ELSEVIER

Automation in Construction 16 (2007) 61 – 69

AUTOMATION IN CONSTRUCTION

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Adapting cellular automata to support the architectural design process

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Abstract

This paper investigates the support of generative architectural design processes using cellular automata systems with a high level of involvement of human designers. Previous applications of cellular automata to architectural design have oftentimes been characterised by their limited generative capacity for top–down developmental control and for pragmatic rule-breaking as they are easily offered by human designers. This paper explores different options for modifying and extending classical cellular automata systems to support architectural form finding. It discusses the potential of cellular automata as generative design tools with respect to the questions: In which part of a design development, during which periods during a design process and in what roles do cellular automata promise desirable results from a practical standpoint? In response to these questions, a theoretical framework for the integration of cellular automata into the design process is presented. An implementation of a dialogue-based cellular automata-supported design process model is outlined and evaluated by remodelling an existing architectural design project.

Keywords: Cellular automata; Design process; Generative design; Urban morphology

1. Generating variety

Generative design approaches have emerged from the search for strategies to facilitate the exploration of alternative solutions in design, using computers as variance-producing engines to navigate large solution spaces and to achieve unexpected but viable solutions [1]. In generative design, algorithmic procedures are often used to produce arrays of alternative solutions based on predefined goals and constraints, which the designer then evaluates to select the most appropriate or interesting. One strength of the computer as a generative design tool stems from its capability to perform tasks that rely on numerically formalised dimensional or relational constraints. Design decisions that require more holistic, context-based understanding and judgement are typically left to be decided upon by human designers [2]. Thus, computer-supported generative design processes can feature different levels of automation and manual user intervention, respectively. Generative design processes are often implemented as completely automated systems, as is the case in rule-based systems such as the 'emergent design' process developed by Testa et al. [3]. Fully automated generative design processes rely heavily on formalisable evaluation methods to distinguish appropriate solutions from others automatically in order to produce meaningful results in their respective design contexts [4]. Seeking to automate the process of evaluation, evolutionary approaches to design have introduced evaluation mechanisms that test potential solutions for validity without the need for a designer's judgement during the design process. In fully automated generative design systems, the designer usually interacts with the system by initially defining constraining relationships and setting relevant variables, typically by means of computer programming. After the generative process is completed, the designer decides on whether to accept the outcome or to repeat the process with modified initial settings. Other generative processes, however, are more responsive, involving the designer to make choices at certain stages in otherwise rule-driven processes, as is often the case in shape grammars [5]. In evolutionary design approaches, the design process is organised as cyclic process that generates increasingly appropriate solutions by way of repeated selection at every design cycle [6].

The use of generative approaches in design is motivated in part by the need to manage and express increasing complexity of often interrelated factors that determine the design processes. In designing contemporary urban environments, a multitude of

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doi:10.1016/j.autcon.2005.10.005

requirements and constraints have to be observed, that can often overwhelm designers [1]. In this context, cellular automata (CA) have received attention from architects and urban planners as a generative strategy that is characterized by the simplicity of its mechanisms on one hand and the potential complexity of its outcomes on the other. Driven by local communication between cells over time, behaviour in CA is based on often strikingly simple rules executed in parallel by cells arranged within larger grids. Relying on geometrical neighbourhoods to determine individual cell states, CA are inherently spatial, context-sensitive systems. Originally developed by the mathematicians Ulam and von Neumann [7], CA have been applied to a wide range of fields to study complex phenomena, ranging from physics to biology and have found some application in Architecture as described in Section 3 below. As a generative design tool, CA are typically used in the form of volumetric models that transcend traditional types of models in that individual volumetric units are capable of changing their properties according to predefined rules. Representing a standard approach for experimentation in generative design, CA have been used mainly to explore variations of possible solutions resulting from the tempo-spatial development of initial setups over time. Design constraints are typically implemented in a bottom–up manner in form of simple rules that govern the local behaviour of each cell. The overall outcome of a CA system, however, is often complex and difficult to predict from these rules. Similar to shape grammars, CA are characterised by deterministic rule sets that are capable of producing unexpected results. The interdependencies of neighbouring cell states, however, provide more localized evaluation mechanisms. This characteristic supports local instead of global control models, and is seen as a future opportunity to further generative architectural design [8]. As a generative design strategy, CA are typically chosen for tasks that involve simple constraints operating on large numbers of elements, where differentiation and variety are sought [9].

With CA processes yielding potentially surprising results, CA-supported design processes typically emphasise experimentation and exploration of solution spaces. CA systems developed for design or planning purposes are usually implemented as fully automated generative systems. After initial variables are set, the CA process is run without a designer's interaction for either a specified time or until a desired situation has been reached. Without the feedback of a designer during run-time, however, self-sufficient CA tools are unlikely to produce desirable, practically useful architectural designs. Desirable outcomes in the context of this investigation involve primarily improved contextual relevance of generative CA outcomes as well as a more responsive and flexible design process. This paper explores alternatives to current models of CA-supported design processes. While Section 2 outlines possibilities of adapting CA to suit architectural design tasks in terms of modelling, Sections 3 and 4 deal with the role CA have played in architectural design processes so far and introduce a more dialogue-based alternative. Section 5 introduces an example implementation of the proposed design process.

2. From generic to specific models

While design and research on CA in architecture have mostly relied on abstract classic models, other fields have developed their own, more problem-specific types of models. This section examines several modifications to classical CA models that have resulted from the need to describe more specific contexts in other fields. Such modifications and extensions, especially those explored in architecture-related fields, can be useful to inform future architectural research in this area. Rather than attempting to give a complete overview, the focus is on how areas of applications have resulted in the development of alternative CA models. Classic CA systems rely on discrete (non-continuous) notions of time and space in combination with simple transition rules and very limited numbers of states. At this highly reduced abstraction level CA oftentimes fail to satisfy experimenters in terms of their capacity to model more differentiated phenomena. To deal with this issue, a number of modifications and extensions are available to better fit the nature of more concrete problems and situations. Numerous CA applications have been developed in the fields of urban planning and geography, which have typically focused on capturing the dynamic and non-linear properties of urban growth processes [10]. Next to modelling and simulating urban growth, CA models have been used to evaluate the consequences of potential planning scenarios. Such models are usually based on previous observations of urban growth processes and combine traditional statistic models with CA to capture process characteristics related to spatial relationships. These models differ from classic CA in that they are typically adapted to particular situations by defining specific transition rules, a larger number of possible states—usually describing types of land use—or different definitions of local and global neighbourhoods. Cell neighbourhoods may become extended 'interaction neighbourhoods' that can be more extensive than the classic neighbourhoods which are based on immediate adjacency. Further extensions to generic classical models include alternative state transition models: stochastic or majority models, for example, aim to describe continuous processes. CA applications are increasingly concerned with empirical applications rather than theoretical explorations [11], which has resulted in further extensions of these models with agent-based simulations. Cells that are able to change their position in model space as well as their transition rules are of particular interest in studies of pedestrian or motor traffic behaviour. For this purpose, cells may also be able to remember their history and to refer to past events in their decision making.

While a large number of attempts have been targeted at extending the discrete notion of time in classic CA models, neighbourhood relationships and over-simplified transition rules, only few researchers have investigated spatial models different from classical grid lattices. For some tasks, CA models may be combined with other spatial modelling techniques into hybrid concepts. In this context, O'Sullivan [12] has explored graph automata, a combination of CA and graph theory, to approach a more natural variety of spatial