Customised Collaborative Urban Design

A Collective User-based Urban Information System through Gaming

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As we step into a new data-based information age, it is important to get citizens involved in the whole design process. Our research tries to build up a user-based urban information system by collecting the data of neighborhood land use preference from all the residents through gaming. The result of each individual decision will be displayed in real time using Augmented Reality technology, while the collective decision dataset will be stored, analyzed and learnt by computer, forming an optimal layout that meets the highest demand of the community. A pre-experiment has been conducted in a. an abstract virtual site and b. an existing site by collecting opinions from 122 participants, which shows that the system works well as a new method for collaborative design. This system has the potential to be applied both in realistic planning processes, as a negotiation toolkit, and in virtual urban forming, in the case of computer games or space colonization.

Keywords: Collaborative Design, Customization, Urban Design, Gaming, Information System

INTRODUCTION

As part of everyday life, each citizen has his own judgment of the spatial environment he or she lives in. Since the profession of architects began to exist, the citizens have long been living in the urban structure that is designed and given by the professionals, having limited means to make decision or change themselves. Meanwhile there are several semantic differentials between the designers and the users, causing great conflicts and misunderstandings which can lead to further urban issues. As several researchers (Stamps A et al. 2005; Cubukcu E et al. 2007; Bai N et al. 2017) argued, architects and users have different spatial judgment throughout the urban contexts. Gifford R et al. (2002) used the lens model in environment perception process to systematically identify the differences of cognitive properties judged by the two groups, suggesting that though great differences exist, the architects and laypersons could still understand each other better by negotiation.
As we are believed to be in the 4th industrial revolution, which approaches the information age, it is getting more and more important to get the customers involved earlier in the whole production line of the industry, to have the products meet the maximum demand of all the users along the process, fulfilling the concept of Mass-customization as suggested by Du-ray R et al. (2000). As Bunschoten R (2017a) suggests, the same situation goes for the architecture and urban design industry.

This research focuses on the aspect of how to get citizens involved in the decision process of city making. We create a system which can collect the preference data of each user in a certain urban area through interactive gaming. Then the information is processed by computer, making a self-adapting urban layout that performs the optimal satisfaction among the citizens.

PREVIOUS STUDIES

Collaborative Urban Design
As reviewed by Vardouli T (2013), the very early prototypes for computer-aided collaborative design came from the French architect, Yona Friedman in 1960s and the MIT Architecture Machine Groups in 1970s. As a Utopia mind-experiments in the middle 20th Century, Spatial City was famous for the idea of mobile architecture and mega-construction. However, the most important thing that differed Yona Friedman from his followers like Archigram was his strong concern in social participation. Using so-called spatial dictionary of Flat writer, the users themselves could make every decision related to the building he or she is going to live in followed by several professional advices or warnings from the architects. Ten years later, Negroponte N (1975) from the Architecture Machine Group followed the idea of Friedman and created a more adaptive procedure for collaborative house planning, so-called Soft Architecture Machines. As Vardouli pointed out, the idea of performing an architecture which is totally interactivity produced and unpredictable fell “victims to a modernist impulse” in their time, but offered a potential in participatory design computation, when “user-centric design and collective authorship comes back to the architectural actuality” (Vardouli T 2013).

Besides the highly developed regions as France and US, Chile, as a developing country, also contributed to the development of democracy within urban policy process, with the projects of Cybersyn and Cyberfolk in early 1970s, as reviewed by Espejo R (2017). The Utopian idea of democratic governance developed by Stafford Beer intended to set a world of conversation spaces which balance the information in real time. The Cybersyn proposed to have the “measurement of the complexity of interactions”, meanwhile the Cyberfolk focused on the “interactions between citizens and politicians”.

Collaborative decision making in urban design went on through the gaming methodology. As Mayer IS et al. (2005) suggested, during the urban renewal process, gaming procedure could help create a shared understanding among different groups. The Conscious City Lab in TU Berlin has been working on an urban design negotiation game (Bunschoten R 2017a; 2017b), named Urban Gallery. The gaming process mainly consists of simple cards within four categories, namely action plan, stakeholders, prototypes and the database of necessary knowledge. By having players sitting around a table, playing in turns, the urban development process is being negotiated. Meanwhile the process is being displayed on a projector, creating feedback loops for the players. The Urban Gallery intends to integrate all stakeholders in the design process through negotiation. Our approach, following the Urban Gallery methodology, intends to expand on the stakeholder level within the game and add later analyzing and learning process. It can be regarded as a DLC (Downloadable Content) for the game.

Interactive Urban Modeling
With the help of computation, both the digitalization of existing urban environment and the visualization of future urban context have been made achievable, allowing interactive modeling with in-time feedback
(Batty M et al., 2000).

Speaking only in the context of urban modeling for non-existing environment, which is the case for planning new cities from scratch, studying intrinsic logic in urban graphics and building world in computer games, the method for creating urban morphology could be classified into two main categories - example-based or self-generated. The former is the method of learning from the existing cities, analyzing the spatial syntax of the urban environment, building a supervised geometrical algorithm or even sometimes behavioral algorithm, and initially generating the layout of machine learning (Aliaga D et al. 2008; Vanegas CA et al. 2009). The latter, on the other hand, gives more freedom to the participants in urban environment structure generating. Some researchers’ projects (Chen G et al. 2008; Esch G et al. 2007) allow the participants to draw an underlying tensor field with flows representing the structure of streets, which would be later applied for street network generation. Either regular patterns as grid networks and radical networks, or mutations and variations like randomly-oriented streets, slight curves, dead-end roads, and other irregularities could be added interactively. Some other researchers (Lipp M et al. 2011) have been working on an even more user-friendly interface for street adjusting and block generating.

In either category, the steps of street generating in 2D maps works always more reasonable and rational than the following steps of functional clustering and height generating. The procedure of making the maps from 2D to 3D is skipped and directly given the results (Chen G et al. 2008), based on clustering with k-means algorithm by setting functional centroids around the urban context resulting a city with isolated functional areas (Siva PB et al. 2015), or relied on complex simulation algorithm in land use, setting coherences and conflicts between the local and global goals (Weber B et al. 2009). None of the studies mentioned above really takes the opinion of citizens into consideration, still making an empirical professional model in the end, regardless of the need for mass-customization.

Besides the computational approach, land use pattern in existing urban environment has been studied through, yet without a certain conclusion. Different countries have their own land use master plan, giving various proportions to each function. The trial to build up the model for optimal distribution of urban land also proved to be rather complicated (Rossi-Hansberg E 2004).

Our approach is to collect the opinions of land-users, trying to build up a collective information system which can be applied to the urban modeling done by previous and future researchers. Since the street network can be easily adjusted in the first steps of urban modeling as mentioned above, we decide to test our method in a pre-experiment within two phases, first in a more generalized and abstract virtual grided street prototype, and then in one realistic site in the city of Berlin. The data collected and the result of analyze would be helpful in future on-site practice.

**METHOD**

**Dataflow and Working Process**

The collective information system bases on a gridded typology as abstraction of the real world. The site proposed for opinion collection would first be projected and transformed into squares. Then, given the city context, participants from all around the site will be asked to arrange their ideal functional layout on the site by using paper cards. In a game like environment, the arrangement of all the functions in the blocks would be then displayed spontaneously with Augmented Reality technology.

After several rounds of the board game, the computer will have collected the data of functional preference of each participant, through certain analysis and learning process, the computer then gets an integrated optimal city model showing the collective result, which would also be displayed as feedback for later participants.

The whole process is shown in figure 1.
**Process of Gaming**

The interactive board game would be carried out on a touch table with a grid showing the map with urban context, which corresponds to the actual site. Except for the experimental sites, the functions of the neighborhoods will be shown in advance on board.

Before starting the game, all the participants would receive a certain number of papers marked with nine different city functions, such as residential, educational, commercial, greenery, etc. While deciding the functional arrangement of the site, the participants should take the surroundings into consideration and then define the functions for each square by posing paper cards on the table grid.

While participants are making choices, the computer would read the QR code on each paper card. By applying the Augmented Reality technology through Unity, the choice of participants would be displayed spontaneously with the preset 3D virtual buildings of each function, making an interactive feedback loop during gaming.

The result of each participant during the gaming process would be recorded, analyzed, and learnt by the computer, which at the same time would conduct an optimal urban layout, meeting the maximum requirement of all the participants. The result would also be shown aside in the gaming process. The extent of changes caused by the choices of individuals would be adjustable with a coefficient balancing the controversies, which functions as another layer of feedback to the participants.

**Pre-experiment for default Database**

The method is at this point first tested with a pre-experiment based on online questionnaires. 129 participants involved in the experiment, 7 of them deleted since their reaction time fell shorter than 100s which is far behind the average of 342.8s, leaving 122 valid questionnaires. The average age is 25.20±5.49. The ratio of participants’ gender is 58 to 64, with slightly more females. 62 of the participants have received architecture education before, while 60 have not.

The experiment includes two phases, with a. a virtual situation and b. an existing site, respectively. The first phase asks the participants to fill in eight blanks in a 3×3 grid with nine urban functions, namely greenery, sport, residential, educational, commercial, industrial, healthcare, cultural, and religious facilities. The participants are told that they can decide their neighborhood on Mars in year 2218 as part of the colonization program. The only
The abstract forms of urban environment, which is an existing site in Lichtenberg, east Berlin, in the second phase of the experiment. The red dots indicate the residential area of the participants. The white blocks with numbers show the areas needed for decision by the participants with different functions.

Restriction of the surrounding is their own residential area in the northwest corner of the grid. The second phase also have eight blanks with the same nine possible functions, while the blanks are several empty or occupied blocks in an existing site in east Berlin, making a 9×9 projected grid with most of the blocks having their functions already. One of the central block is also taken as the residence of the participants. The interface of the second phase of experiment is shown in Figure 2.

The first phase of the experiment within the virtual situation functions as the training dataset, while the second phase as testing dataset. Both phases of the experiment will be analyzed based on the Manhattan distance system using SPSS 20.0. Functions distributions in different districts would be analyzed using Chi-square test and paired t-test, generating a ranking within the functions. The strength of the connections between each pair of the functions would be counted and weighed using the co-existence of functions in adjacent blocks. With the ranking information, the strengths of connections, and the actual choices made by participants, an eigenfunction judging the satisfaction of participants could finally generate the initial optimal layout with the collective dataset.

RESULTS

Overall Differences

Chi-square test is made through all the 16 blocks (8 virtual and 8 realistic) with the 9 functions selected. All the blocks except for the 5th and 7th in virtual situation and the 8th in realistic situation have a significant $X^2$ model with $p < 0.001$ and none of the units have an expectation frequency smaller than 5, suggesting that the distribution of functions in each block significantly varies. The $X^2$ and $p$ values are shown in Table 1.

Gender and educational background are used
as grouping variables within \( X^2 \) tests, none of the model is significant, with \( p \) all larger than 0.05, suggesting that the choices are made similarly within different genders and educational backgrounds.

The result supports the later analysis within different blocks and functions.

**Function Rankings in each Distance**

Within each of the four different Manhattan distances from the given residential block, there are different numbers of blocks. For each distance, similar statistical analysis process is taken. The numbers of nine different functions chosen in a certain distance by each participant is counted. Paired t-Test is tested within each pair of the nine functions, forming a matrix of average differences and \( p \) values for each pair of the comparison. Hierarchies could be recognized through the result of t-test and the average value of each function. As shown in figure 3, different functions distribute variously in different distances, the most popular function within distance of one is greenery, meanwhile within distance of four industrial and religious.

The different function rankings contribute as the first layer of weighed collective information.

**Strengths of functional Connections**

In the results of the first phase of experiment, the relationship of each pair of functions is another important factor. The researchers calculate the coexistence of functions in every pair of adjacent blocks, rearrange the result into the form of possible connections within each single function, and use Chi-square test to see the variance of distribution. The \( X^2 \) models of the entity and of every single function except for religious are all significant, with \( p < 0.05 \), as shown in Table 2, suggesting that the relationship of each pair of functions differs from each other. The strengths of connection between each pair of functions are shown in Figure 4.

![Figure 3](image)

Function distributions in different distances

![Figure 4](image)

The strengths of functional connection contribute as the second layer of weighed information.

<table>
<thead>
<tr>
<th></th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
<th>Block 5</th>
<th>Block 6</th>
<th>Block 7</th>
<th>Block 8</th>
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</thead>
<tbody>
<tr>
<td>virtual ( \chi^2 )</td>
<td>88.541**</td>
<td>31.295**</td>
<td>43.902**</td>
<td>64.754**</td>
<td>13.000</td>
<td>26.869**</td>
<td>9.754</td>
<td>141.803**</td>
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<tr>
<td>( p )</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.001</td>
<td>.001</td>
<td>.283</td>
<td>.000</td>
</tr>
<tr>
<td>realistic ( \chi^2 )</td>
<td>87.066**</td>
<td>28.197**</td>
<td>27.459**</td>
<td>61.836**</td>
<td>112.295**</td>
<td>50.918**</td>
<td>63.607**</td>
<td>11.967</td>
</tr>
<tr>
<td>( p )</td>
<td>.000</td>
<td>.000</td>
<td>.001</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.153</td>
</tr>
</tbody>
</table>

**Table 1**
The result of Chi-square tests

\( ** p<0.001 \)
**Eigenfunction and Trade-off**

With the first two layers of data as discussed above and the third layer given by the actual selection in the second phase of experiment, we generate an eigenfunction for the optimal layout which meet the most requirements by combining the three layers of collective information, using the realistic site as demonstration.

For the blocks where all the adjacent surroundings are preset with certain functions, the possibility of initial function in the block follows the eigenfunctions below:

\[
p_i = d_i \cdot \sum_{j=1}^{4} \sum_{k=1}^{9} (n_{jk} \cdot c_{ki}) \cdot t_i^2, \quad q_i = \frac{p_i}{\sum_{i=1}^{9} p_i}
\]

(1)

In the eigenfunction, \(q_i\) means the possibility of each function in the block, \(p_i\) means the existence value of that function, \(d_i\) means the weight of that function in certain distance from the residential block of the participant, \(n_{jk}\) means the logistic existence of each function in each of the adjacent blocks, \(c_{ki}\) means the connection strength of the pair of functions in center and adjacent blocks, \(t_i\) means the actual percentage of choice for each function.

For the situation when un-built blocks stand adjacent to each other, similar eigenfunctions are listed for both sides and solved by certain rounds of iterations until the result of both blocks are convergent.

The initial result of the possibilities of each function in all the blocks are shown in Figure 5.

After the system is stabilized using the methods above, any real-time acquisition from a new participant can be adjusted into the system by setting the Important Coefficient \(l\) in the trade-off function below, where \(t_{i0}\) means the real-time choice from the new participants for each block.

\[
F_i(X) = q_i(X) + t_{i0}l
\]

(2)

The higher the value \(l\) has, the more important the status of the new participant represents, the more significant his or her choice will affect the collective result, the more likely the real-time layout will show the new choice rather than the collective choice, vice versa. The different layouts with a changing \(l\) is shown in Figure 6.

**Display and Demonstration**

With the information of selection from the participants and the connections of possible functions, the researchers also conduct a physical prototype as an interactive display of the dataflow. As Figure 7 shows, the blocks of given functions are painted specifically in different colors, while the blocks included in the gaming process are filled with numerous sticks, the color of which corresponds to its function, and the quantity of which represents the possibility of the function. Strings connect the centroid sticks with the adjacent blocks, expressing the strengths of connections within the functions. At certain states during the gaming process, the model would be rather stable, demonstrating the collective opinions of participants. However, as the gaming goes on, this prototype might as well change correspondingly.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The result of Chi-square tests of connections within each function</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Entity</td>
</tr>
<tr>
<td>(\chi^2)</td>
<td>627.795</td>
</tr>
<tr>
<td>df</td>
<td>41</td>
</tr>
<tr>
<td>(p)</td>
<td>.000</td>
</tr>
</tbody>
</table>
DISCUSSION
The conducted pre-experiment has led us to several results that are worth mentioning.

The default information system based on the first phase of choices shows the similar collective preference for urban functions in the neighborhood, regardless of gender, race, and even whether receiving architecture education or not. While urban planning is a professional job which can only be done through training, the perception of space and the preference for land use does not differ greatly. Our research shows that when thinking about the life and limited urban space, there is no significant difference for decision making. Everyone likes to live near the greenery and be convenient to buy daily retail nearby, but how to make the balance when different interests are at stake is what urban designers must think about. Our findings support the reliability of collaborative design, meanwhile still call for trade-off control by professionals.

The recent layout of the collective decision making is through online questionnaires from 122 unrelated participants, yet still correlates to the realistic situation. The distance factor $d_i$, connection factor...
and the actual choice $t_i$ have significant correlation with each other, while the collective result from eigenfunction also has strong relationship with some existing actual functions in certain blocks.

Our result gives the grade of each function in every block in the form of percentage, which could be interpreted differently in practice. If the block is pre-decided to be monofunctional, then the percentage shows the possibility of making final decision to have that function on board. However, if the block would be multifunctional, then the percentage can also work as reference to the proportion of functions in the planning phase.

As the research was part of a one semester project, further steps have been identified. First, though producing the entire system of data collection through interactive gaming, our recent result still comes from online questionnaires which has little to do with the actual gaming process. The research agenda will focus on how the result would change if all participants can really see the urban layout of their choices and the collective trade-off layout spontaneously. With changing $l$, the strength of weight varies, leading to different feelings of control while making decisions. How strong would the influence of existing collective result be to the participant in the decision-making process is also worth thinking about. Another issue is the source and quantity of participants, which is recently mainly hundreds of young Chinese participants. What would happen if the participants are actually all the residents for the testing site? Will there be different for the results from the local residents, the unrelated participants and the decision makers in the government?

**CONCLUSION**

This research project focused on developing an information collection system for collaborative urban design through interactive gaming. With a pre-experiment testing the system in both a virtual site and an existing one. The result of the experiment shows that the system can generate an understandable collective urban layout. This system has the potential to be applied in planning processes, as a negotiation toolkit, since it considers the opinion of each participant in the decision-making process and tries to meet the maximum demand. It can also be applied in virtual urban forming, in the case of computer games or future space colonization, by generating programmatic suggestions supported by a database containing the proportion, distribution and connection of different urban functions. With the help of information revolution, the future for collaborative urban design could be gradually realized. Our research could work as a stepping stone.

**ACKNOWLEDGEMENT**

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