the proposed system has integrated an urban pattern formation algorithms dealing with urban mass and volumes only. Although the agents themselves are able to generate the buildings and patterns, the model is still limited in providing more precise street network layout. The visualisation of the model itself is simplified and expressed in a higher level of abstraction, but understandable for experts. Moreover, the model deals with the urban growth based on spatial requirements and it does not take into account broader aspects of urban metabolism. Nevertheless, the system can be enriched with more diverse modelling approaches as

the LUCI middleware allows it. The positioning of the agents and the urban mass need to be improved in order to obtain more rational urban patterns taking into account more realistic infrastructure and urban criteria of connectivity, visibility and centrality.

5.2. FUTURE WORK

By means of the proposed modelling approach introduced here, the planners, architects and stakeholders will prospectively identify the most significant processes within a city which influence the urban changes and might contribute to the phenomenon of self-maintenance, adaptability and self-sufficiency which can be characterised as processes of the urban autopoiesis. Based on these observations and external sources of information, the spatial urban solutions can be designed and assessed, showing more complex relational qualities of the urban space. Multi-disciplinary approach of complexity science framework, consisting of computer science, urban design, Citizen Design science, and game development integrated into an advanced urban simulation and visualisation, will help experts to find more appropriate model of a liveable and adaptive city.

The research will continue in testing and developing the modelling and simulation framework linked with a visualisation system in a game engine (Cristie & Berger 2017) integrating aspects of urban self-maintenance and self-creation of urban patterns based on local conditions, communities' interactions, relay of external information (e.g. from social networks) and actual people's behaviour and tendencies in one urban design-modelling platform harnessing more complex urban phenomena. We would also like to use game engines as views potentially using Blender-based services to bake textures in real-time.

The system is open to be enhanced by more advanced algorithms, such as multi-objective criteria within urban synthesis methods as an input for the urban layout generation (König 2015). The proposed approach could contribute to the field of Cognitive Design Computing integrating more complex urban tasks and embedding artificial intelligence and recognition-based learning processes into the generative modelling workflow.

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