ROLE OF DIGITAL TOOLS IN HOUSING DESIGN BY MASS CUSTOMIZATION

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ABSTRACT

The concept of housing has different meanings and values for each user. Until recently, this idea was ignored by design implementations done by logic of mass standardization to fulfill increasing needs of housing in mega cities. However, it has gained its popularity with new changing design approaches. This paper focuses on the potentials of digital design processes with support of generative tools and users' choices as an alternative to recent approaches of housing design. Accordingly, a new computational model based on the cellular automata and mass customization approaches is presented and its implementation, limitations and possibilities are discussed.

Key words: digital design, mass customization, cellular automata, form generation

1. INTRODUCTION

In recent years, in mega cities where a rapid population growth has been experienced and needs of housing have increased rapidly, in the same way the importance of 'housing' concept has increased, arguments based on it have also emerged. In this context, it is seen that practices of the past, which are based on short-term mass production techniques and evoke monotony, uniqueness, non-identity and the logic of standard user type, have been slowly abandoned. Instead, it is observed that an understanding of housing including concepts like collaboration, uniqueness, diversity and individuality in a certain level has started to take its place. In this change, mass customization techniques presented as an alternative for classic mass production have made a great contribution. However, there are also important effects of developments of digital technologies and design tools on the intensive choice of this method existing since 1970s.

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Through the support of developments in digital production, mass customization has been usually seen in industrial design fields (automobile, plane, shoes, furniture etc…). In these fields, mass customization defines a process which provides users' participation and accelerates interaction of user-designer-producer (Crayton, 2001). This concept needs modularity and configuration. Clearly, it includes products' properties of breaking into components and subsystems, which are re-composed, with modularity and qualifications like users' selection and method definition with configuration. In other words, mass customization is establishing equilibrium between choosing freedom and standardization for user.

In design works, mass customization differentiates as directional interaction with users (collaborative customization); constrained interaction with users in decision-making process of designs which are generally standardized (adaptive customization); and generalized user evaluations made without users' participation (transparent customization) (Niemeijer et al. 2010). Among them, approaches of adaptive customization are suitable for multi-residential buildings. When these approaches are realized in the form of users' material selection and choices of building components, their participation in spatial planning is ignored. Therefore, in these building samples, other approaches, especially transparent customization, are still preferred about spatial planning.

In our country, "Izmit New Housings Project" done by "United Architects" for worker families with low income is one of the original implementations where users' participation took place at early design stages (Cavdar 1978).These houses providing users' satisfaction, are a consequence of one to one and collective negotiations with householders. In the work, traditional processes were evaluated, need of a digital design tool was pointed out especially to manage the information coming from users.

In this work, it is presented that a digital design implementation incorporates interactive design processes with techniques of Cellular Automata (CA) approach. With its properties of simulating neighborhood interactions, samples of growth and social phenomenon, CA is used actively for conducting the structures from simplicity to complexity in context-sensitive and grid-based designs (Singh and Gu 1978). As a traditional process, Schön's approach of reflection in action gives a designer opportunity of one to one interaction with his/her work. It is considered that integration of these two approaches with each other contributes to both elimination of laborious practices of traditional process on information management and intervention to autonomous processes CA brings with.

With this work, developing cooperation of user, designer and design tools for design models comprising complex relationships and functions and requiring users' preference, and also indicating potentials of design models which may contribute to designer as design-decision tools are aimed. So, we define frameworks of a process where designers are able to evaluate sample model and alternatives with CA supported –simulation of spatial organizations in multi-residential buildings which are similar to a CA lattice and formed by users' data.

2. DIGITAL DESIGN TOOLS AND CELLULAR AUTOMATA

Generative design tools commonly used are listed as Shape grammars (SG), L-Systems (LS), Genetic Algorithms (GA), Swarm Intelligence (SI) and Agent Based Models (ABM) and Cellular Automata (CA). Design development fields of these tools, which are different from each other in terms of their properties, structures and solutions, are summarized as follows (Singh and Gu 2011):

BG and LS are interpreted as form-based design processes and used for form and style generation. CA, SI and ABM are seen as behavior-driven design processes. Among them, when CA is evaluated for context-sensitive design practices (urban design problems, zoning, block design etc…), SI and ABM are used for generating designs composed by self-organized structures, analyzing designs' usability and simulation of circulation and movement in design development samples. GA is applied to design optimization studies.

As a computational process, Cellular Automata (CA) simulates growth process by way of defining a complex system with simple individuals following simple rules. This process can be defined as an operating system and feedback mechanism used for division of issues and events in the form of cells and determination of each cell's position in the future based on other neighbor cells in a homogeny interactive work (Yuzer 2006). Its basic properties are as follows:

- Consisting of regular cell lattices
- Emerging in time stages
- Characterizing each cell with its state
- Development of each cell based on the same rule related TO THE numbers of state of the cell and finite neighbor cell
- Having relationships of neighborhood which are local and similar to each other

CA can be represented as different models like classic models (Wolfram's one dimensional, Conway and Ulam's two and three dimensional samples) and advanced models adapted to different disciplines (physique, biology, urbanism etc..). In architecture, CA practices have been usually made by using rule sets of existing classic systems like Conway's Game of life and interpreting their results as an architectural form.

In this field, early CA practices have started with Price's "Generator" and Frazer's "Universal Constructor" models (Herr and Kwan 2007). Price's "Generator" aimed at demonstrating variations of the physical form by replacements of architectural spaces like a CA system including volumetric units in functionalist perspective. Frazer's "Universal Constructor" was composed of hardware CA and based on logic states not including any architectural concept. With this model, Frazer intended to determinate an architectural manner with logic states in space and time.

With regard to different architectural states and environmental conditions, Coates and his team (1996) tried to develop an extended classic CA system more customized with more logic states. In addition, they exhibited CA's abilities of architectural form as an external data. Krawzcyk (2002 and 2003) researched architectural potentials of CA by changing formal representations, states and rule sets of CA between implementation steps. As a result of his experiences, he stated that this CA-supported process was getting raw data from a generative method, finding a sample model and defining methods for interpretation of the sample due to additional architectural requirements (structural elements, horizontal relations etc…). Furthermore, Clarke and Anzalone (2003) studied on the development of structural models using one and two dimensional CA.

As opposed to other CA experiences, Herr and Kwan (2007) offered a hybrid model for using CA in architectural practices more effectively. This hybrid model was formed by integration of Shön's "Reflection in Action" approach with CA. In this manner, they considered that as an interactive way, Schön's approach was able to eliminate negative properties of CA incompatible with architecture. They evaluated its potentials with a sample model. Later, Herr (2008) also indicated advanced practices of this opinion in his doctorate thesis.

3. HOUSING DESIGN WITH CELLULAR AUTOMATA

Against identical residential buildings, with inspiration of natural processes, cell-like residential models have been developed. In these models, units constitute a whole on a skeleton which allows their development. In this way, it is considered to provide flexibility to satisfy inhabitants' changing requirements in time. There are very few constructed samples of these models, the majority of which have remained as a proposal so far and the best known of which was Safdie's project of Habitat 67. However, the numbers of the studies like Levent Loft in Istanbul, Mountain Dwellings and Lego Towers in Copenhagen have started to increase partially over the last decade.

In terms of the style of this approach, there are similarities between structure of CA and multi-residential buildings both logically and formally. CA with its properties of having bottom-up process, relations of neighborhood and logic of form following function supports the structure responding to time-dependent renewal requirements in housing buildings and changing user's preferences, and encourages innovative form alternatives. Besides, in such an approach, a digital design-decision tool is needed exceedingly owing to its complex content.

This tool can be CA itself, but it is not available to use with its autonomous structure and formal attributes in a design process effectively as it can be seen from the examples in the literature. For this reason, such a process supported with CA should be configured with comments in parallel with architectural purposes in a suitable design context.

Characteristics of Shön's theory of "Reflection in Action" are formed by concepts like "reflection in action", "indeterminate zones of practices", "framing-moving-reframing" and "practitoner's artistry". As a traditional process in this theory, a design process is fragmented with frame steps which can be interpreted, developed or reconfigured by a designer. In these steps, the phases which require automation and organizations of neighborhoods can be managed by a customized CA support.

3.1. Introduction of the protocol

In multi-residential housing implementations, design approaches can be evaluated from two different perspectives of urban context and building scale. In urban context, especially housing designs formed by separate building masses involve general concepts like aesthetics, transportation, common places, legal restrictions, natural lighting etc… However, in building scale as a small reflection of a city, there are spatial organizations where individuals meet their basic needs and common relationships among inhabitants develop. For both perspectives, they can be considered to be simulated and generated by a customized CA aided design. Accordingly, in this work, some scenarios based on them have been developed.

3.2. Housing Block Placement

In this stage, basic decisions of a site plan are interpreted by CA logic. To accomplish this, plot information (layouts of plot, rates of public spaces, and min/max heights of building masses) is primarily collected by user. Then, this information is evaluated in the framework of defined restrictions (distances of buildings from the layouts and positions of the building masses relative to each other) and sample generations are performed (Figure 1 and Figure 2). The progress adapted on principles of CA can be summarized as follows:

- Firstly, according to the restrictions, a building mass is placed randomly on the defined area.
- Secondly, building mass is generated similarly. However, if new generation is in the borders of first building mass which is defined by setback distances of buildings, death occurs and the generation is repeated. This process continues until it reaches to value of the parameter at startup.
- When total floor areas of the generated masses are equivalent to the construction area of the lot, during remaining generations, one of the generated masses are removed randomly and new mass is created.

Theory of "Reflection in Action" is applied taking designer reviews into consideration before and after generation. Accordingly, provided that the generated models are suitable for the designer's criteria, this stage is completed and the other stage is started. Otherwise, the designer has to go back to the beginning of the stage and the process is repeated by changing the parameters.

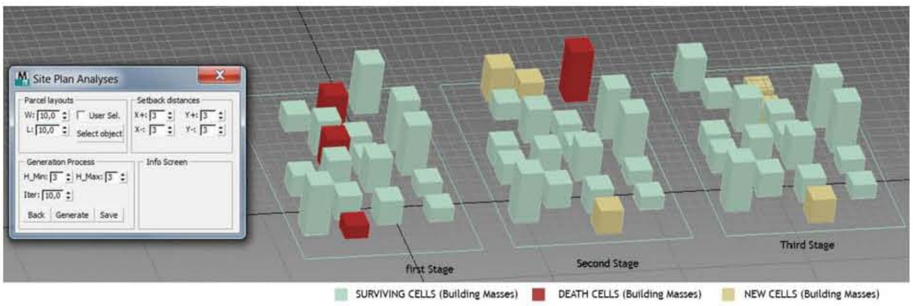


Figure 1. A sample interface and implementations of the site plan analyses.

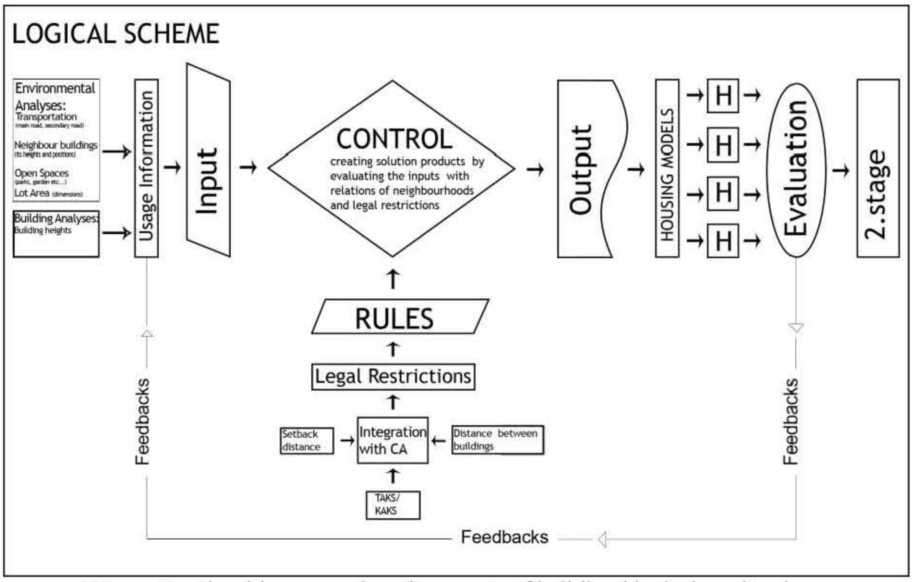


Figure 2. Algorithm managing placements of building blocks in a site plan.

After the placement of building masses in the first stage, for each block, reviews of floor plan organizations are initialized.

3.3. Organizations of Floor Plans

In modern housing plan understanding, users are given the right to choose partially by presenting samples of house including different sizes and amounts of room and a generalized user potential is presumed in design approaches. Proposal model also follows a similar route. However, open floor plan in this model has a feature that supports notions of more flexibility and more variation in housing designs with the aid of a parametric tool trying all possible alternatives. In other words, this model defines a mechanism where user preferences are transformed into a digital expression; each spatial unit affects and triggers generations of others; and innovative properties are involved.

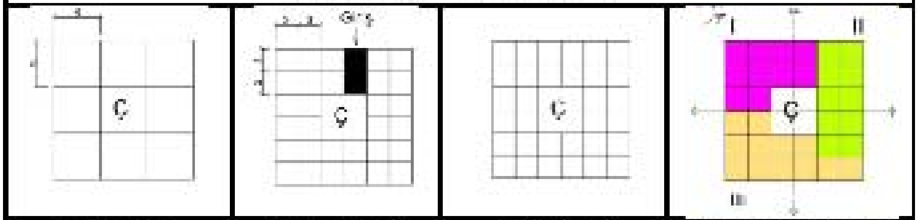
Proposal of open floor plan comprises a service core of building whose position never changes throughout all the floors and also changeable spatial units around it. With a structural system adapted to diversity and innovation, it has a feature that is able to grow and develop vertically.

The proposal is a skeleton structure including a plane of 18*18 m grid which can be subdivided by 6*6m and 3*3m smaller grids and squares on each floor. While the cells on the center of the plane define the service core, the remaining cells come together with their spatial descriptions to form different housing types grouped by examples of one (1+1), two (2+1), three bedrooms (3+1) and more (double flat).

The housing types on a floor depend on amounts of min and max spatial area determined for each. These amounts are seen as constraint criteria. So, a comparison is made between area of a housing type, a result of percentile values of user preferences, and these criteria. If the results match with one another, that housing type occurs on that floor. Otherwise, it is removed and its area is allocated among others. After this stage is completed, spatial analyses are started (Table 1).

Table 1: Logic of the process for housing types.

PROPERTIES OF A FLOOR PLAN

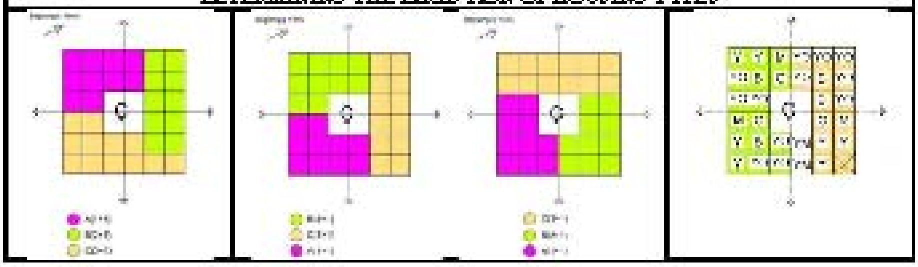


A floor plane	Ground Floor	Upper Floor	Allocation of dwellings

AREA ACCOUNT OF HOUSING TYPES

Total(m2)	Housing type		Min. (m2)	Max. (m2)	Rate of Pref.	Cal. of Area		Left	Num. of Cells	Num. of Housing
A unit cell: 6*6=36 m² A total of eight cells =36*8=288 m²	A	1+1	36	63	%30	288*0.3	86.4	5.4	10	2
	B	2+1	72	99	%30	288*0.3	86.4	14.4	10	1
	C	3+1	108	135	%40	288*0.4	115.2	7.2	12	1
	D	4+1	144	162	-	-	-	-	-	-

DETERMINING THE DIRECTION OF HOUSING TYPES



When interior spaces are designed for each housing type, with its customized structure, CA is seen as a tool whose duty is to run transition rules and the neighborhoods for them (Figure 3). The process is as follows:

- If the process is on the ground floor plan, entrance hall of the building is created. Additionally, a space of fire stair (YM) for all floors is defined arbitrarily. Both spaces are evaluated as constraints for other spaces. Otherwise, the settlement process of spatial units starts in the fields of defined housing types.
- First of all, according to the amount of housing types, cells of entry spaces (G) are added on the field of each housing type. These cells are close to service core of building. During the process "G" cells are primarily

positioned not to be adjacent with other "G" cells, but this rule can be changed in special cases.

- WC-Bath (B) cells are related to service core like "G" cells. Besides, at least one of them is expected to be adjacent to "G" cells. Furthermore, there is a criterion that maximum two "B" cells are adjacent to each other on the same floor, for the same housing type.
- Kitchen cells (M) must be adjacent to "G" cells. Except in special cases, they have at least one neighborhood with living spaces. The special cases are valid for kitchen cells related to the service core. Herein, "M" cell is primarily adjacent to open or semi-open spaces, called "Death cell", instead of living space cells. In this way, linking these spaces directly to the external environment is aimed.
- For the creation of a living cell (Y), there is a rule of having at least two or maximum three sequential neighborhoods with these cells. There is a difference for a housing type having one bedroom and minimum area. For this type, a living space having one cell can be created. Furthermore, on the same floor and for the same housing type, a living space can have up to four cells. For some cases, according to living cells, open or semi-open spaces may exist.
- Finally, cells called "bedroom" (YO) are generated. For them, if these cells are created in the region close to service core, a neighbor "YO" cell or an open/semi-open space is created automatically in the external region of the floor.

During spatial analyses, all progress is executed automatically. After each solution of an open floor plan, the results are evaluated by the architect's interpretation. When the results are acceptable, the information concerned with solution of this floor plan is saved and this process is repeated for solution of an upper floor plan. Otherwise, the feedbacks are made. In solution of an upper floor plan, a similar approach is followed. As a difference, during placement of spatial cells, the relationships of cells not only on the same floor but also lower floor are analyzed.

Finally, elevation analyses are performed simultaneously together with creation of floor plans. However, these are promoted by additional rules organizing adjustments of setbacks and cantilevers for diversity and dynamism on the facade with CA rules. Some of these rules are also exemplified as follows: in the vertical direction, if three spatial units having on a cantilever are ranked sequentially and an upper spatial unit following them in the same direction can't any cantilever, but a setback can exist on dimensions of that unit. Furthermore, in the horizontal direction, more than one cantilever does not exist on a space consisting of some units (like living rooms), but it can emerges sequentially on both spatial units defining different spaces and having a horizontal neighborhood with each other.

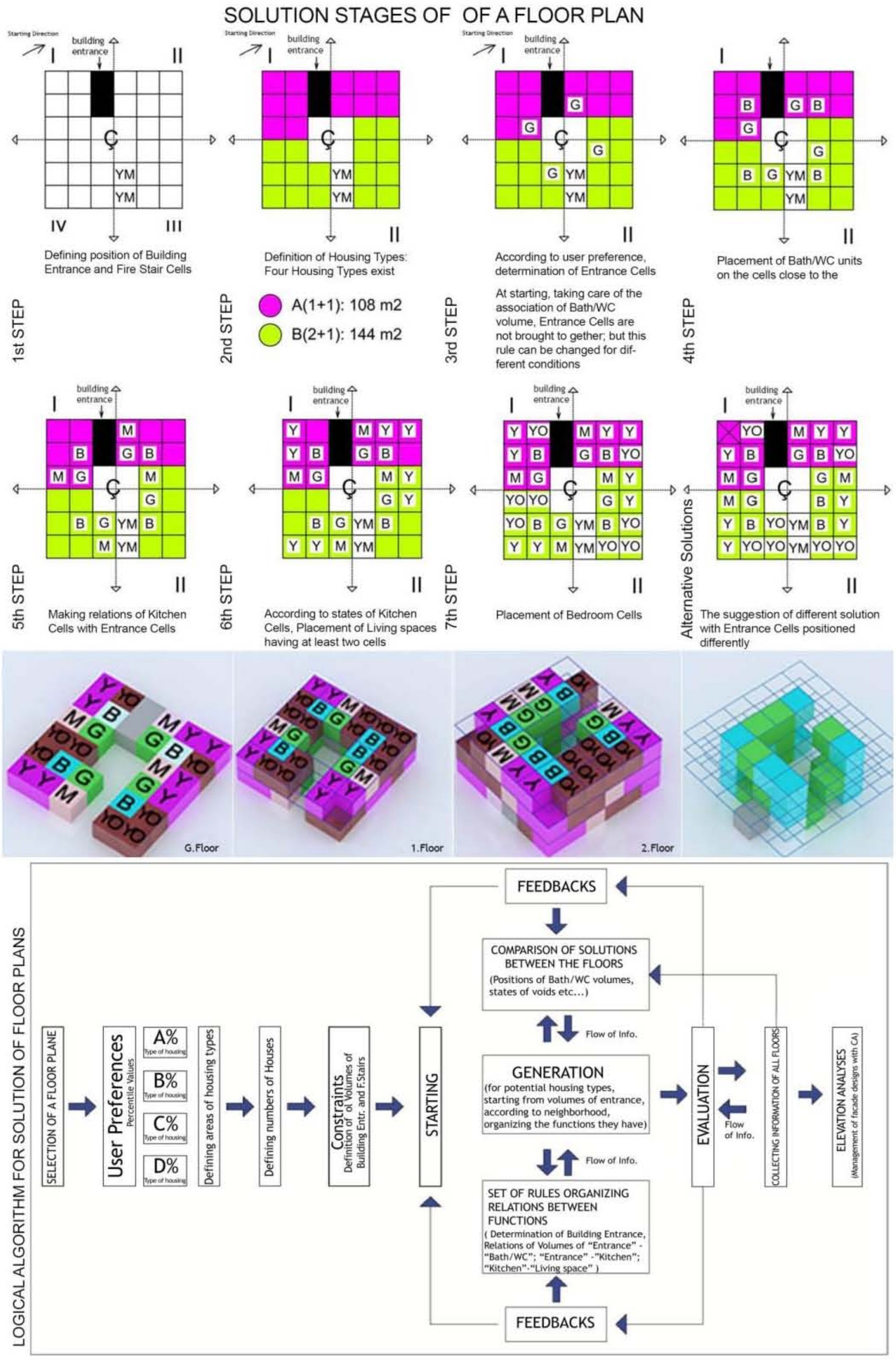


Figure 3. Solution stages and logical algorithm of a floor plan.

4. CONCLUSION

The basic findings and results which have been obtained from this ongoing study in the extent of PhD thesis together with the jury comments and individual evaluations so far are summarized as follows:
Firstly, it has been logically confirmed that the process of CA comprising relations of neighborhood has similarities with the framework where comprehension of open spaces can be organized flexibly by user preferences and does not depend on a form with its convenient structure. Accordingly, it is understood that CA can be adapted to this framework with designer' intermediate interventions during the process.
Secondly, when the suggestive scenario is completed, it is thought that the design process supported with CA is rather useful for considering the need of variety and uniqueness in terms of architectural logic; and the flexible functionality in terms of users' satisfaction. For, it is observed that integration of bottom-up structure of CA and emerging spaces with different user preferences is able to result in innovative and variable form generations, indispensable criteria for all design works.
Finally, owing to ill-defined structures of design problems, preparing changeable algorithms of CA for each stage repeatedly is usually seen as a compelling situation for these design models, but it is thought that this situation can also be an advantage as a technique evaluating all potentials having influences on the future of a design.

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