ARCHITECTURAL SPACE PLANNING USING PARAMETRIC MODELING

Egyptian National Housing Project

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Abstract. The Egyptian government resorts to prototype housing for low-income citizens to meet the growing demand of the housing market. The problem with the prototype is that it does not meet specific needs. Consequently, users make modifications to the prototype without professional intervention because of the high cost. This paper discusses an automatic multi-stories space planning tool that helps low-income citizens to modify their prototype housing provided by the government. Social, spatial and functional design aspects were set in the original design prototype by an architect. The proposed tool simulates spaces spatial locations in the original design by simulating the analogy of mechanical springs through an interactive simulation of a parametric model. The authors developed the used algorithm in the generative design tool Grasshopper and the live physics engine Kangaroo, both working within the Rhino 3D environment. The algorithm has two versions, one-floor level version and two floors version targeting the wealthier users. Results indicate that this tool integrates with the exploratory nature of the design process even for non-professional users. The authors designed a tool that will help the users to study the effect of the desired modifications against the originally provided prototype, it also makes it easier for users to express their requirements to a professional designer, conserving time and financial cost.

1. Introduction

The Egyptian government resorts to prototype housing to meet the growing demand of the housing market. In recent years, the government launched the National Housing Project (NHP) for the low-income citizens by providing small land plots and limited financial support for the users to build their
homes through a provided prototype designs. The problem with the prototype is that it is inadequate for everyone's needs.

This paper discusses an automatic multi-stories space planning tool that helps low-income citizens to modify their prototype housing provided by the government. Social, spatial and functional design aspects were set in the original design prototype by an architect. The tool introduces an algorithm that simulates the analogy of mechanical springs through an interactive simulation of a parametric model. The role of spring forces is to solve proximity relations between spaces after users’ modifications.

This paper is trying to explore some of the undiscovered areas regarding the validity of physically based space planning theories in multi-stories and exploring related design objectives through a design tool used by normal users.

2. Background

The problem of architectural space planning is a *wicked* problem (Rittel & Webber, 1973). The problem is concerned with the allocation of a set of space elements according to certain design criteria (Wong & Chan, 2009). Others describe such problem as an unsolved problem in computer science (NP) (Gero & Kazakov, 1998). To date, there are no known algorithms for this problem (Jun *et al.*, 1998). However, for architectural space planning problem, we may not be looking for an optimal but feasible solution based on varied parameters.

Per Galle had describe an algorithm which generates all possible rectangular plans on modular grids with congruent cells, subject to constraints (Galle, 1981). Another genetic algorithms concept is grouping activities together and optimally placing these groups at the first stage of the computation. At a second stage, the algorithm is optimally placing activities within these groups (Gero & Kazakov, 1998). Another attempt is a design method based on constructing an evolutionary design model borrowed from nature genetic. (Jun *et al.*, 1998).

Weinzapfel and Handel describe an approach to automated space planning in which a design problem consists of a set of spaces and a set of relationships describing constraints on the spaces (1975). Software Environment to Support Early Phases in Building Design (SEED) is addressing architectural programming, schematic layout design, and the generation of a fully three-dimensional configuration of physical building components (Flemming & Woodbury, 1995; Flemming & Chien, 1995). Grason, designed an experimental computer program called GRAPH Manipulating PACKAge (GRAMPA) (Grason, 1971). Then, Mitchell developed the system by setting rectangular rooms arranged within a simple
rectangular overall plan shape (Steadman and Liggett with W. J. Mitchell, 1976). Roth presents a systematic method for the design of a floor plan when given the list of cells data (Roth et al., 1982). Later, Roth developed the Rectangular Dimensioned Plan (RDP) model (Roth et al., 1985) which Flemming suggest. In 1978, Flemming described a procedure which generates dissections of rectangles into rectangular components which are restricted through topological and dimensional constraints (Flemming, 1978). Later, he developed the system to include loosely rectangles (Flemming, 1986).

Physically-based space planning is a means to automate the conceptual design process by applying the physics of motion to space plan elements. Baraff uses that method to model the realistic behavior of rigid bodies in resting (non-colliding) contact (Baraff, 1989) and building objects by dynamic constraints (Barzel & Barr, 1988).

The current paper is a contraption for Arvin & House work. They applied the mechanical metaphor technique to the generation of architectural floor plans by using the analogy of mechanical springs and dampers to model a variety of design objectives (Arvin & House, 2002).

3. Problem

The Egyptian government launched the NHP to meet the growing demand of the housing market. The low-income users receive land plot with prototype design and direct financial support to build their own homes. The problem with the prototype is the lack of user participation in the design stage. Consequently, the prototype design does not fit into everyone's needs. Users make modifications to the prototype design without professional intervention because of the high cost and limited time allowed for construction. This paper proposes an automatic interactive space-planning tool that helps low-income citizens to modify their prototype design within social and human aspects set in the original design by an architect.

3.1. ORIGINAL DESIGN

The landform in NHP is an almost identical rectangular shape 8.60 m wide and 17.50 m long. The total area is 150.50 m² and the allowed built up area is 75m². The unit consists of a staircase, entrance, two bedrooms, terrace, kitchen, bathroom, reception, and dining (Figure 1).
4. Methodology

The theoretical approach that authors use is the simulation of the analogy of mechanical springs and boxes collision to reorganize and amend architectural spaces proximity.

The authors developed the algorithm in the generative design tool Grasshopper and the live physics engine Kangaroo, both working within the Rhino 3D environment. Users use the spreadsheet interface to set out design parameters. Simulation then goes in two steps. Evaluation messages will help the users to evaluate results. If results are not accepted, users can manipulate design parameters or generate alternatives. There are two versions of the tool for one and two levels.

5. Usability

The usability test aims to evaluate the proposed tool by targeted NHP users. The goal is to identify any usability problem, collect qualitative and quantitative data and assess the participant's satisfaction.

Due to project eligibility terms, all users have almost the same age, marital status (married) and income. Volunteers were randomly selected through an announcement on social network sites and users’ coalitions. The announcement was clearly stating all requirements, conditions and a brief description of the tool.

5.1. INPUTS

The tool interface allows users to control design parameters and provide illustrative tools like coloring spaces, floor area, spaces information chart, and evaluation system. Users can do the following: add or delete spaces, set
spaces proximity, set external design objectives, spaces dimensions, each floor setbacks, each floor height, generating alternatives, specify the allowed difference ratio for space dimensions.

The input interface is coded to keep users’ modifications within building code. Modifications appear instantly on the software screen as a 3D colored models with dynamic dimensions (Figure 2).

5.2. SIMULATION

The simulation goes mainly in two steps. Step one achieves topological objectives which determine how each space relates to another. Step two solves the geometrical objectives which are responsible for the orthogonal aggregation.

5.2.1. Topological design objectives

Users start first simulation step from the interface (Figure 2:5). The first step uses ‘spring force’ mechanical simulation to solve the space proximity relations which influences the location of individual spaces and affects how one space relates to another. The physics engine Kangaroo simulates the spring force physics. It represents the logical relations among spaces as forces that operate on point nodes at the center of each space. It also controls the response to external objectives like street location and preferred orientation. The authors divided the spring forces into groups to achieve the hierarchy in the desired space relations.

The stair is starts in the first level and is represented as a space connected to other spaces. Then, the core is extruded as one mass and the upper part is connected by forces to the spaces on the second level. The core position is thus affected at both levels.
In a hidden step, spaces are simulated as spheres to allow sliding over each other. The sphere size depends on the desired space volume by set users (Figure 3:a and b). The resulting spheres from the first simulation are converted into boxes based on each sphere volume and center (Figure 3:c).

![Figure 3. The simulation process: a) The initial position of spaces showing volumes and springs action directions. b) Spaces behavior under spring forces. c) First simulation result. d) Second simulation result.]

5.2.2. Geometrical Design Objectives
When the system stabilizes, users can start the second simulation step from the interface (Figure 2:6). The second step uses 'box-collide force' simulation by another Kangaroo engine to solve the orthogonal aggregation for these 3D masses which influences dimensions and volume of space boundaries. The concept behind this step is using the analogy of masses collision to fill the in-between gaps by adopting both dimensions and volume of masses depending on the collision strength and setting to achieve the most possible compacted shape. The result of step two is orthogonal compacted spaces (Figure 3:d).

5.3. EVALUATION AND ALTERNATIVES
After step two is completed, users use the design evaluation section in the interface to help in evaluating the resulting solution (Figure 2:7). If the solution is accepted, users end the process and print the solution. If not, users can manipulate inputs and redo the process or else generate another alternative because results are affected by the spaces initial position. Randomizing space arrangement before simulation generates a new solution every time (Figure 2:3).

The evaluation system evaluates both spaces proximity relations and the allowed space dimension tolerance through interactive messages. If users try...
to run an inappropriate simulation step, the system will send warning messages to guide them.

6. Results and Discussion

The majority of users were interested in adding one more room in both versions. More than half of the users reach a complete solution (Figure 4:a and i) or complete solutions with comments such as wet areas without natural ventilation (Figure 4:b and h).

Some spaces were not logically placed or not accessible (Figure 4: c, d, e and g). Other spaces were deformed due to the conflict between required spaces dimensions and logical relations (Figure 4:f and c). In some results, solutions were loose and not compacted in setback because of inappropriate results from step one (Figure 4:b, c, d and f). Switching width and length were useful in improving solutions that require elongation (for example see the kitchen in) (Figure 4:c).

![Four sets of diagrams representing results samples.](image_url)
NHP users show a high technical level in construction and good architectural background. The most raised question from users about typical floors is the coordination between the existing structural columns in the ground floor and the new design in typical floors. The on-screen interactive results and 3D dynamic spaces are widely acclaimed by users.

Users feel confused while setting spaces proximity and determining spaces hierarchy, they mostly use the first-degree relation only. Another technical problem is understanding the need for transitional spaces. For instance, entrance in the original design act as a lobby for the two bedrooms Figure 1, but when some users add an extra room that will require a new lobby as a transitional space to access rooms.

Users’ survey show that the tool is easy to learn and easy to use. Learning curve increases after repeated usage. Users commented on the evaluation messages ‘it's useful to determine the problem, but it is not suggestion a solution’. Users find the final product is much better than traditional architectural drawings Table 1.

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Completely disagree</th>
<th>Completely Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tool demonstration was adequate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>It’s easy to learn how to use the tool.</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>I am easily able to perform the required tasks.</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>UI convenient and easy to use.</td>
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<tr>
<td>5</td>
<td>I totally understand all UI components.</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>I need help in the first time I use the tool.</td>
<td></td>
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<tr>
<td>7</td>
<td>I can deal with all raised problems.</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>Evaluation system is helpful.</td>
<td></td>
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<tr>
<td>9</td>
<td>Tool has all I need to modify my unit design.</td>
<td></td>
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<tr>
<td>10</td>
<td>The tool is sufficient for the initial concept.</td>
<td></td>
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<tr>
<td>11</td>
<td>Final product presentation is better than traditional.</td>
<td></td>
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<tr>
<td>12</td>
<td>I am satisfied with the final product.</td>
<td></td>
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<tr>
<td>13</td>
<td>In general, I am satisfied with the tool.</td>
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</table>

7. Conclusion

According to users, the tool is easy to use and functionally working, but they find problems with the final product and design process. The users can take direct design decisions, but cannot take design advanced decisions or setting spaces proximity to achieve relations hierarchy. Normal users get a deeper
understanding of the design process and the conflicting nature of design objectives without engaging in the underlying system. The proposed tool is not replacing the architect but helping users to assess the impact of their proposed modifications conserving time and financial cost.

The current paper showed that the physically-based space planning approach is working with multi-level design. The authors explored a new design objective as a result of multi-levels which is the attraction to the vertical core.

References


