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RESEARCH

# Algorithmic Design Paradigm Utilizing Cellular Automata for the *Han-ok*

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**Abstract** This paper investigates using a Cellular Automata (CA) as a generative design strategy that creates a design framework for a contemporary house. This is done in a way to reflect the unique spatial configuration of the Han-ok with Chae and Madang. When the Han-ok, the traditional Korean house, was modified to adapt to social change and urbanization in the modern era, the spatial diversity and order of the Han-ok with Chae and Madang were lost. This study aims to define the spatial configurations of the Han-ok, then uses CA to offer numerous possibilities that accommodate today's life-style while keeping these core relationships. The significance of this study is in seeking the application of CA in a generative design process for modernization of the Han-ok.

**Keywords** Automation · Cellular automata · Computer technology · Generative design · Design theory · Design methodology · Modelling · Simulation · Han-ok

## Introduction

Public interest in the Han-ok, the traditional Korean house, has increased remarkably recently because of the need for sustainability and a desire for cultural identity. Modernizing the Han-ok has become both an urgent task and a rising market for Korean architects (Kim and Jeon 2012, 239–243). The Han-ok is diverse in regard to building layout and organization depending on the period when built, region, and class of occupants. The Han-ok for the Yangban (aristocrat) class in the Chosun Dynasty had separate Chae (individual buildings) and Madang (courtyard)

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belonging to each Chae, based on Confucian tradition and a system of social hierarchy; An-chae for women, Sarang-chae for men, Hangrang-chae for servants and storage, and Sadang-chae for a shrine. The different combinations of Chae and Madang coupled with Feng-Shui Theory (風水) created diverse characters of space in the Han-ok. Social changes in the early modern era including the collapse of the medieval social hierarchy system and decline of Confucian tradition caused changes in the layout of the dwelling (Shin and Kim 2014, 523–529). An-chae (buildings for women) and An-madang (the courtyard belonging to the An-chae) became a central living space, combined with the Sarang-chae (buildings for men) and Sarang-madang (courtyard belonging to the Sarang-chae). The introduction of the urban Han-ok in the 1920s decreased the number and size of Madang, changing the significance of the Madang, once the centre of the Chae (Lee and Park 2009, 153–162). The spatial diversity and order of the traditional Han-ok with its Chae and Madang were lost during these changes. Though there have been many studied attempts to modernize the Han-ok, these have been limited to mere reconstructions of the materiality, structure, and exterior of a Han-ok. There are limits in attempting to accommodate today's lifestyle while maintaining the unique exterior and configuration of a traditional Han-ok (Kim 2006, 211–218).

This study seeks to define the relationships between spaces of the traditional Han-ok and then to apply these relationships to the rules for Cellular Automata (CA) simulation, offering a vast number of possibilities to accommodate today's lifestyle. The first step in this research explores spatial configurations found in the Han-ok with Chae and Madang. These then become the assumed rules for CA simulation. The CA literature relevant to the study is briefly introduced to explain how CA can be used. The process of rule setting to govern simulation is then investigated and evaluated through a series of simulation results in varying conditions. The final simulation is then provided, offering spatial characteristics of Chae and Madang. As the final step of the design process, the simulation results are interpreted and visualized into a tangible piece of architecture as an example of integrating the computer-based generative and conventional design processes. Finally, a discussion is provided along with a conclusion.

## Spatial analysis of the Han-ok

The first step of this research defines relationships among the spaces of a traditional Han-ok in order to understand fundamental design considerations in the layout of Chae (individual buildings) and Madang (courtyard). This is then used as a base to generate algorithmic rules for the CA model provided in the next section. The analysis targets are the Han-oks of the Yangban (aristocrat) class built prior to the early modern era, because these show the diverse spatial order of the traditional Han-ok with the aforementioned Chae (individual buildings) and Madang (courtyard) (Fig. 1). The lists of the Han-oks explored for analysis are provided in Table 1. It should be understood that these were explored with a focus on architectural plans, not elevations or sections. We describe generalized design considerations though all targets exhibited distinctive variations that are specific to the site and occupying family member.

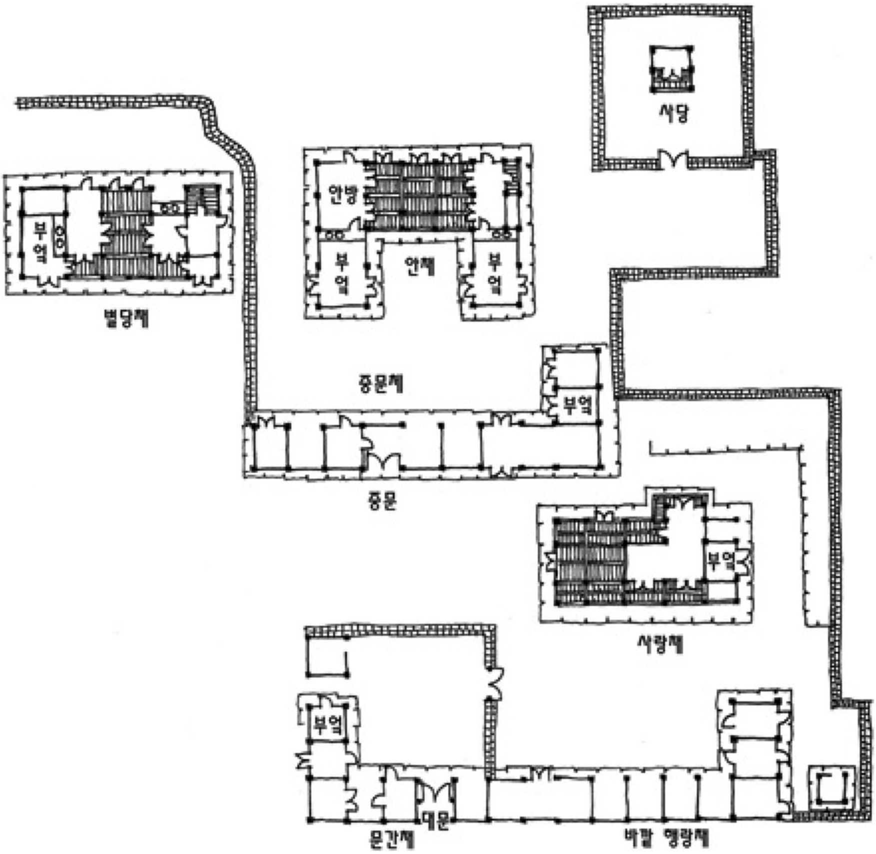



**Fig. 1** Example of the Han-ok with Chae and Madang (Kim Dong-Su's house, 1784), downloaded from Encyclopedia of Korean Culture (http://encykorea.aks.ac.kr/)

The Confucian tradition differentiated each spatial domain and provided residential space with order through hierarchy and directionality (Lee and Park 2009, 153–162). This resulted in the integration method of Chae (individual buildings) and Madang (courtyard). The general sequence follows the order of Daemoon (main entry), Sarang-chae (buildings for men)/Sarang-madang (courtyard belonging to Sarang-chae), Joongmoon (middle door), and An-chae (buildings for women)/An-madang (courtyard belonging to An-chae). The An-chae and An-madang, as the centre of domestic life for women, are located farthest from Daemoon (main entry). The privacy of this space blocks direct visual access from the Joongmoon (middle door), providing visual filtering. The An-chae typically has an An-bang (wife's room), a Geoneon-bang (daughter-in-law's room), a Daechung connecting these two rooms, and a kitchen. The An-madang, as a multi-functional exterior space, is enclosed by an An-chae in the shape of "ㄷ" or "ㄱ". It is interesting to note that the Daechung, which acts as a connection and buffer between the An-bang and the Geoneon-bang, is completely open to the An-madang and

**Table 1** List of Han-ok for spatial analysis

| Name of Han-ok | Location | Year of construction |
|---|---|---|
| Yung Jeung's old house | Non-san, Chungcheong-namdo | Late 1600s |
| Eunnongjae | Du-gye, Chungcheong-namdo | Early 1600s |
| Yoon Hwang's old house | Non-san, Chungcheong-namdo | 1730s |
| Kim Jung-hee's old house | Ye-san, Chungcheong-namdo | Mid-eighteenth century |
| Yun's Nogudang house | Hae-nam, Jeola-namdo | Mid-fifteenth century |
| Kim Dong-Su's house | Jeong-eup, Jeola-namdo | 1784 |
| Unjoru | Gu-rye, Jeola-namdo | 1776 |
| Yang Dong-ho's house | Hwa-soon, Jeola-namdo | Early 1700s |
| Kwon Hee-moon's house | Jang-su, Jeola-bukdo | 1733 |
| Jung Yeo-Chang's old house | Ham-yang, Gyungsang-namdo | 1570s |
| Choonghyodang | An-dong, Gyungsang-bukdo | 1600s |
| Hwa-heo-daek | Seong-ju, Gyungsang-bukdo | 1630s |
| Choe Jun's house | Gyeong-ju, Gyungsang-bukdo | 1700s |
| Manchuidang | Yeong-cheon,Gyungsang-bukdo | 1781 |
| Park Younghyo's house | Joong-gu, Seoul | 1700s |

partially open to the backyard, contributing to cross-ventilation, daylight, and horizontal openness (Fig. 2). The Sarang-chae and Sarang-madang are where the master of the house receives a guest, or studies. The Sarang-chae consists of a few Sarang-bang (master's room) and Sarang-maru (a veranda belonging to the Sarang-chae). Sarang-bangs abut against each other. The Sarang-maru is located at one corner facing the Sarang-madang, extending to it visually and connecting the Sarang-bangs with the Toen-maru (balcony) (Fig. 3). Walls of various heights usually prohibit direct visual access from the Sarang-chae and Sarang-madang to the An-chae and An-madang, but visual access in the reverse is possible. The Sadang-chae, a building for a shrine, is not part of daily life. It typically resides outside the main circulation from Daemoon to An-chae and is located behind the An-chae, matching its orientation (Fig. 4). Hangrang-chae, including the Daemoon, servants' dwelling, storage, and a stable, become part of the thick layer of the wall of the entire complex. The Hangrang-madang (courtyard belonging to the Hangrang-chae) is a work place for servants and may or may not be provided. If not, it is also replaced with a Sarang-madang.

The main circulation occurs through Madangs (courtyards). In other words, they both separate Chaes (individual buildings) and link them (Fig. 4). They are always open to the sky for daylight and ventilation. Chok-maru (small veranda) and Toen-maru, both found in An-chae and Sarang-chae, become the transitional circulation between Madangs and each room, and secondary circulation joining each room when the rooms themselves face the Madang (courtyard). They act as multi-functional circulation that can accommodate small activities. When on the opposite side of the Madang (courtyard), they are transformed into balconies to the exterior (Figs. 2, 3).

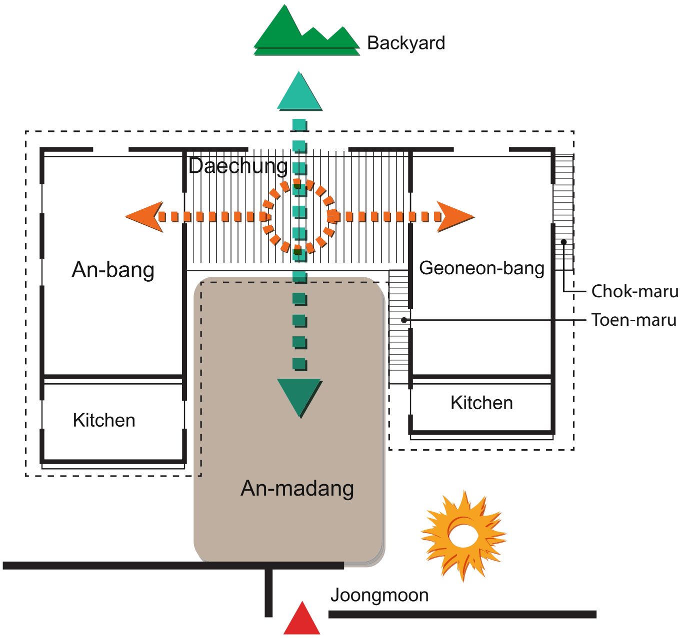
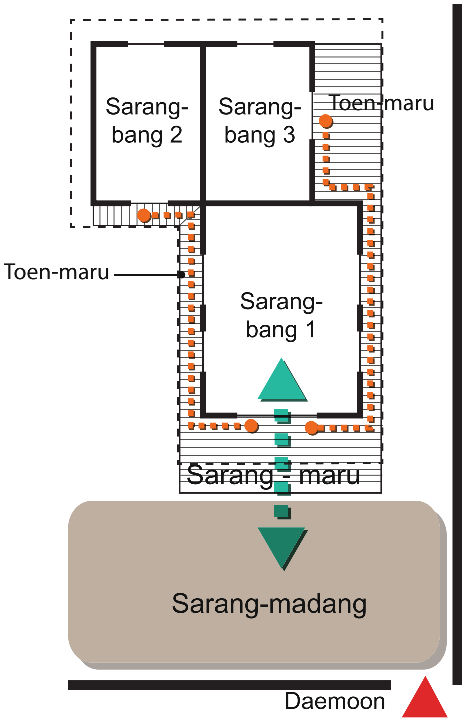



**Fig. 2** Spatial analysis of the An-chae (building for women)

**Fig. 3** Spatial analysis of the Sarang-chae (building for men)



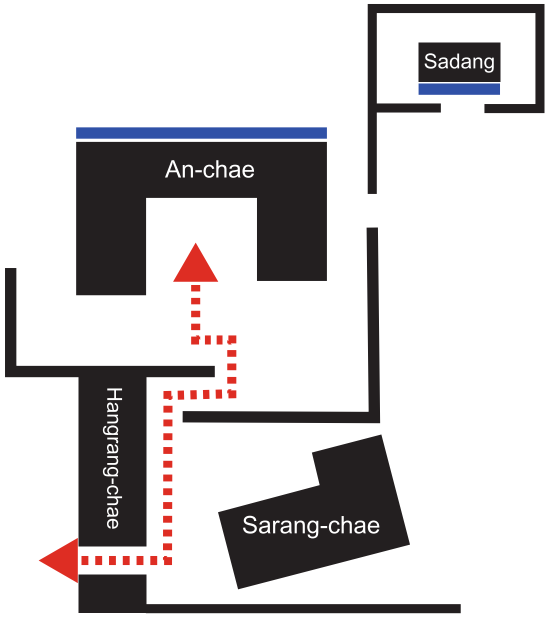



**Fig. 4** Spatial analysis of main circulation and Sadang-chae (a shrine)

## Simulation Utilizing Cellular Automata and Workflow

The approach presented in this study takes advantage of an algorithmic design process that offers numerous design possibilities. This section explains the selection of Cellular Automata (CA) as a generative design tool. CA, introduced by von Neumann (1951) and further developed by Ulam (1962), is the computational method that can simulate the process of growth by describing a complex system based on simple rules. Krawczyk (2002) argued that CA, viewed as a mathematical approach, differs from traditional deterministic methods in that current results are the basis for the next set of results and that the outcomes in CA's recursive methods usually cannot be easily anticipated, while the results in parametrically-driven digital methods can be. This offers an interesting and rich platform from which to develop possible architectural patterns (Krawczyk 2002). The major characteristic of a CA generative system is to produce a vast number of solutions and generate complex morphologies by applying simple rules to cope with the majority of constraints. The majority of CA applications in architecture perform conceptual form generation, allowing designers to explore a variety of results from which they can select potential solutions (Araghi and Stouffs 2015, 152–162). In this same vein, CA is utilized to offer a vast number of possibilities from which a design framework will be proposed for a contemporary house reflecting the unique spatial configurations of Han-ok with Chae and Madang. CA is a powerful generative design tool, but it is not able to create usable architectural spaces without the assistance of a designer. The computer-based generative process is therefore integrated with the conventional design process, entailing manual effort. The workflow represented in

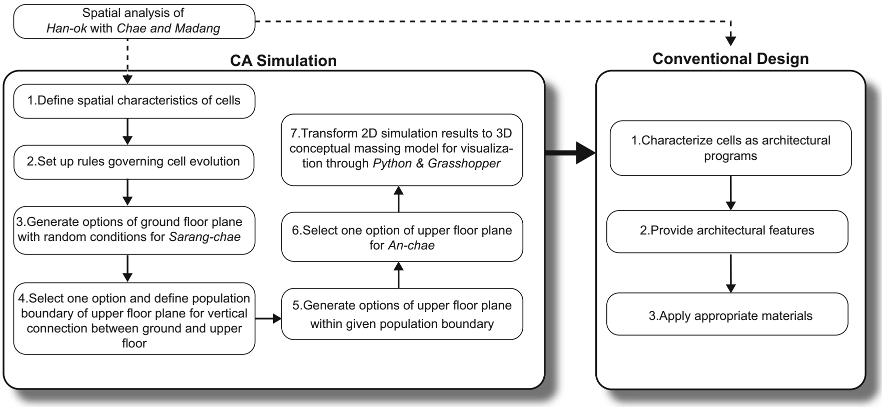



**Fig. 5** Workflow diagram

Fig. 5 outlines how the simulation utilizing CA is implemented and its result is fed into the conventional design process to be interpreted within a particular architectural context.

CA simulation is the second step of this study and the following sections will investigate critical assumptions among individual spaces found in the Han-ok with Chae and Madang, rule setup to govern each cell's evolution in the simulation based on interpretation of individual spaces, experimental simulation per constraints including population boundary and entry location to verify the relevance of our assumptions, and a final simulation meeting all of these complex rules.

## Simulation Assumption and Method of Rule Setup

As described thus far, it is difficult to literally apply the traditional configuration of the Han-ok with Chae and Madang to a contemporary house for today's life style. This section describes critical assumptions on the spatial characteristics as a prerequisite for simulation, explores Conway's Game of Life that is selected as a starting point of this simulation, and then investigates the process relating Conway's Game of Life to the explored simulation approach. This section also gives a detailed description of basic cells as players of simulation and their relationships to each other that drive the simulation.

The study focuses on the An-chae/An-madang and Sarang-chae/Sarang-madang for spatial analysis of Han-ok, since the traditional function of the Hangrang-chae typically no longer exists. The Sadang-chae (a shrine) is also included as a sort of experimental cemetery, reflecting a recent increase in cremations due largely to a lack of graveyard space. The divisions of the Chae (individual building) based on traditions of the past, a medieval social hierarchy system, and Confucianism needs to be replaced with a contemporary division: a family-oriented private space vs. guest-receiving public space, which can be assigned to the traditional An-chae

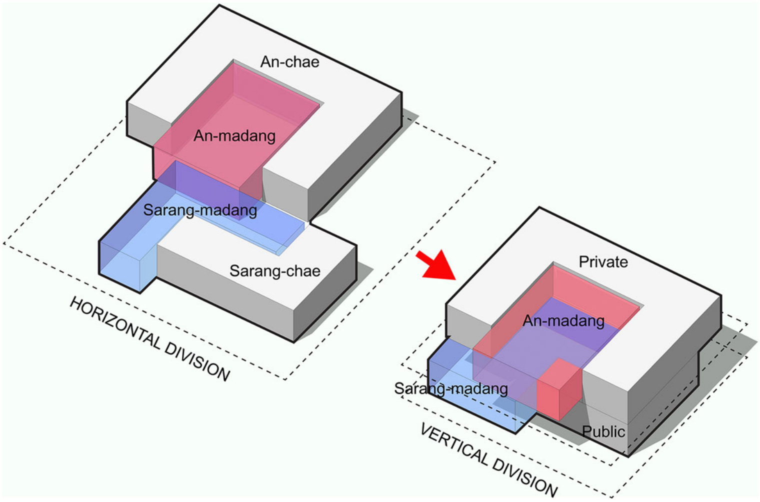



**Fig. 6** Change of division of Chae (building)

(buildings for women) and Sarang-chae (buildings for men), respectively. The consideration of degrees of privacy locates the Sarang-chae on the ground level and the An-chae on the upper level, which can be integrated by the Madang (courtyard) (Fig. 6).

On the basis of these assumptions this study focuses on two-dimensional CA rather than one or three-dimensional CA. It begins with an 8-cell Moore neighbourhood (Fig. 7), one of the most commonly used two-dimensional neighbourhood types. An 8-cell Moore neighbourhood enables a cell's evolution to achieve maximum sampling, offering vast design possibilities. The following step utilizes Conway's Game of Life, a cellular automation based on an 8-cell Moore neighbourhood. Conway's Game of Life, introduced by the British mathematician John Horton Conway in 1970, is an infinite two-dimensional orthogonal grid of square cells, each of which is in one of two possible states, alive or dead. Each cell has eight neighbouring cells, four adjacent orthogonally, four adjacent diagonally (Shiffman 2012, 343–344). The rules are:

- Survivals. Every alive cell with two or three alive neighbours survives for the next generation.
- Deaths. Each alive cell with four or more alive neighbours dies (is removed) from overpopulation. Every alive cell with one alive neighbour or none dies from isolation.
- Births. Each dead cell adjacent to exactly three alive neighbours—no more, no fewer—is a birth cell. An alive cell is placed on it at the next move.

Gardner (1970) argues that there should be simple initial patterns that grow and change for a considerable period of time before coming to end. This can create

| | | |
|---|---|---|
| x-1, y+1 | x, y+1 | x+1, y+1 |
| x-1, y | x, y | x+1, y |
| x-1, y-1 | x, y-1 | x+1, y-1 |

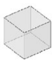
**Fig. 7** 8-cell Moore neighbourhood

binary patterns based on the rules between cells while there should be unpredictable outcomes without explosive growth.

We apply the method of Conway's Game of life for controlling overpopulation and isolation to generations of patterns in our simulation by controlling overpopulation and isolation of the Bang (room), Madang and Maru cells. Differing from the traditional rules where each cell has exactly two states (1-alive, or 0-dead), the approach here changes the state of a specific cell into one of three states based on the rules described in Table 3. The basic cells are characterized in Table 2. Because this transition of one state to another is beyond the more basic binary states (1-alive, or 0-dead), as many colours as the number of basic cells shown in Table 2 had to be introduced in order to show the cell's evolution of state. The fundamental rule matrix to change the state of a specific cell at T = i into another at T = i+1, creating relationships among rooms in the An-chae/An-madang and Sarang-chae/Sarang-madang is shown in Table 3, with examples. Rules A and B control the Sarang-chae/Sarang-madang and An-chae/An-madang, respectively.

The basic cells are divided into two: an external and an internal cell. The external cell is considered to be an exterior component given by the site condition, so its state is unchanged during simulation, while an internal cell is an interior component that can change in undetermined ways during a simulation. Two separate rules must be established: one for the transitional process between internal cells, the other for the transitional process between internal cells and external cells because the relationships between exterior and interior, and between interior and interior are

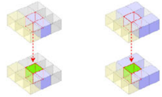
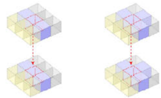
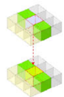
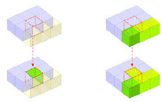
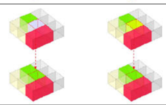
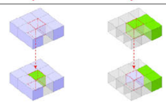
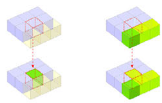
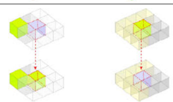
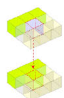
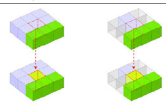
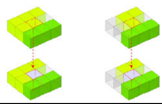
**Table 2** Characteristics of cells

| | |
|---|---|
| Internal Cells | |
|  | *Bang** Typical rooms. Function to be determined in later design stage |
|  | *Maru*** Corridor or a balcony or a veranda |
|  | *Madang**** Interior/exterior open space with or without roof. Must be open to sky |
| External Cells | |
|  | *Entry* Entry to building. Same level as *Sarang-chae* |
|  | *Null-A* Open space that is subject to be adjacent to *Maru*** or *Madang**** |
|  | *Null-B* Empty space by building setback requirement |
|  | *Obstacle* Physical obstacles to avoid |

*Bang** room, *Maru*** corridor or a balcony or a veranda, *Madang**** courtyard, *Sarang-Madang***** courtyard belonging to Sarang-chae, *Sarang-chae* buildings for men

different. The rules for in-between internal cells assumes that an internal cell neighbouring with internal cells only, which can be called an internal cell without border condition, will be affected by other internal cells including Bang, Maru and Madang only in order to generate patterns according to the defined rules. These rules are set up to prevent a lack of circulation or open space due to an overpopulated Bang and, conversely, a lack of Bang due to excessive circulation or open space while creating various patterns. Additionally, the rules between internal cells and external cells are prescribed such that an internal cell, which can be called an internal cell with border condition, is affected by internal and external cells concurrently to reflect the Han-ok's relationship to exterior space and its unique spatial sequence from entry to interior space, as observed in the previous section

**Table 3** Rule matrix for cell evolution

| | | Rules | Purpose | Rule Base Generative Model |
|---|---|---|---|---|
| A1-1 / B1-1 | Adjacent to Null-A or *Madang**** | Isolation. If a *Bang** has fewer than 2 *Bangs** and adjacent to Null-A, it turns into *Madang****<br>Overpopulation. If a *Bang** has more than 3 *Bangs**, it turns into *Madang**** | Control proportion of *Bang**, *Maru*** and *Madang****. Prevent overpopulated *Bang** and increase *Madang**** | T=i<br>T=i+1  |
| A1-2 / B1-2 | | Happiness. If a *Bang** has either 2 or 3 *Bangs** and adjacent to Null-A, it stays | Provide adequate number of *Bang** | T=i<br>T=i+1  |
| A1-3 | | If a *Bang*/ Madang**** is at (x, y) and neighbors; (x, y+1), (x, y-1) are *Madangs**** and adjacent to Null-A, it turns into *Maru*** | Provide continuous access via *Maru*** between *Madang**** and *Maru*** or *Bang** | T=i<br>T=i+1  |
| A1-4 / B1-3 | | If a *Bang** has more than 5 *Bang*s and* adjacent to Null-A, it turns into *Madang***,* or else it turns into *Maru*** | Provide *Maru**s* as a corridor between of *Bang*s* & generate various results of the pattern | T=i<br>T=i+1  |
| A2-1 | Adjacent to Entry | If a *Bang** or *Maru*** is adjacent to Entry, it turns into *Madang**** | Provide *Madang**** access from Entry to *Sarang Madang***** continuously | T=i<br>T=i+1  |
| A3-1 | Internal Cell without Border condition | If a *Bang** has more than 7 *Bangs** and has no border condition, it turns into *Madang**** | Prevent overpopulated *Bang** | T=i<br>T=i+1  |
| A3-2 | | If a *Madang**** has more than 2 *Madang****s and has no border condition, it turns into *Bang** | Prevent overpopulated *Madang**** | |
| A3-3 | | If a *Bang** has more than 5 *Bang*s and* adjacent to Null-A, it turns into *Madang***,* or else it turns into *Maru*** | Provide *Maru**s* as a corridor between of *Bang*s* & generate various result of the pattern | T=i<br>T=i+1  |
| B2-1 | Adjacent to Null-A, Null-B or Obstacles | If a *Bang** has more than 1 *Maru*** and adjacent to Null-B, it turns into *Maru*** | Expand *Maru*** cells into the external boundary | T=i<br>T=i+1  |
| B2-2 | | If a *Maru*** has more than 1 *Maru*** and adjacent to Obstacles or Null-A, it turns into *Bang** | Reduce *Maru*** cells next to Obstacles and Null-A and increase *Bang** cells | |
| B3-1 | | If a *Bang** has more than 3 *Maru***s and adjacent to Null-A, it turns into *Maru*** | Provide adequate number of *Bang** adjacent to Null-A | T=i<br>T=i+1  |
| B4-1 | Adjacent to inside *Madang**** | If a *Bang** has more than 5 or 1 *Bangs** and adjacent to inside *Madang**** cells, it turns into *Maru*** | Prevent overpopulated *Bang** and increase *Maru*** cells adjacent to *Madangs**** | T=i<br>T=i+1  |
| B4-2 | | If a *Maru*** has more than 3 or 2 *Maru**s* and adjacent to inside Madang*** cells, it turns into *Bang** | Prevent overpopulated *Maru*** cells adjacent to *Madangs**** | T=i<br>T=i+1  |

*Bang** room, *Maru*** Corridor or a balcony or a veranda, *Madang**** courtyard, *Sarang-Madang***** courtyard belonging to Sarang-chae, *Sarang-chae* buildings for men. *A1, A2, B1, B2, B3, B4* internal Cell with border condition, *A3* internal cell without border condition

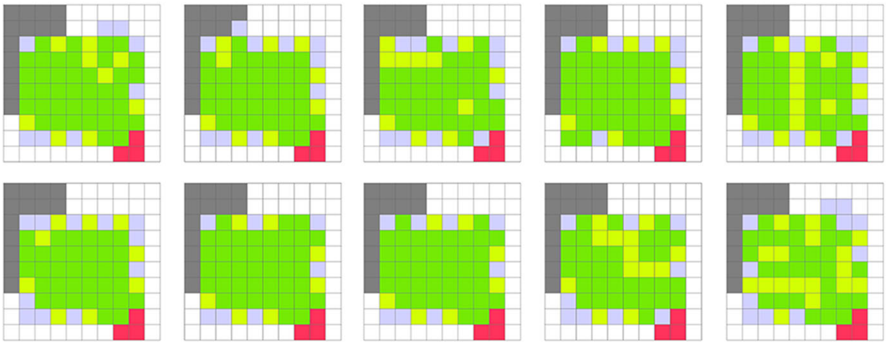


Fig. 8 Result of test simulation with an internal cell without border condition

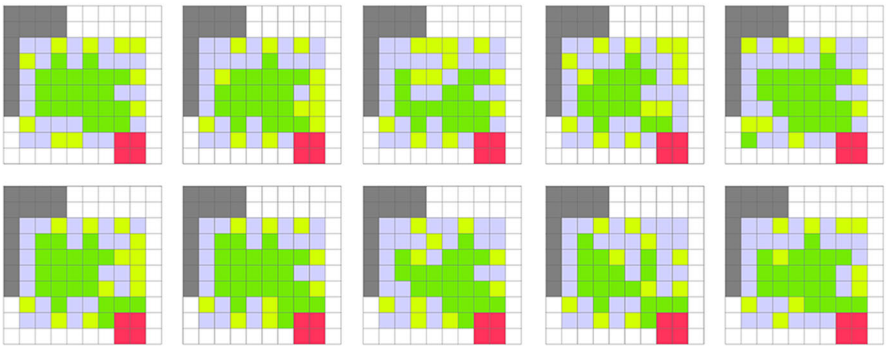


Fig. 9 Result of test simulation with an internal cell with border condition

analysing the spatial quality of the Han-ok. Figure 8 shows the result of a simulation implemented with internal cells without border condition using only the rules A3-1, A3-2 and A3-3 in Table 3. On the other hand, Fig. 9 represents the result of a simulation implemented with both internal cells without border condition and internal cells with border condition using all of the rules in Table 3. The comparison of these simulation results with and without the application of a border condition proves that an internal cell with border condition helps in creating appropriate numbers of Bang, a better sequence from entry to Bangs, better connections from exterior space to Bang and Madang, and from Bang to Madang through Maru.

In short, what begins with the logic of Conway's Game of Life is modified in order to generate numerous patterns by controlling overpopulation and isolation of specific cells and attracting intentional sequences of space observed in the analysis of Han-ok with Chae and Madang. The size of a basic cell of the simulation is a modular cube of 3.3 m per side that offers design flexibility in later design stages. The specific spatial characteristics of each cell's group after simulation are assigned during translation of the final simulation results into tangible architectural space. The transitional process begins with given constraints including population boundary and entry location and progresses by a set of rules to succeeding generations. The rules determine which cell at T = i changes to which states in the next generation, T = i + 1. The rules govern only horizontal evolution, not vertical, which is justified in the following section (see "Simulation Result: Creating Chae and Madang"). This study uses Python, a widely used high-level programming language, as the main programming and simulation platform for this study.

## Simulation Constraints: Population Boundary and Entry Location

In the previous section rules were established to drive simulation. The realistic conditions of a building site on which a simulation is implemented are now discussed and its relevance is demonstrated through test simulations. Every building on this planet has its own site and main access from the street. Local codes and the given locations of obstacles such as large trees, boulders, utility and sewage lines can significantly affect the building footprint. The building footprint in this study is therefore described as one population boundary within which cells can populate. This population boundary is defined by various combinations of external cells given by site conditions, including obstacles and Null B, described in Table 2. The other external cell defining the population boundary is Null A, which is not related to a given site condition. The presence of Null A prevents the populations of other cells, creating Maru or Madang around it. These can be located both inside and outside the building footprint, allowing designers to place this Null cell based on their design intentions. The size of the site in our simulation is a 10 × 10 square grid with each cell being approximately 10 $m^2$, with the assumption that a typical urban residential site is 33 m × 33 m. Figure 10 shows several simulation results per various conditions of a population boundary defined randomly for test purposes.

The other factor considered a simulation constraint is the entry location. Typically the main entry of a house faces a road and its character is defined by the building façade. The location of the main entry to a building is critical to the Han-ok since it is often the starting point of a spatial sequence, as described earlier. Differing locations, therefore, can result in a different layout of Chae and Madang.

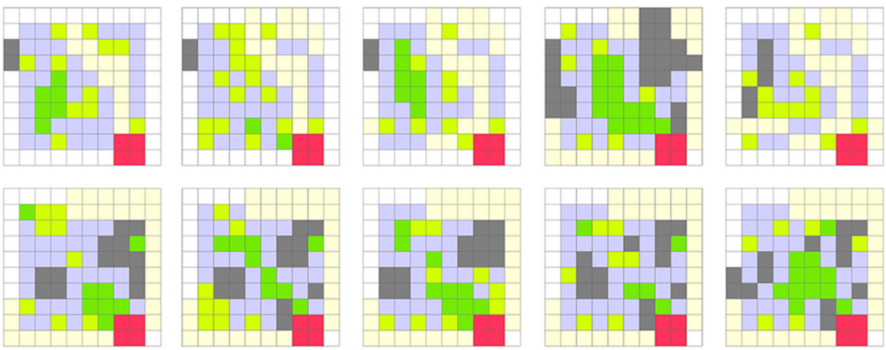


**Fig. 10** Result of test simulation per different population boundary

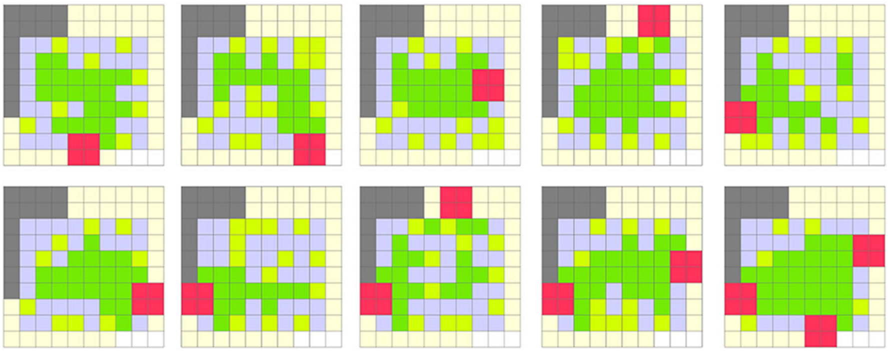


**Fig. 11** Result of test simulation per different entry location

It can be on any side of the site in this study, however, depending on design intentions. Figure 11 shows how a different location for the main entry can create a direct path to the Sarang-madang (courtyard belonging to the Sarang-chae), and the subsequent sequences of space in different way as the main entry is located randomly for test purposes.

## Simulation Result: Creating Chae and Madang

Thus far a series of procedures for simulation have been introduced, including the spatial analysis of Han-ok with Chae and Madang, the definition of basic cells and rule setup, and the review of simulation constraints. The final simulation meeting all of these constraints can now be explored. It begins with a ground floor plane that has a main entry and building footprint randomly defined. Based on the assumptions made previously (see "Simulation Assumption and Method of Rule Setup above"), the Sarang-chae and Sarang-madang are simulated following rules within given constraints. Figure 12 shows parts of a vast number of possible layouts that meet all of these complex rules. The same ground plane simulation used to define the Sarang-chae/Sarang-madang on the ground floor is then used to define the An-chae/An-madang, separated to the upper floors for privacy. This creates a uniformly defined space connecting the two floors vertically, acting as the Sarang-madang on the lower floor and the An-madang on the upper floor. For this purpose, one boundary of the Sarang-madang works not as a physical obstacle but as a pre-defined space, with the aim to integrate the An-chae and Sarang-chae through the Madang, as shown in Figs. 6 and 13. Figure 14 displays some of the numerous options for the upper plane that the CA simulation has generated based on these rules and constraints.

Since the Sadang-chae, the shrine building, is no longer a significant space in modern life, a Bang cell was used to place it. Having the Sadang-chae appear at the initial generation would limit the potential population of the other cells, especially when considering that it is much less important than the other scripted spaces. Its

Fig. 12 Simulation results of ground floor plane options

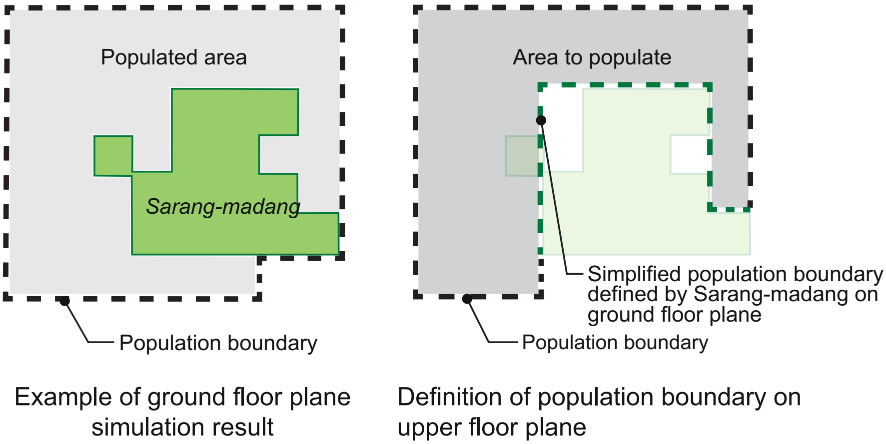



Fig. 13 Diagram showing the relationship between the resultant Sarang-madang on the ground floor plane with the population boundary of the upper floor plane

location is determined if a Bang cell is neither bordering the An-madang nor blocking access to other Bang cells. The final process of simulation is to transform the 2-dimensional results into an abstract 3-dimensional massing model. The

**Fig. 14** Simulation results of upper floor plane options

generation of a separate layer by its function in Python and the 3D morphing features of Grasshopper in Rhinoceros enable visualization of the cells in a 3-dimensional massing. Though this 3-dimensional massing model isn't necessary in the subsequent design process, it offers a better visual understanding of the simulation results (Fig. 15a, b).

## Architectural Interpretation

The simulation result in the previous section offers various possibilities for developing the spatial relationships of Chae (individual buildings) and Madang (courtyard) in the traditional Han-ok at a conceptual level. The subsequent design process develops these concepts into architectural spaces by dividing groups of cells, characterizing divided spaces, and applying architectural materials as well as openings in a convincing manner. This stage entails manual effort and the subjective design inclination of the designers. The first stage of manual effort includes those steps listed below. It should be noted that this does not need to follow the listed order:

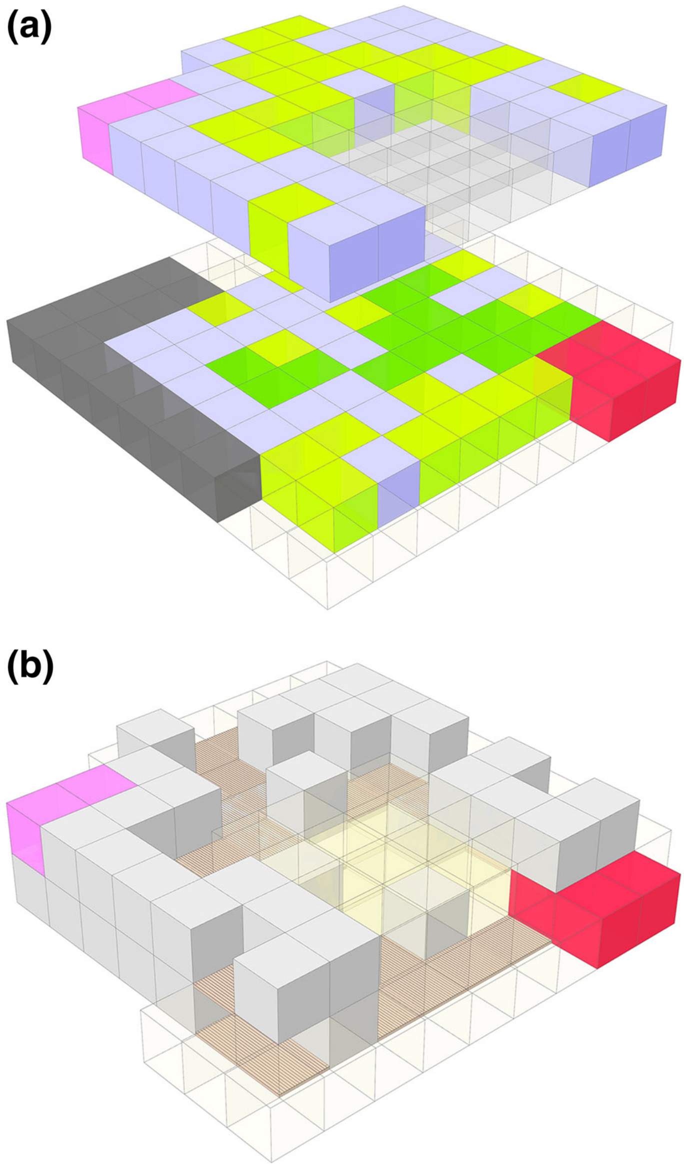



**Fig. 15** **a** Conceptual 3D massing model of combined simulation results. **b** Morphed 3D massing model from conceptual 3D massing model

- Re-define the edge of groups of cells to create regularly shaped spaces for clean edges and a better furniture layout.
- Divide groups of cell into rooms for specific functions; living room for guest or family, guest room, kitchen and bathroom for Sarang-chae (guest-receiving

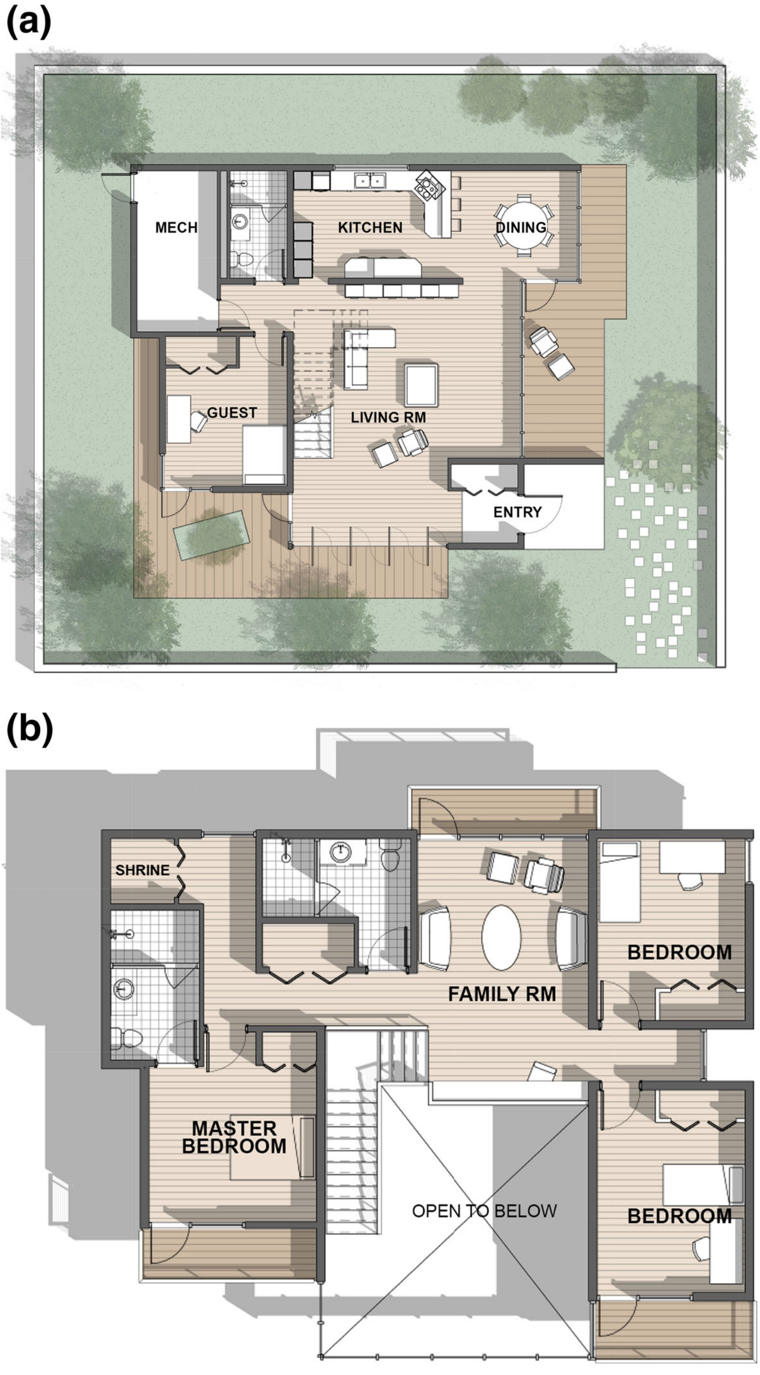



**Fig. 16** **a** Illustrative ground floor plan of proposed house. **b** Illustrative upper floor plan of proposed house

public space as assumed in the simulation assumption and method of rule set up); master bedroom (An-bang), other bedrooms (Geoneon-bang) and family room (Daechung) for the An-chae (a family-oriented private space as assumed in the simulation assumption and method of rule set up).

- Define the character of the Sarang-madang as an interior living room for guest and family, an exterior space, or a combination thereof.
- Provide vertical circulation between the Sarang-madang and An-madang to keep the character of the traditional Madang as the main circulation and access point to each room.
- Provide a visual filter between the main entrance and An-chae by either angled circulation or an architectural element such as a wall.
- Provide a room with a balcony in a cell functioning as the Maru (balcony or a veranda) at the outer edge.
- Apply an operable transparent material to the family room and the space for Sarang-madang and An-madang to allow visual openness to the exterior.
- Apply a translucent material in appropriate sizes between the space for the Madang and rooms, and between the family room and rooms.
- Provide space for the Madang with a skylight offering openness to sky.

The example presented below exhibits one of the numerous possible architectural interpretations of the simulation results. The possible character of the architectural spaces is shown in Figs. 16, 17, 18, 19, 20.

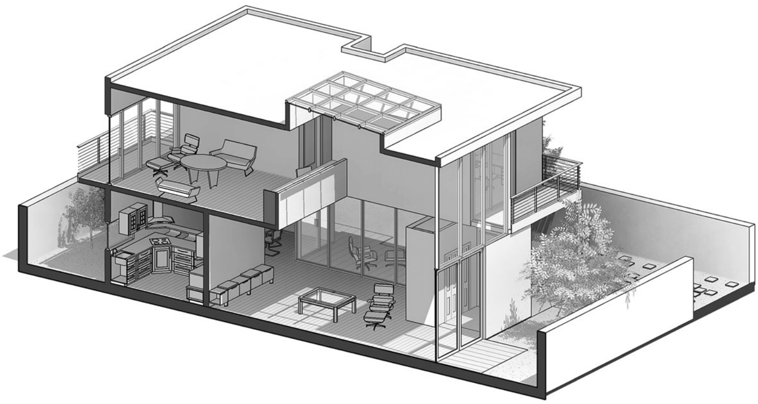


**Fig. 17** Sectional axonometric of proposed house

**Fig. 18** A view from entry to a living room on the ground floor and a family room on the upper floor

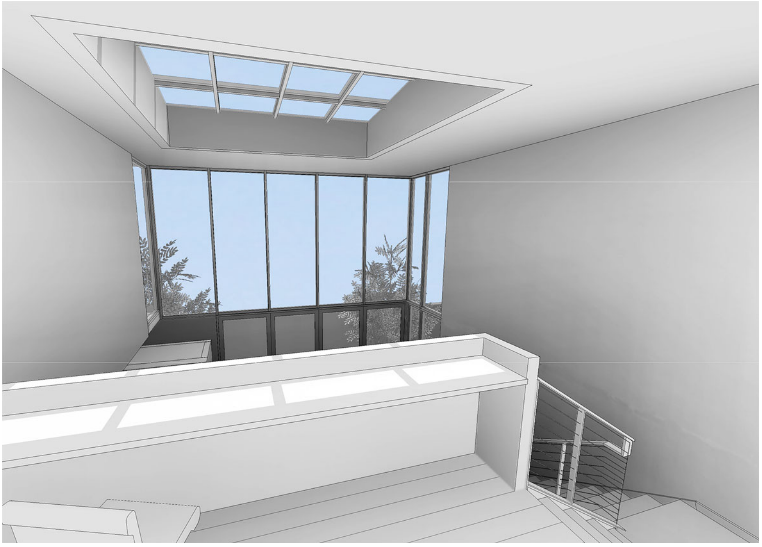


**Fig. 19** A view from a family room on the upper floor to a living room on the ground floor

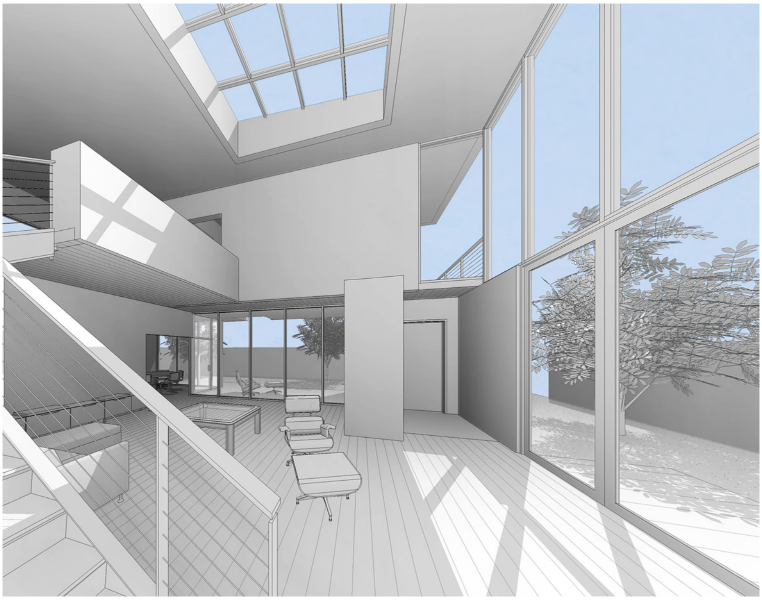


**Fig. 20** A view of the double-height living room showing the vertical connection to a family room and sky

## Conclusion and Discussion

Recent increase in public interest in the Han-ok, the traditional Korean house, has led to many research endeavours to revitalize it in a modern way. These have been limited, however, to simple reconstructions of the material, structure and exterior of the Han-ok, which fail to accommodate today's lifestyle. This study begins by defining the unique relationships among spaces of the traditional Han-ok, focusing on the Han-ok for the Yangban (aristocrat) class in the Chosun Dynasty that had separate Chae (individual building) and Madang (courtyard), of which various combinations contributed to spatial diversity and order. The significance of this study lies in the use of Cellular Automata as a generative tool to produce a vast number of solutions by applying simple rules that are translated from the spatial characteristics of a traditional Han-ok with Chae and Madang. The division of Chae based on a medieval social hierarchy system and Confucian tradition is reinterpreted to fit a modern context: they become a family-oriented private space and a guest-receiving public space, the An-chae and Sarang-chae, respectively, in order to match today's lifestyle. This simulation begins with Conway's Game of Life, a cellular automation based on an 8-cell Moore neighbourhood, which can create binary patterns based on the rules between cells where there should be unpredictable outcomes. We altered the traditional rules where each cell has exactly two states (1-alive or 0-dead) into varying colours to represent the state change of a specific cell into one of three states. The Cellular Automata simulation is also planned to integrate two separate Chaes through the Madang vertically for an urban context. The consecutive simulation results from a 2-dimensional diagram level to 3-dimensional massing demonstrate that our design approach could generate a vast number of design possibilities that propose a framework for contemporary housing reflecting the unique spatial configuration of the Han-ok with Chae and Madang in a quick and serendipitous way. A conventional design procedure is introduced to further develop the simulation results into a more usable architectural result. The most valuable aspects of this research are not only the reinterpretation of traditional space and its application to contemporary space but also the algorithmic design process of that application. This study focuses on the planar relationships among spaces in the Han-ok with Chae and Madang. Future research and study could investigate the critical design considerations of the sectional and elevation relationships of these spaces.

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## References

Araghi, S., and R. Stouffs. 2015. Exploring Cellular Automata for High Density Residential Building Form Generation. *Automation in Construction* 49 (A): 152–162.

Gardner, M. 1970. Mathematical Games: The Fantastic Combinations of John Conway's New Solitaire Game "Life". *Scientific American* 223: 120–123.

Kim, J. 2006. Development of Continual Plan Type of Korean Folk House. *Journal of the Architectural Institute of Korea Planning and Design* 22 (3): 211–218.

Kim, J., and B. Jeon. 2012. Design Integrated Parametric Modeling Methodology for Han-ok. *Journal of Asian Architecture and Building Engineering* 11 (2): 239–243.

Krawczyk, R. 2002. Architectural Interpretation of Cellular Automata. In: *Generative Art,* Conference proceedings (Milano, 2002). http://cumincad.architexturez.net/system/files/pdf/ga0205.content.pdf. Accessed 1 Jan. 2016.

Lee, Y. and S. Park. 2009. A Study of the Meaning and Use of Madang through the Evaluation of the Detached House Residents in Busan. *Journal of the Architectural Institute of Korea Planning and Design* 25 (8): 153–162.

Shiffman, D. 2012. The Naure of Code: Simulating Natural Systems with Processing. http://natureofcode.com/book/. ISBN 9780985930806.

Shin, W. and K. Kim. 2014. A Study on the Characteristics of the "An-chae with Wings" in Jollanam Province, Korea. *Journal of Asian Architecture and Building Engineering* 13 (3): 523–529.

Ulam, S. M. 1962. On Some Mathematical Problems Connected with Patterns of Growth of Figures. In: Proceedings of *Symposia in Applied Mathematics* (Providence: Am. Math. Soc., 1962), 14: 215–224.

von Neumann, J. 1951. The general and logical theory of automata. In: *Cerebral Mechanisms in Behavior*-The Hixson Symposium (New York, 1951), 1–31.

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