Computer-Simulated Growth Processes in Urban Planning and Architecture

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Abstract

Urban structures, developed and grown over a period of time, are created by processes that, due to the number of influential factors, are not longer comprehensible as a whole. Their development is very complex and depends on a big number of reciprocal factors that even architects or planners sometimes cannot recognize the formal, functional and rational processes of thinking behind it. The involved mechanisms however are particularly obvious in historical urban structures that came to exist over a period of centuries. The planned relationships within these conglomerates are governed by nearly indiscernible rules and show similarities in form and shape to living and non-living forms in nature. They are clearly analogous to fractals or systems with chaotic behavior. In the course of the research project "media experimental design", financed by the German Research Foundation, algorithms are sought that are able to simulate urban analogous structures digitally. To this effect the main rules of growth processes are researched and extracted. Then, by following these rules, virtual structures are developed and shown by using powerful three-dimensional techniques. The developed mechanisms allow urban planning to be process-oriented, interactive and flexible for permanently changing parameters. With an implemented set of rules the computer is able to create a design and to react to changing situations.

In several experimental studies structures were successfully generated which have different forms and qualities depending on their set of rules. For example, structures were programmed which are similar to a big city while other look like a village in hilly landscape. Diverse rules and strategies have been used in order to reduce them to shape specific factors. The rules for growth are administered by a specifically developed databank with sophisticated search mechanisms using the Issue-Concept-Form tool as case-based-reasoning method.

Keywords: Simulation; urban growth-processes; virtual reality

1 Simulation of alterations in urban development

The making of architecture is a process affected by numerous different influences. Architectural and urban planning's are cutouts of a large-scale structure and refer to a certain scale. Depending on the chosen or given precision the abstractions of the desired or planned reality are drawn. With this well-established and necessary procedure indistinctnesses are generated. It results in an urban situation with a certain detail. External influences as for example topography, existing green and buildings, direction as well as building relevant data like program, structural density or proportion make the overall design. Sometimes there is just a hierarchic road system the integral part of a design, on other times it is a whole village with all the single houses thought out down to the last detail. The levels of detail, which are not captured in the respective scale develop individually and are not controllable. They are beyond the architects control and his formal, functional and rational considerations. These principles can be seen particularly well with historic urban structures, which have grown over centuries. The planned coherence within these conglomerates is complex and it is difficult to detect discernible rules. Interestingly these settlements are similar in form and shape to

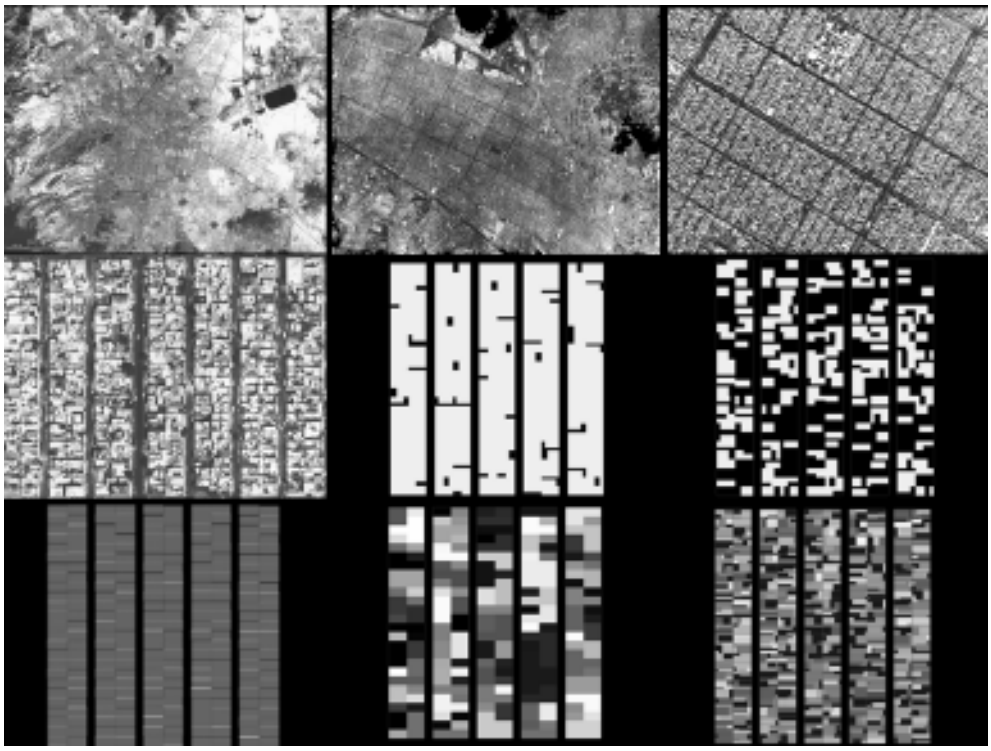

Figure 1.

the animate and inanimate nature. Aerial photographs and satellite pictures of these structures remind of the expansion of plant populations and cell formations.

The research project 'Media-Experimental Designing in Architecture and Urban Planning' sponsored by the DFG is dealing with a creative use of computers in the field of architecture. Under the leadership of Prof. Dr.-Ing. Bernd Streich (University of Kaiserslautern) and Mrs. Dr. Rivka Oxman at the TECHNION in Haifa / Israel, growth processes of urban structures are explored and programmed. The aim is to make out the apparently unplannable courses of urban growth and to convert them into algorithms. These growth rules implemented into a Virtual Reality environment via computer allow simulating artificial city growth. By programming the rules, standards and laws of a virtual world this technique and philosophy makes it possible to let urban structures grow and to observe their individual behavior. Several experiments on different levels of abstraction led to promising results. As in a test-tube, cities can be bred. One part of the current research actually is to 'interbreed' urban development modules and their algorithms evolutionary and genetically. These thoughts are derived from the field of 'Artificial Life', where from information technological view artificial organisms are created and bred in a computer. Because of the similarity of organic behavior and urban growth this thought seems to be natural.

2 Village Generator: Urban Structures as Organisms

In this virtual environment just a few different elements were implemented. Direction and topography are to be absolutely important for the growth of the building. The virtual buildings are produced by generators moving independently in space. On their way they check the prevailing attractivity of a position, which results from the given 'natural' environmental factors. The generators were programmed to perform a kind of 'social' behavior among themselves, so that they are able to change direction depending on the proximity to a neighbor. This so called 'flocking behavior' is known from nature and adapted from birds or insects. When the given conditions are met the generator produces a building. Because of interactions among the generators this relatively simple programming results in very harmonic and even motion paths, which wouldn't have been predictable like in this case. The emerging forms of life are organic in the sense of a term in architectural theory, meaning that they developed from the inside. Essential in this experiment was to see, that the adjusted behaviors were not directly derived from the experiences in urban development but are very similar to existing village structures in mountainous regions. This kind of using analogies for developing complex architectures were explored for instance at the Institute for Lightweight Structures at the University of Stuttgart under Prof. Frei Otto, the designer of the roofing for the Olympic Stadium in Munich. There architectonic form was adapted from examples found in nature.

Figure 2

3 City Generator: Simulation of Formation Processes in Cityscapes

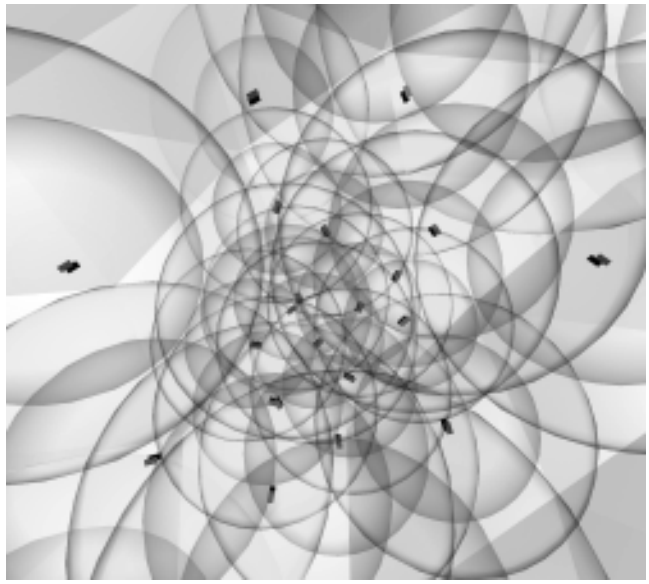

Figure 3.

In their use of form structures of villages seem organic, incomprehensible and complex. They are also less subject to formal rules than the 'grown' city. The cityscape is characterized by axes, squares and spatial density. For a simulation of a cityscape other rules and behaviors for the urban development modules had to be determined. Whereas simple and clear rules ensure the necessary lighting and circulation of the virtual houses, wide regulations of behavior patterns are needed to control position and alignment of the neighbor modules. This happens discreetly within the whole virtual city, which means, that every single house refers formally to his environment. Every building is telling his environment where from his point of view the follow-up buildings can be positioned. As a base for communication a grid of attractions was introduced in which the single factors are added. The more powerful the influence of a neighbor on a city module is, the more it will align orthogonal to it and turn the open side if possible towards the imaginary roadside. Building line and squares result from an extra high attractivity given to the sides or the firewalls. Structures and building blocks can be imported into the city generator, so that he has to react to the existing. Especially with these experiments astonishing similarities to real urban situations were achieved. Older building formations become surrounded by the growing city with distinct axes and squares and integrated into the designed center.

4 Compression Machine: Three-Dimensional Quantitative Analysis of Urban Situations

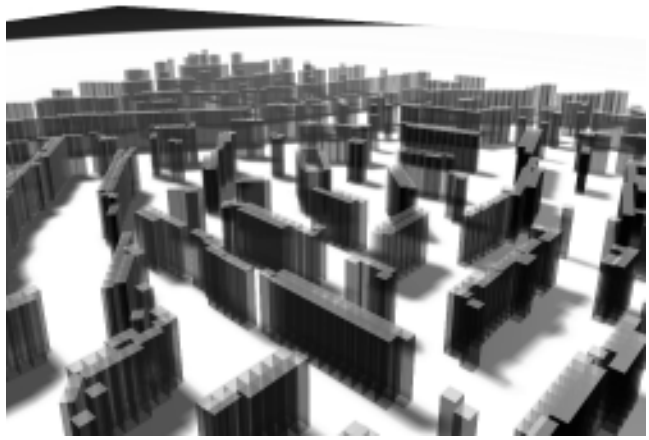

Figure 4.

One of the most important and most difficult tasks in the field of architecture and town planning is building in an existing environment and the compression of urban situations. A proper classification of the numerous influence factors, which regulate the attractivity of the single building sites, is essential. With a concrete example a guided re-compression process was produced in a computer simulation. By means of CAD a building block was drawn and given properties in a virtual world. These are quantitative values like structural density, land price and population density, which are filed in data fields, as well as formal factors like size, use, topology and semantics, which are assigned directly to the objects. The process data can be given values depending on how the designer thinks this is relevant for the situation. The following attractivity is visualized real-time as a three-dimensional object in the virtual environment. It is possible to view the single factors separately or as the total amount. The result is an abstract building of which its shape already can be used for inspiration. The designer determines, which conditions the new building structure has to meet within his design, e.g. the desired population density or the rough distribution of the single building types within the area. Furthermore he defines the limits of the building types (max. height, optimal orientation, depth of the building etc.). The software now proposes compression measures and computes the respective effects. In this way programmed loops and recursive functions produce an optimal result under the given conditions allowing the designer to intervene at any time.

5 Design Machine: Work in Progress

Besides the clearly defined rules there are especially in the field of designing a multitude of factors, which can't be expressed numerically or logically. In the appearance of architectures non-programmable design mechanisms turn up as for example zeitgeist, local materials and the individual taste of the architect or client.

The current work is concentrating on developing software, where different urban development modules learn to design themselves. Using neural nets, a kind of programming and genetic algorithms adapted from the human brain, allows training the elements of the virtual world, an intuitive

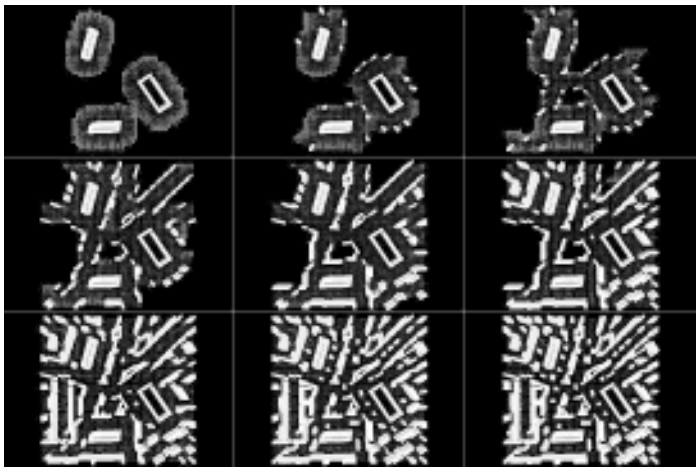

Figure 5.

behavior. With support of Prof. Michael M. Richter of the department 'Expert Systems and A.I.' at the University of Kaiserslautern it is supposed to succeed in teaching these intelligent elements a specific perception of their environment and to increase their knowledge in training sessions. The modules get confronted with an urban situation transferred from reality. According to their reactions the designer can support or forbid certain behaviors depending on his opinion and design knowledge. The modules trained in this 'arena' can be released into the virtual world, where they have to maintain themselves with regard to other modules. Particularly successful modules can 'interbreed' with others and pass on their genetic knowledge, less successful will die. The roots of growth and resulting, their structural development, can be fixed within the WebPAD (a specific database, developed at the Technion in Haifa, Israel). This process happens over a continuous period of time. These evolutionary principles raise the hopes to achieve further knowledge about the characteristics of natural urban growth and to find new ways of planning for a sensible dealing with the built environment.

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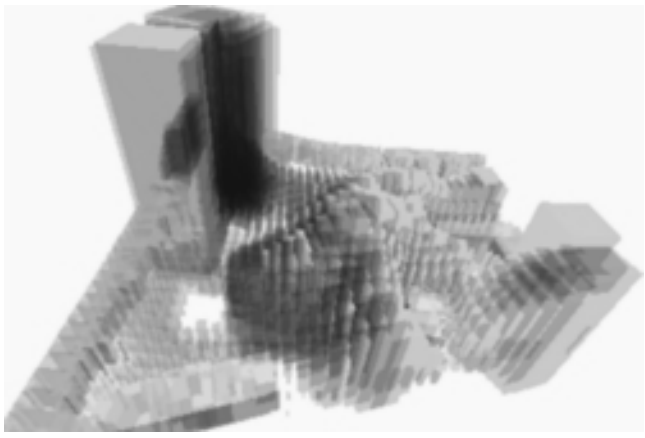

Figure 6.

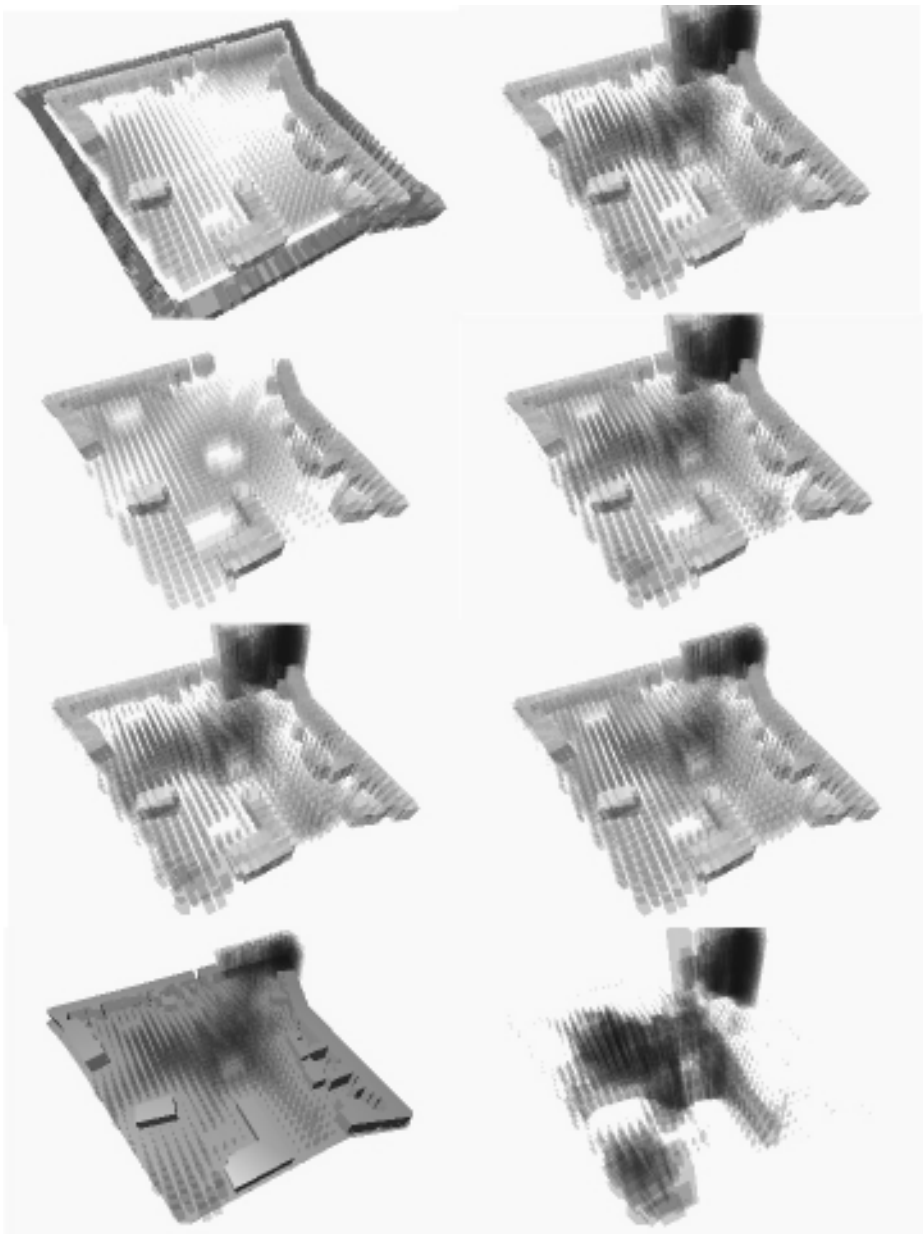

Figure 7.

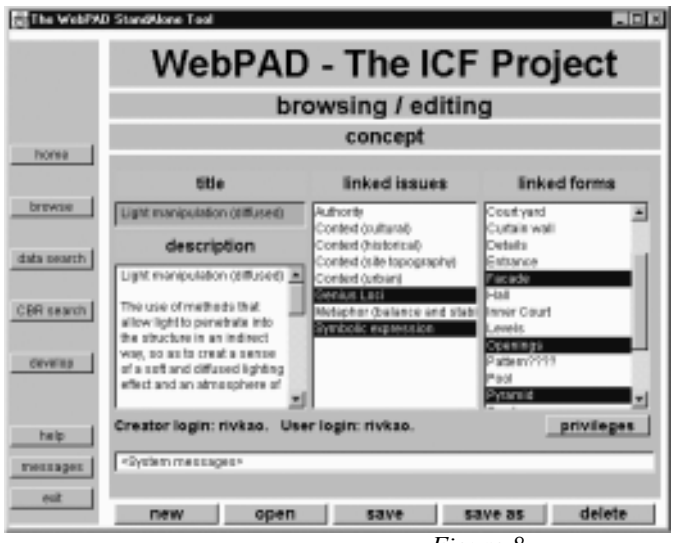

Figure 8.