ADAPTING CELLULAR AUTOMATA AS ARCHITECTURAL DESIGN TOOLS

CHRISTIANE M. HERR1 and RYAN C. FORD2
1Xi’an Jiaotong-Liverpool University, Suzhou, China
Christiane.Herr@xjtlu.edu.cn
2Pofart Architecture Design Company Limited, Shenzhen, China
Ryan.Ford@outlook.com

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 generic CA to specific design tools is not yet well understood. To describe this transition, we first examine this aspect in a number of previous studies relating CA to architectural design. In a following detailed analysis of an applied design case study, we trace similarities between findings made in the literature review to findings made in the case study and extend them with additional observations. We conclude with a summary of challenges and opportunities met by architectural designers employing and developing CA for design purposes.

Keywords. Cellular automata; generative design; design research; design tools.

1. Introduction: CA between generic tools and specific applications

Following on previous work introducing cellular automata (CA) to digitally supported architectural designing (see for example Coates, 1996; Krawczyk, 2002, Anzalone and Clarke, 2003; Herr and Kvan, 2007; Herr, 2008; Khalili-Araghi and Stouffs, 2013), this paper examines modes of CA use in architectural design processes and analyzes typical adaptations and modifications to CA when applied as architectural design tools. While such adaptations and modifications routinely occur in applied design practice, few have been adequately documented in existing literature. This may be due to designers concentrating on the outcomes of their designing rather than on detailed docu-
mentation 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 the reasons for this absence of detailed documentation is difficult to determine, it has led to a pervasive lack of awareness of such processes among those aiming to apply 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 sets out to examine and make explicit processes of adaptation in CA employed as architectural design tools, with a focus on how characteristics of CA translate into constraints and opportunities for architectural design.

In the following, we first present a concise review of literature documenting changes of CA systems as a result of their use as architectural design tools. We then analyze a typical case study that illustrates CA modification strategies developed by designers in order to make sense in, and support, architectural designing. We conclude with a general overview of typical adaptations of CA used as architectural design tools.

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 Burks, 1970). CA form part of a variety of generative design approaches classified as “bottom-up” oriented (Schmitt, 1993; Chase, 2005). In bottom-up generative design, configurational rules are iteratively applied to generate forms that are initially difficult to predict. Architects’ interest in CA is typically motivated by the simplicity of CA mechanisms on one hand and the potential complexity of generated outcomes on the other. 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” (Gardner, 1970). 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 Krawczyk, 2002; Khalili-Araghi and Stouffs, 2013). Other CA implementations have focused on generating building form through creating a physical “trail” of CA development over time (as shown by Anzalone and Clarke, 2003; Herr and Kvan, 2007; Bojovic, 2013). Yet another way to apply CA to design is to conceptualize building form as a matrix in which space is re-configured over time as explored by Frazer (1993) as well as Herr and Fischer (2004).
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 often similarities across different studies. In the following, we list those adaptations that are typically described by architectural designers. This list is kept brief to suit the limited scope of this paper, and may be extended further in a future publication.

2.1. ADAPTATION OF CA RULES

Typically starting from Conway’s Game of Life (Gardner 1970), most previous studies focused on CA as design tools have experimented with the variation of CA rule sets. Coates et al. (1996) 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 (2003) illustrate the growth of CA in response to encountered objects in a similar manner. Watanabe (2002) also reflects context 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 (2002) describes variations to CA cell shapes and scales, and adds additional elements that suggest load-bearing structure. Anzalone and Clarke (2003) interpret a one-dimensional CA three-dimensionally in terms of a space truss. Herr and Kvan (2007) show how a variety of cell shapes and sizes used in one CA model can support highly specific architectural design processes.

2.3. ADAPTATION OF CA CELL NEIGHBORHOODS

Krawczyk (2002), Coates et al. (1996), Herr and Kvan (2007), Bojovic (2013) and Khalili-Araghi (2013) 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 allow generative CA-based systems to respond more flexibly to context, Coates et al. (1996) introduce new cell states. Herr and Kvan (2007) describe the linking of cell states and expressions of cell states in terms of different shapes. Khalili-Araghi and Stouffs (2015) use cell states that indicate levels of natural lighting, similar to Watanabe (2002).
2.5. ARCHITECTURAL INTERPRETATION OF CA RESULTS

Few studies yet have documented the architectural interpretation of CA-based results. Krawczyk’s (2002) description of manual changes to CA-generated forms can be understood in this way. In addition, Herr and Karakiewicz (2007) show how architectural interpretation of generative CA, seen as abstract diagrams, makes architectural development possible. Khalili-Araghi and Stouffs (2015) describe the development of a CA model through conventional design methods following initial CA-based conceptual model generation.

2.6. INTEGRATION WITH COVERSATIONAL DESIGN PROCESSES

Only few previous works have discussed the use of CA as ‘conversational’ design tools, integrating human and digital aspects to share control of the generative process and the generated outcomes (Fischer and Herr 2007). Herr (2007) describes conventional CA processes as typically run without a designer’s interaction for either a specified time or until a desired configuration has been reached. Without the feedback of a designer during run-time, however, Herr (ibid.) argues that self-sufficient CA tools are unlikely to produce desirable, practically useful architectural designs.

3. Adaptation of CA for design purposes case study: Designing a hotel residence for an astronomical observatory

To verify and further examine the findings made in the preceding literature review, we employ a case study approach in the following. The case study (Ford 2013) involved the design of a hotel residence for engineers and scientists working on the E-ELT (European Extremely Large Telescope) located in the Atacama Desert in Chile. In responding to this design task, Ford aimed to create a CA machine that would adopt architecturally relevant rules to generate architectural forms. The project development was accompanied by ongoing discussion between the authors through an extended email exchange, in which most of the observations made in the following became explicit.

Like many previous CA-based architectural explorations, Ford (2013) initially based his CA design process on John Conway's "Game of Life" (Gardner 1970), implemented in NetLogo. A series of initial explorations using Conway's model however quickly showed the limitations of this approach: generated forms, while interesting in their intricacy, were also arbitrary and did not adequately address the architectural design task (Figure 1). This observation raised the issue of a lack of rules relating explicitly to architectural requirements. As previous studies (see Krawczyk, 2002;
Anzalone and Clarke 2003), Ford subsequently employed Conway’s CA model as a platform to build upon and to extend, to create a new CA machine capable of producing more suitable and architecturally relevant results.

3.1. EXTENDING RULES TO FIT ARCHITECTURAL REQUIREMENTS

To address architectural requirements, Ford first concentrated on CA rules. New rules were developed to consider issues of light, spatiality, structure, scale, and topography. Attempts to implement such rules however indicated a high level of complexity required for each rule to operate and produce architecturally relevant results. Moreover, this degree of rule complexity for even simple architectural outcomes indicated that attempting to design rule sets sufficiently specific to generate complete buildings would defy the characteristic simplicity of rules in CA systems, as observed by Herr and Kvan (2007). Ford’s next stage of experimentation focused on introducing changes to the initial Game of Life-based rule parameters. This had strong effects on the CA outcomes and also led to a design process in which the initial CA configuration remained the same while results could vary. One major issue in the development of rules at this stage was found to lie in the architectural restrictions imposed by mostly symmetrical outcomes of the CA system, as illustrated in Figure 1.

3.2. CHANGING CELL SHAPES TO FIT ARCHITECTURAL DESIGN

Experimenting with extended CA rule sets generated various shapes that seemed interesting, but at closer inspection had little potential for accommodating architectural programme requirements. The main reason for this shortcoming was found in the lack of connected cells useable for continuous architectural spaces. Ford adopted Krawczyk’s (2002) method of enlarging cells by a uniform scaling factor to create overlapping areas between cells (Ford, 2013, p. 58), thus generating larger spatial units. As directed control
over the outcomes of the generative process was limited, Ford (2013, p. 59) resolved to post-rationalize CA results, similar to Krawczyk (2002).

Along with the question of cell shapes arose the question of scale, a central consideration when designing architectural spaces. During the early stages of designing, Ford (2013, p. 56) conducted a series of investigations to explore potential scaling options and their effects on the functions of architectural spaces (Figure 2). Testing CA cells as cubes of 1, 2 and 3 meters edge length, Ford found that a scale of 3 meters cubed was most suited to the architectural programme.

3.3. ADDRESSING CONTEXT THROUGH CA RULES

In addition to rules shaping the generated architectural forms, rules addressing the site surroundings were implemented to respond to CA’s inherent limitations in taking context into account. Ford (2013, p. 54) decided to set up the CA system such that it could interact with a topographical model, providing a surface (also constructed from cells) that the CA system could respond to (Figure 3). By providing a basic notion of site context through topography, Ford intended to make possible perception and judgement of architectural aspects such as form, layout, scale and natural lighting (Ford, 2013, p. 55). This allowed a more accurate architectural understanding of the CA growth, and also affected the way CA generation was directed as part of the design process.
3.4. INCLUDING THE DESIGNER IN THE CA PROCESS

The preceding explorations resulted in a new understanding of the implications of CA as design tools. If a CA machine does not generate architecture per se, what does it generate? Ford (2013, p. 59) points out that CA results lacked architectural definition in terms of the nature and role of individual cells. Ford (ibid, p. 61) thus decided to introduce a new type of rule capable of changing the states of cells into more abstractly defined ‘public’ and ‘private’ or ‘open’ and ‘closed’ etc. This was realized as a Boolean on/off value, illustrated qualitatively as cell color (Figure 4), and introduced a new level into the CA-based generative design process. The abstraction of cell states required a considerable level of interpretation by the designer working with the CA system and made explicit that a process of translation was necessary to make architectural sense of generated results (Ford, 2013, p. 61). Ford observes that the role of the CA was that of a conceptual form generator that allows him to explore abstract features of spatial configurations. This process is somewhat similar to sketching a conceptual idea manually, and places the architect in an evaluating and selecting position. As a result, the purpose of the CA system within the case study gradually changed from being conceived as a fully automated tool for generating architectural shapes to a more collaborative tool suggesting to the designer conceptual forms for further development.

3.5. THE DESIGNER IN THE CA PROCESS: CONVERSATION

Experimenting with different interpretations of CA then raised the question of how much should be expected from a CA system within the architectural design process? Ford observed that generated cell configurations offered only certain areas of architectural interest that could be further developed after the CA process had finished. This observation led to a different perspective on the CA-based design process. If there was more interactive reasoning
happening between a CA system and designer throughout the generative process, then more control in terms of architectural and programmatic requirements could be achieved (Ford, 2013, p. 61).

Figure 5. Generating, and interpreting architectural results in a conversational generative design process.

As pointed out by Herr and Kvan (2007), CA can be understood not only as a fully automated system, but as dynamic sketches interacting with designers throughout design processes. This perspective on CA recognizes the iterative nature of design processes, described by Schön as ‘reflective practice’ (Schön 1984). Allowing the architect to start and stop the CA, and select and combine partial results of the generated results produced more successful architectural outcomes in the case study. Ford (ibid, p. 64) observes that this approach of shared control, while maintaining potential for surprise and novelty, could better meet specific programmatic requirements. The specification and description of this new type of CA-based design process formed a core part of the research findings of the case study (Figure 5).

4. Discussion

The case study examined in detail in section 3 shows strong similarities to results of previous works, as analyzed in section 2. Ford’s design development of CA can thus be described as a characteristic one that also offers detailed process documentation. This process of adapting conventional CA into design-related contexts illustrates differences between common conceptions of the nature of CA and their actual potential in generative architectural design. While designers tend to set out to design complete buildings in an emergent manner, using merely basic configurational rules, this approach has so far not been shown to generate adequate results. Following this insight, designers tend to manipulate various aspects of CA. In addition, designers often choose a particular architectural setting that matches with the rigid volumetric compositions generated by conventional CA systems – such as the cubic ‘follies’ in Tschumi’s Parc de la Villette (Devetakovic et al., 2009). The understanding of CA-generated forms as ‘conceptual’ tends to be
employed as a next step to allow designers greater flexibility in the interpretation of CA-based results. A further step that is taken only rarely is to understand CA in terms of and as part of the cyclical process of designing, in analogy to sketching by hand (see Herr 2007, Herr 2012). Reasons for why these steps are not taken very often may be due to designers’ views, as expressed in the case study. Ford makes reference to an initially ‘un-biased’ CA-based generative process that turns ‘biased’ as soon as the designer is involved directly. It is important to Ford to emphasize the capacity of the CA system to generate results not solely predetermined by the architects’ goals. This echoes Coates et al. (1996), who describe CA-based design processes as transcending ‘aesthetic whim’ and getting back to the ‘true determinants of form’. An element of surprise is typically valued but at the same time imposes strong limitations, as results often do not respond directly to the design task. This may be described as the central challenge of employing CA as generative architectural design tools. As the review of previous works and the case study have shown, there are however numerous ways to respond to this challenge – usually by adapting the CA system or its use in some way. Such adaptations have yet to be appreciated and further developed in the field of architectural CA research. If CA are essentially based on deterministic rules, then it may be useful to consider what Schön (1988) has noted when examining designers’ use of rules: rules as used in design are mostly implicit, overlapping, diverse, variously applied, contextually dependent and subject to exceptions as well as critical modification.

5. Conclusion

In this paper, we have documented and analysed a variety of adaptations that generic CA systems typically undergo when used as architectural design tools. Among these adaptations and modifications are: changes to CA rules, changes to CA cell shapes, the addressing of site context, adapting CA to specific architectural scales, the interpretation of CA results in an abstract manner to gain more architectural options, and finally, the conceptualization of CA systems not as self-contained deterministic systems but as non-deterministic conversational design tools. This paper is based on the review of a limited set of existing literature documenting design-oriented adaptations of generic CA as well as one specific case study, and is primarily intended to present a new perspective on CA as well as to indicate potential for further research. We expect the documentation of the above described adaptations and modifications to contribute to CA and the wider field of generative design research by pointing out both their necessity and their value. Un-
nderstood as a field of inquiry in its own right, CA research in architecture provides a unique perspective on CA.

References


