A Digital Tool for Customized Mass Housing Design

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Innovative design approaches are needed for mass housing implementations. Especially increasing interaction between user and designer is major important in the design decisions of these buildings. For this, it is seriously necessary to benefit from technological advances in computational designs, because digital tools like shape grammar, cellular automata, genetic algorithm, l-systems and agent-based models in this field provide not only to save time and to manage the relationships but also to generate many different alternatives. Accordingly, a digital support tool for designers has been developed by using cellular automata approach and scripts of 3Ds Max software. It produces samples of housing design plans which is generated by cellular automata approach according to the data of users' preferences. In this paper the interface and contributions of the developed model are introduced and discussed.

Keywords: Computational Design, Mass Customization, Innovative Housing Design, Plugin

INTRODUCTION

Housing is where users’ basic needs and different expectations are met and which has private meanings for each user. Mass housing is a large-scale and dynamic environment where both individual and collective requirements of many different users are met. However, mass housing productions which have been done so far do not fully reflect these properties of "housing" concept because of the reasons like mass production and standardization. Users’ participation has been ignored in the design process. Also, these productions have been emerged as ordinary and identical building samples. This condition has revealed a major problem in terms of both users’ satisfaction and urban aesthetic. So, even though it is in different forms, regarding user preferences is indispensable in housing designs.

Mass customization is a process which provides users’ participation and accelerates interaction of user-designer-producer (Url-1 2014). It includes products’ properties of breaking into components and subsystems with modularity and qualifications like users’ selection and method definition with configuration. Pine (1993) points out that its functionality depends on advanced technology applications like computer aided design, computer integrated manufacturing systems and other computer technologies. Accordingly, with the impact of developing digital technologies in architecture, use of mass customization has been started to increase recently. Mass customization which is used in different forms in architecture can be evaluated in four groups like collaborative, transparent, adaptive and cosmetic customization (Neimeijer et al. 2010). Al-
Figure 1
Neighborhood relations of Housing blocks in a site plan

Figure 2
Neighborhood relations of spatial units in a floor plan

Figure 3
An application of façade orientations on a sample of building model
though it is not preferred, adaptive customization among them is suitable for mass housing designs. In this model, the production is generally standardized, but users are given opportunity to make selection and modifications. This model has been evaluated in the scope of this study.

A digital tool which generates alternative housing plans and facade designs in housing blocks by evaluating user tendencies with cellular automata approach has been developed for mass housing implementations (Dincer 2014). Cellular automata (CA) are a set of cells which has emerged over time by the rules, which is related to local neighborhoods, on a particular grid system (Wolfram 2002). It is usually evaluated in the studies like urban design, zoning and building masses in which social effects can be simulated with neighborhood relations (Singh and Gu 2012).

The basic features of using Cellular Automata in architectural design can be listed as context-sensitive and bottom-up processes, self-organization, graphical representation, etc. Due to approach of "form follows function" and its local relationships, CA may generate many different, coherent and unexpected solutions in a short time. Although CA have negative features like autonomy and inability to manage increasing neighborhoods which depends on the size of context, nevertheless it can be considered to be adaptable to some stages of design (site and space planning, facade orientations etc.) by specific external interventions and feedbacks in smaller scales and to be useful.

In this model, the digital tool is aimed at serving as a decision-support model that is integrated with traditional design processes. Users can’t be directly involved in design process of floor plan schemes, but their tendencies determine which housing type will be designed. CA is evaluated to manage complex relationships of housing blocks, spatial units and facade elements with various design criteria and present many alternatives.

A HOUSING DESIGN MODEL WITH USING CELLULAR AUTOMATA

The developed model is based on interaction of Schön’s "Reflection in Action" approach, mass customization and computational design processes. With "Reflection in Action" approach it simulates stages of mass housing designs which consists of site plan placements, space planning for housing blocks and façade designs just as in traditional processes. Also it provides user/designer to be involved in decision-making processes of each stage. Clearly, the process of the model works in the form of "Framing-Evaluating-Reframing" in these stages as Schön (1985) defines. It evaluates user preferences, which effect on creation of housing types, in the space planning stage. Since the preferences are usually changeable for each space planning, each of the solutions may differ from the others and it is possible to get variety of solution which is quite difficult in traditional designs. Therefore it can be seen as a mass customization model, Cellular automata which are the computational component of the model manage relationships of housing blocks in a site plan, space units in space planning and façade orientations by using neighborhoods and architectural and urban constraints. The model uses both top-down and bottom-up processes.

The model uses Conway’s "Game of Life" (Adamatsky 2010) and Wolfram’s 2D CA experiences as samples of CA. The rules which organize neighborhood relations of both housing blocks in site planning and spatial units in space planning are similar to that of "Game of life" which includes the concepts like loneliness, overcrowded, stasis and reproduction. In site planning, the rules control proximity states of housing units with each other by legislative limitations or "shadow cone" (figure 1). In space planning, the rules are concerned with architectural topological relations among spatial units (figure 2). Furthermore in façade designs, whether spatial units have a cantilever or setback is defined by rules like Wolfram’s 2D CA rules (figure 3). The rules operate the state list of having a cantilever or setback which
is determined by its downstairs and lateral neighborhoods for a spatial unit. During the generation process creating, removing and continuity of housing blocks and spatial units or façade orientations of spatial units are determined by these rules.

All these rules have a feature of being altered or being supported by new rules according to designer’s decisions. The changes can be made on the algorithm instead of on interface directly.

The model is mainly configured on space planning in spite of having three stages. The other two stages are like a support module. The generated housing blocks determine boundaries of space planning in the stage of site planning as different alternatives of housing block placements are generated in this stage. On the other hand, it is aimed at increasing orientations in third dimension and differentiating form of the generated housing types in the stage of façade designs.

The process at the site plan stage starts with the location of a housing block which has a defined floor area and whose height can be changeable, within boundaries of a site. These settlements continue until reaching the value of the total construction area. In the generation, the neighborhood relations of blocks with the previous ones are evaluated after the first settlement. If there is no suitable situation in terms of the criteria, a selection between newly produced and existing building blocks can be made and one of them can be removed and new building blocks are located on the left empty spaces of the land.

Space planning stage includes solution processes of floor plans for each of the generated housing blocks in a chosen site plan. At this stage, because of that plan layouts are same in the blocks and have 24*24 m square form, the process is carried out similarly in all blocks. At the starting of the process, a chosen floor plan is made ready for generation by dividing into smaller core which is 8*8 m and 4*4 m in size for creating building grids and space units. Then sharing area on the floor plan is made for potential housing types which are determined by means of user preferences (figure 4).

Spatial units locate on the shared areas in the framework of their neighborhood relations and they try to define a housing type together. Housing types exemplified as A (1+1), B (2+1), C (3+1) and D (4+1)-double flat models which are determined by numbers of their bedrooms and area constraints. They exist on a floor plan when their minimum area constraints are met. Otherwise their area values are shared among the others.

On a floor plan, generation process starts with the random placements of “Entrance Hall” units in the shared housing type regions and these units trigger creation of other spatial units, which are kitchen, bathroom, bedroom and living room. Similarly each of created spatial units affects generation, transfor-
mation or deletion of further units. This process continues until reaching the criteria of selected housing types and filling in the blanks of the floor plan (figure 5). During the process, the spatial units which can’t meet the criteria of selected housing types are deleted. The empty units which are existed by removing the cells are re-evaluated with new spatial units in the generation of other or new housing types and the process is completed and repeated with different user preferences for other floor plans of a chosen block.

A few samples of neighborhood rules of spatial units, which are used in at this stage, can be given as follow:

- "Entrance hall" units which are generated at starting are placed on the floor plan in case they have a neighborhood with other spatial units except "entrance hall" units. Otherwise, these units are evaluated as "death" and removed.

- "Kitchen" units are usually placed opposite to "entrance hall" units. In some cases, for an example, these units can be created near to right or left of "entrance Hall" units for A(1+1) housing types.
• “Bathroom/WC” units are defined as a single-cell for same housing types. If they are more than one, the operation of removing or changing the function is applied for them.

• If a “bedroom” unit is neighbor with service core, a “void” unit or different “bedroom” unit is created opposite of it according to its state of neighborhood with service core.

• Similarly, if a “living room” unit is neighbor with service core, a different “living room” unit is created opposite of it according to its state of neighborhood with service core.

• If a “living room” unit has neighborhoods with more than two “living room” cells, they are evaluated as “death” and defined as a “terrace” space.

The algorithm of space planning is given in figure 6.

The stage of facade designs starts after solution of all floor plans for a housing block is completed. At this stage, the process progresses as bottom-up from ground floor plan to upper floor plans and controls spatial units on the facade are evaluated individually according to specific procedure. In this procedure, at first, spatial units are grouped according to its functional properties and these groups are ranked as living room, bedroom and kitchen spaces for priority of generation. Then each spatial unit in the groups is chosen randomly and their states of facade orientations are controlled. The controls are done by a set of basic facade rules and additional rules. In the set of rules, lateral and downstairs neighbors of a spatial unit are examined with regard to their states of having a cantilever or not. These states are represented with colors like “black” and “white” or numbers like “1” and “0”. Then the sequence of probabilities which these representations form by together are saved. Additional rules operate specific states of some spatial units and housing types due to their architectural requirements. For example, if a housing type has more than one “living room” units on the same facade, only one of them can have a cantilever, even though they are appropriate for a set of basic facade rules. The generation is made simultaneously on all facades of a block.

In the set of rules the option of randomness is partially applied. Besides the rules are organized in terms of solutions of preventing architectural detail errors, but these rules can be also developed by different architectural ideas. Finally, as explained before, facade orientations support the diversity by differentiating the created housing types dimensionally (figure 7).

At the end of the processes for each of three stages of the model, the results are evaluated and interpreted by designer and user. Depending on the results and evaluations operations are repeated. Furthermore the model generates primitive plan schemes which can be developed and detailed by designers. Also the structural frame which is chosen for the model allows flexible solutions and changes on these created schemes. Thus efficiencies of designers and users are protected.

THE INTERFACE OF THE MODEL

In the model, for the convenience of designers, a simplified data entry interface is designed with 3Ds Max software. On the interface, there are two rollouts which are called “Data of Zoning Status” and “Floor Plan Arrangements”.

Starting rollout is the implementation of “Data of Zoning Status” which allows the generation of housing blocks in a site plan. Firstly, on the rollout site dimensions are defined (figure 8). It is performed by the way of entering data for a sample of site which has rectangular or square geometries or selecting a sample of site which has non-uniform geometries. Also if it is necessary, definition of landscape direction is made. Then the heights (min/max values) of housing blocks and ratio for total construction area according to data of the chosen region are determined. If there is a slope in site or custom building heights for specific region of the site are necessary, slope and height values are defined for these regions. Finally a model
The algorithm of spatial planning stage

Selection of a flat for design

User Preferences

Determining areas of housing types

Determining the number of housing

Starting

Feedback

The rules organizing the relations among functions

Evaluation:
Do floor plans have the desirable qualities?

Yes

Collecting data of all flats

Have the solutions been generated for all flats?

Yes

Facade Design
Generation of flat cartilevers by CA

Terminate

GENERATION
For possible housing types, starting from entrance volume and applying the rules according to relations among functions, the generation of alternative floor schemes

Generating solution of a new flat
Figure 7
Implementation stages of facade generations

States of Spatial placements
- YO (Bedroom)
- M (Kitchen)
- G (Entrance)
- Y (Living room)
- B (Bathroom)
- D (Terrace)
- C (3+1)

States of Housing types
- A (1+1)
- B (2+1)

Placement of cantilevers on the facade

1st Step (Ground Floor)
2nd Step (First Floor)
3rd Step (Second Floor)
4th Step (Third Floor)
5th Step (Fourth Floor)
6th Step (Fifth Floor)
7th Step (Sixth Floor)
8th Step (Seventh Floor)
The interface and the implementation of the Site Planning stage

(shadow cone or legislative limitations) of relationships among housing blocks is chosen for their placements. Optionally, definition of a social area can also be made by entering its dimensions in the site (figure 8).

After operation of data entry is completed, the generation process is started. The results are demonstrated on the main screen of 3Ds Max software. If results are acceptable then they are saved and second implementation is passed for space planning of all generated blocks, else the process is repeated by user/designer until desirable generations are obtained.

Another rollout is the implementation of "Floor Plan Arrangements" which allows the generation of space planning and façade generations for housing blocks. In this stage selection of a housing block which is generated in the site planning is made and creation process of floor plans on the selected housing block is started by user/designer. Then, any one of the created plans is chosen by using "forward" and "back" buttons on the interface. There is no ranking for selection among the floors and the generation processes can be started from any floor. After that, values of the preferences which potential inhabitants made for one of A(1+1), B(2+1) and C(3+1) housing types on the selected floor plan are entered. Also, a prioritization and starting direction among the housing types is determined for starting placement and sharing area on the floor plan. Finally all data is saved and the generation process is started. If the results are acceptable, this procedure is similarly repeated for solutions of the other floor plans according to different user preferences (figure 9).

Another implementation on the rollout is façade designs which concerned with creating cantilevers or setbacks on the façades of the selected block. After solutions of all the floor plans are completed, the module of façade designs is activated. After one of "simple" and "orientation" modes is chosen the generation is started and results are evaluated.

For space planning, the model is supported by additional modules like labeling spatial units, detailing the core, demonstrating "housing type" mode or "spatial units" mode and showing or hiding all floor appearances. All these modules are considered to make the model easier and more understandable.
Figure 9
The interface and the implementation of the Space Planning stage

Figure 10
Practical experiences in the chosen site in Karabuk.
RESULTS
In this study; mass housing design model, which provides integration of mass customization, traditional and computational design processes, is developed. This model is thought to be useful as a design-decision tool which generates alternative housing plans by using the rules, which is determined and changed by designer, according to inhabitants’ tendencies. The applicability of the model has been tested successfully in a site which is located in Karabuk in Turkey by different user scenarios and local legislative constraints. As a result, many useful alternatives have been obtained (figure 10). Furthermore, the stage of space planning in the model is operated in a specific (square) floor plan framework, but the rules and relationships in this stage can be evaluated for other plan schemes in different forms (e.g. horizontally expandable forms). In addition, the content of the model has an extensive feature by increasing the rules and relationships among space units in the model. It is considered that future works can be done in this direction. Finally CA rules have made quite useful contributions about generation of rich alternatives in spite of the excess of the rules. Both adapting CA rules to architectural context instead of classical approaches and using criteria of randomness have been effective on this diversity of alternatives. The graphical representation feature of CA has been helpful and useful in accelerating decision-making processes and interpretations.

REFERENCES