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Cellular automata in architectural design: From generic systems to specific design tools

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ABSTRACT

In this paper we examine the adaptations cellular automata (CA) are typically subjected to when they are applied to architectural designing. We argue that, despite a number of earlier studies that portrayed CA as generic generative design tools, the transition from CA as generic systems to specific design tools for the purposes of design is not yet well understood. To describe this transition, we first examine CA adaptations in a number of previous studies relating CA to architectural design. We then analyze an applied design case study in detail and trace similarities between findings made in the literature review to findings made in the case study. We conclude with a summary of challenges and opportunities met by architectural designers employing and developing CA as design tools.

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1. Introduction: CA between generic tools and specific applications

Cellular automata (CA) are discrete models of space and time and typically involve interactions of cells across homogeneous lattice grids. Cells can take on a given finite number of cell states, which can change according to simple rules each cell executes in relation to its cell neighborhood [22]. While each individual cell state change may seem trivial to a human observer, the patterns generated across entire CA cell lattices are often intricate and difficult to predict [16]. Goal-directed work with CA systems is typically affected by two kinds of difficulties: It is difficult to predict the outcome of simple rules, and it is similarly difficult to determine rules that lead to desired outcomes [20]. Contemporary applications of CA can be characterized broadly within two main lines of research [16]: The first line of research employs CA in goal-directed ways for simulation and analysis and is usually found in applied sciences and engineering. The second, less well-known line of research employs CA systems in open-ended and speculative explorations. This second line of research can be found in pure mathematics and theoretical computer science, and is particularly prominent in design-related fields.

In this paper, we address CA systems that form part of architectural design processes. Our understanding of designing is based on a conversational model in which designers externalise and re-interpret various manifestations of their ideas in a cyclical process, as described by Glanville [13]. This process has also been characterized as *reflective practice* by Schön [28]. In architectural design, intricate patterns generated by CA systems are appreciated for their spatial qualities as well as for the often unpredictable or surprising nature of their results, which allow designers to extend the scope of their imagination [7,25,26]. Design processes may be described as a repeated generation and subsequent reduction of potential proposals, with designers alternately seeking unpredictable inspiration or analytical assessment of generated results. With CA systems firmly established as means to achieve the latter, such as in finite element analysis or pedestrian simulation, use of CA systems to generate unpredictable and inspirational variety has received comparatively little attention in existing literature. Following on previous work introducing cellular automata (CA) to digitally supported architectural designing (see for example [1,14,18,23,24,26], this paper examines modes of CA use in creative architectural design processes. Our specific focus is the documentation and analysis of typical adaptations and modifications to CA when applied as architectural design tools, in a further extension and development of an argument we initially presented as Herr and Ford [21].

While CA are routinely adapted in architectural design practice, few examples have been adequately studied and explicitly discussed in existing literature. This may be due to designers concentrating on the outcomes of their designing and not seeing the purpose of detailed documentation of their design processes. It may also be due to the perception that CA, once adapted to the specific contexts and requirements of particular design projects, are perceived as "tampered with" and less valuable than generic design tools. While reasons for a lack of detailed documentation can be difficult to determine, it has led to a pervasive lack of awareness of such processes among those who seek to apply

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CA as design tools in architecture. It also prevents continued learning and exchange across different projects, leading to individual projects often having to re-invent the wheel anew. This paper aims to examine and make explicit processes of adaptation in CA employed as design tools, with a focus on the following question: How do the specific characteristics of CA translate into constraints and opportunities when applied to architectural design processes as design tools? And, following from this, what are the adaptations required for CA to fit better into architectural designing?

In the following, we first present a concise review of documented cases of CA systems that were changed as a result of their introduction to architectural design as design tools. To complement the few previous cases providing details or explicit reflection on such adaptive processes in existing literature, we then analyze an exemplary case study in depth, which was documented in detail as part of a Master of Architecture thesis. This case study serves as a characteristic example for the challenges designers typically encounter in employing and adapting CA as architectural design tools. It also illustrates strategies developed by designers in modifying and adapting CA to make sense in, and support, architectural designing. From the analysis of the case study, we develop more generalized patterns of adaptations CA typically undergo when introduced to architectural designing. In the final section of the paper, we discuss findings from the analysis of the case study in relation to examples documented in existing literature on CA in architectural design and conclude with a general summary of commonalities in CA modifications. The scope – and contribution to existing literature – of this paper lies primarily in a qualitative analysis of how CA systems are integrated into creative design processes, to establish a framework for discussing CA applications in the field of architectural design. With this study, we mainly aim to inform those who engage with CA systems as part of creative architectural practice and education.

2. A review of previous research: CA as architectural design tools

CA are systems of cells capable of generating intricate patterns based on rules relating to local cell neighborhoods (for a detailed introduction see [5]). CA form part of a variety of generative design approaches in architecture classified as "bottom-up" oriented [2,6,27]. In bottom-up generative design, configurational rules are iteratively applied to generate forms that are initially difficult to predict. Architects' interest in CA is generally motivated by the simplicity of CA mechanisms on one hand and the potential complexity of the outcomes on the other, and the tendency of CA-generated results to resist attempts at creating predetermined outcomes. Previous applications to architectural design have employed CA mainly to generate representations of physical building form, and typically start from "found" CA models adopted from other fields of study, such as Conway's "Game of Life" [12]. In terms of architectural form generation, CA have been used mainly to explore variations of possible solutions resulting from the tempo-spatial development of initial cell configuration setups over time (as found in [7,23,24]). Other CA implementations have focused on generating building form through creating a physical "trail" of CA development over time (as shown by [1,3,18]). Yet another way to apply CA to design is to conceptualize building form as substrate changing over time, in which architectural elements move dynamically as explored by Frazer [11] as well as Herr and Fischer [17].

While more studies have examined the potential of CA in architecture, the focus of this study is on those works that have made the process of adapting CA to architectural design most explicit. While adaptations can manifest in a variety of ways, there are also often similarities across different studies - even though authors seem often unaware of such commonalities. In the following, we list those adaptations that are most often described by architectural designers. This list is kept brief, with a view to the limited scope of this paper.

2.1. Adaptation of CA rules

Typically starting from Conway's Game of Life [12], most previous studies focused on CA as design tools have experimented with the variation of CA rule sets. Coates et al. [26] for example show a variety of different rule implementations, among others taking into account context through limiting growth when obstacles are encountered. Anzalone and Clarke [1] illustrate the growth of CA in response to encountered objects in a similar manner. Watanabe [30] also reflects context implicitly in his adaptation of CA rules to simulate natural lighting within CA-generated shapes.

2.2. Adaptation of CA cell shapes and scale

To generate architecturally appropriate results, Krawczyk [24] describes variations to CA cell shapes and scales, and adds additional elements that suggest load-bearing structure. Anzalone and Clarke [1] interpret a one-dimensional CA three-dimensionally in terms of a space truss, and explore a variety of architectural element types. Herr and Kvan [18] show how a variety of cell shapes and sizes used in one CA model may support highly specific architectural design processes, such as the modelling of high-rise buildings. Khalili-Araghi and Stouffs [23] explore CA systems that model residential units for mass housing. Cruz et al. [7] discuss variations of classic CA cell shapes to derive a variety of architecturally feasible forms.

2.3. Adaptation of CA cell neighborhoods

Krawczyk [24], Coates et al. [26], Herr and Kvan [18], Bojovic [3] and Khalili-Araghi and Stouffs [23] all adapt cell neighborhoods beyond the classic von Neumann and Moore CA cell neighborhoods to suit new cell shapes or selective CA development for architectural purposes.

2.4. Adaptation of CA cell states

To better allow generative CA-based systems to respond more flexibly to context, Coates et al. [26] introduce new cell states. Herr and Kvan [18] describe the linking of cell states and expressions of cell states in terms of different shapes. Khalili-Araghi and Stouffs [23] use cell states that indicate levels of natural lighting, similar to Watanabe [30].

2.5. Open interpretation of CA results

Few studies yet have documented the open architectural interpretation of CA-based results. Krawczyk's [24] manual changes to CA-generated forms can be interpreted in this manner. In addition, Herr and Karakiewicz [19] show how architectural interpretation of generative CA as abstract diagrams makes architectural development possible. Khalili-Araghi and Stouffs [23] describe the further development of a CA model through conventional design methods after initial CA-based conceptual model generation. Cruz et al. [7] also acknowledge the need for further architectural interpretation of CA-generated shapes.

2.6. Integration of CA into conversational design processes

Even fewer previous works have focused on the ability of CA to be used as *conversational* design tools in the sense of Glanville [13], integrating human and digital aspects to share control of the generative process and the generated outcomes [10,20]. Herr [14] describes conventional CA processes as typically 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, Herr [14] previously argued that self-sufficient CA tools detached from human feedback are unlikely to produce desirable, practically useful architectural designs.

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