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SCULPTING THE SPACE: A CIRCULATION BASED APPROACH TO GENERATIVE DESIGN IN A MULTI-AGENT SYSTEM

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Abstract. This paper discusses an MAS (multi-agent system) based approach to generating architectural spaces that afford better modes of human movement. To achieve this, a pedestrian simulation is carried out to record the data with regard to human spatial experience during the walking process. Unlike common practices of performance oriented generation where final results are achieved through cycles of simulation and comparison, what we propose here is to let human's movement exert direct influence on space. We made this possible by asking "humans" to project simulation data on architectural surroundings, and thus cause the layout to change for the purpose of affording what we designate as good spatial experiences. A generation experiment of an exhibition space is implemented to explore this approach, in which tentative rules of such spatial manipulation are proposed and tested through space syntax analyse. As the results suggested, by looking at spatial layouts through a lens of human behaviour, this projection-and-generation method provides some insight into space qualities that other methods could not have offered.

Keywords. Performance oriented generative design; projection; multi-agent system; pedestrian simulation; space syntax.

1. Introduction

Although it has been long since generative approaches were introduced into architectural design, performance-oriented generations are far less mature than their form-oriented counterparts. One of their major hampers is the gap between performance evaluations and generation rules. Usually, evaluations are based on a simulation, which is itself based on a given space. This means that evaluation results, being hindsight feedbacks, give no direct instructions on how space can be improved. That is why performance improvement is usually, in fact, accomplished by a trial-and-error (not generated) method.

Previous studies have made successful forays into the potential to generate spaces that "perform" well in terms of circulation. One impressive result was the ecological approach (Turner et al, 2004), where changes of the space are controlled by genetic algorithm (GA): qualities of randomly created spaces are either preserved or abandoned depending on how well they allow agents' circulation to conform to certain criteria of good spatial experience. This way, the space gradually evolves to become circulation-friendly.

However, there is one problem: the use of GA may help to generate satisfactory end results, but at the cost of missing out the detailed mechanism of space-behaviour relationship. GA is itself a trial-and-error method.

To cope with this problem, we try to synchronize simulation and generation: while simulating, "humans" are asked to project data concerning their spatial experiences directly on architectural surroundings. These data, then serve as a real-time indication of how space should be changed in order to enhance performance. That is what we mean by "sculpting in space": letting human's behaviours exert direct influence on spatial layout.

2. Background

Physical layout of the architecture is far less than itself. Schöning's (2008) equation "Matter* Process=Physiology" points out that physical space and human experience in it are an inseparable integrity. Hillier (2007) also said "buildings are fundamentally about movement and how it is generated and controlled". As for exhibition spaces, they "not only spatialise objects by virtue of the arrangement, but also socialise them by placing them in the context of a spatially sustained pattern of visual encounter" (Bataille, 1930), which means that the way people perceive the exhibition supplements the exhibition itself, and they concurrently form the understanding of the exhibition content. Choi's (1999) discovery of "virtual communities" corroborated this theory from another angle: an individual's perception of an exhibition space is subjected to subliminal influences of "coexistent others".

In sum, we posit the possibility to construct an integrity of space and process by introducing the temporal concept "process" into the study of space. This is a rationale for the subsequent space analysis and generation.

3. Methods and Settings

3.1. PLATFORM: MUILTI-AGENT SYSTEM

MAS is a complex system which consists of multiple interacting Intelligent Agents and their Environment. Intelligent Agents, in other words individual decision-makers, follow certain pre-defined rules to react to (and to influence) other agents or the environment (Figure 1).

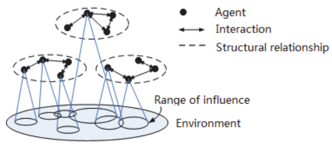

Figure 1. A Multi-agent system (taken from web, 2012).

In NetLogo, a MAS programming platform for our experiments, there are two types of Intelligent Agents: turtles are mobile and regarded as visitors, and patches are static, like the architectural environment. Turtles can read patches' attributes and hence tell the "walls" from the "floor area" (Figure 2).

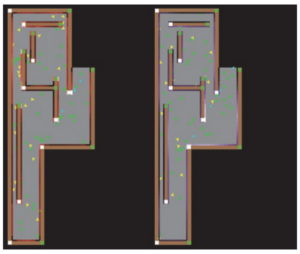

Figure 2. Brown-coloured patches mark the location of walls, and gray ones the floor area. Green and yellow arrows are visitor-agents.

To channel between this virtual model and the reality, we determined the spatial and temporal scales of the model's units. The size of patches decides how refined the data we are going to get, and we set it 1m*1m because it is close to human scale. The time unit is called "tick" in NetLogo, and we made it 1 second per tick according to human's normal walking speed.

3.2. SETTING: EXHIBITION

We conceptualize "exhibition space" here as an area where freestanding walls serve to partition the space as well as to hang the exhibited contents. It is not a strictly speaking "museum" with multiple functions. Barcelona

Pavilion designed by Mies van der Rohe resembles this preset to a large extent, so we used it for the sample study (Figures 2–3). The reason for this preset is quite simple: different parts of such a space are functionally homogeneous and thus ensure this research to stick to its focus, i.e. the "curatorial" quality of the space and how it correlates with movement.

3.3. SIMULATION MODEL AND EXPERIMENTAL PROCESS

The pedestrian model we applied was the ecological model of Turner et al, where "sighted agents with 170 degrees of vision, who select a point within their field of view randomly, move towards it three pixels and then repeat the process" (Turner et al, 2004; Hillier 2004). To reduce computation load, fields of view (i.e. Isovist) from each floor-patch (vantage point) are calculated and stored in them beforehand (Figure 3) for visitor-agents to read.

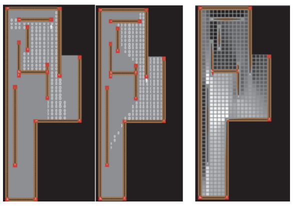

Figure 3. Left: isovists from two different vantage points. Right: colours of the floor-patches indicate scales of isovist areas.

Our experiment logically breaks down into 2 parts: projection and generation (though they actually occur simultaneously):

- The projection process makes the simulation results visible by asking visitors to change some of the attributes of architectural space (patches).
- In the generation process, patches make reactions according to the change in their attributes, and thus cause the spatial layout to evolve.

4. Experiment

4.1. PROJECTION

4.1.1. Logic: movement as the measurement of space

The purpose of projection is to measure the influence of architecture on human activities, so as to control the evolvement of space in the generation process. One should note that a certain space invariably leads to a certain pedestrian simulation result; therefore, the projected information reflects intrinsic properties of a space rather than extrinsic interventions from people.

From this perception, the pedestrian model is introduced to measure some aspects of the space in the same sense as a ruler is used to measure length.

4.1.2. Quantifying human activity

First of all, we should determine what types of data to project. For exhibition visitors, an exhibition board (or wall-agent) has two functions:

- It offers information for reading.
- It leaves an impression on visitors (and possibly cause them to change routes)

Translating these into a data language, the distance from which a person sees a board decides whether he is "reading" or "being impressed", that is:

- If a wall-agent within a visitor’s isovist is less than 1m away from him, and is in his 170-degree viewing angle, add 1 to Time of Reading (TR).
- If a wall-agent within a visitor’s isovist is in the visitor's 170-degree viewing angle, add 1 to the Time of Impression (TI).

TR and TI are both attributes of wall-agents. "170-degree" is the humans’ natural viewing angle. "1m" approximates to the general distance between the visitor and the board when reading. After projecting those data to Barcelona pavilion, we got Figure 2, where left, red colour shows TR and right, the purple shows TI, darker means smaller.

4.1.3. Criteria for a good experience

To conduct tentative generation experiments, we define a good spatial experience from the following aspects:

- No areas in the space are unreachable.
- Unavoidable repeated visits are reduced to the most extent
- The space size changes orderly along the visitors' routes

Next, we transferred the descriptions above to the data projection mode to mark the areas conforming and not conforming to those descriptions:

- **To eliminate unreachable space:** After the program operates for a sufficient time (200 "ticks" in our experiment, and the value depends on space area and visitor density), wall-patches with a TR of 0 are unreachable areas.
- **To reduce repeated visits:** If a board (wall-agent) is being read by a visitor-agent, it enters his memory list. When he reads the board for the second time, this wall-agent gains 1 "repeated reading time" (RR). However, wall-agents with a large TR tends to win more repeated reading times (RR). To solve this problem we divided RR with TR, and got the "rate of repeated reading" (RRR), then projected this value to the wall-agent (Figure 4).

- **To create a series of spaces that are diversified in scale along visitors' route:** This rule is expected to avoid a monotone in spatial experiences. The approach is: at each step, read the isovist value of the visitors' standpoint. Then transmit the average of this value over the previous 20 steps, to all visible wall-agents now. We name this projected value "experiential isovist" (EI), and it shall be projected to both wall and floor agents, in order to control both disappearance and generation of boards (Figure 4).

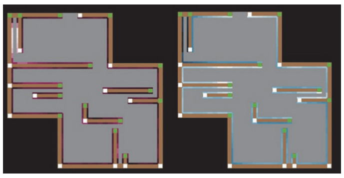

Figure 4. RRR (left) and EI (right), darker means lower. Note that highest EIs do not correspond to the largest areas, but areas that can be reached after passing through large areas.

4. 2. GENERATION

4.2.1. Reactive architecture

Our generation experiment enabled architecture to react to human's experiences by treating it as agents too (previously humans were considered as active "agents" while architecture as static "environment"). The wall-agents can read the data projected by "human" and decide how to react. With this manipulation, a previous gap between simulation and generation is bridged.

4.2.2. Geometry construction mechanism

A response mechanism is needed for space to react to people's activities properly. To make the rule simple while at the same time ensuring a wide diversity of possible spatial layout, only two types of change are allowed: walls either emerge or be eliminated.

- **To eliminate walls:** Determine all wall-agents that are eligible to be eliminated. Then randomly chose one of them as the target wall-agent, and eliminate the entire wall it belongs to. (Figure 5 left)
- **To create new walls:** Determine all floor-patches that are eligible to generate walls. Then randomly select one patch as the target, determine one direction (either x or y) and the wall length. Taking the target patch as the middle point,

generate a wall of the given length, until both ends of the new wall becomes blocked by older walls. (Figure 5 right)

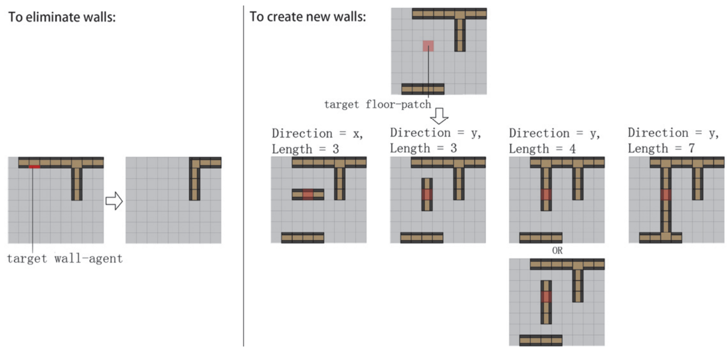

Figure 5. Eliminating a wall (left) and creating a wall (right).

Corresponding to the criteria for good space listed in section 4.3, rules to determine eligible wall (or floor) agents are:

- **To eliminate unreachable space:** wall-agents with a TI of 0
- **To reduce repeated visits:** wall-agents with top 10% RRRs
- **To create a series of spaces diversified in scale along visitors' route:** wall-agents with top 10% EIs and floor-patches with the lowest 10% EIs

4.2.3. Generation experiment

Below are the steps that the generation process follows:

- 1. Firstly, generate an original space randomly. We fix the external contour of the space, and randomly partition it with horizontal and vertical walls. The external contour consists of walls and an entrance. The lengths of all internal walls are between 4 and 15 meters. Any two endpoints (those white and green squares in Figures 4) keep a distance longer than 1.5 meters (to ensure the space between two walls is passable for a person).
- 2. Then run pedestrian simulation for 200 ticks
- 3. Create or eliminate one wall following the criteria for good space in section 4.1.3. The priority of those criteria is: eliminating isolated space > reducing repeated visits > creating diverse space. This means, if there is no eligible agent according to criterion 1, then check criterion 2, then 3.
- 4. Reset all values of walls and floors agents to 0 (including TR, TI, RR, etc.)
- 5. Repeat steps 2 to 4, until the program is manually stopped.

5. Results and Discussion

5.1. HUMAN ACTIVITIES AS THE MEASUREMENT OF SPACE

One purpose to propose such a circulation-oriented method is to provide a new lens in terms of describing spatial characteristics. This method makes it readable when certain parts of a space are not so appealing to human. For example, Figure 4 (left) marks one particular area with white colour, suggesting that repeated visits are very likely to occur there. This complies to our judgment of that area without the help of this computer program: it is very narrow and blocked, which detracts from a good spatial experience.

This type of "spatial imperfectness" may be eliminated by pure geometrical manipulation (i.e. Specifying the minimal space between parallel walls, for example), but other spatial qualities are more subtle for normal lenses to detect. In Figure 6 (the background is identical to Figure 4 right), the distance between parallel walls in zone 1 is the same as that in zone 2, but they are at the two extremes of EI values. This is perhaps because visitors must walk across the large "foyer" to get to Zone 2, where the average isovist in the 20 previous steps is already high. Unlike Zones 1 and 2 where eligible wall and floor agents are dense (suggesting a necessity for space improvement), in Zone 3, where the space is better partitioned and enclosed, the moderate colours indicate a better spatial quality.

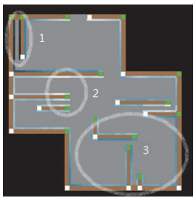

Figure 6. EIs of three different areas coincide with their respective spatial qualities.

5.2. HUMAN ACTIVITIES AS THE GENERATIVE FORCE OF SPACE

In Figure 7, phases of a complete generation experiment are subjected to isovist analysis using UCL Depthmap. It is detectable that isovists in all sub-areas are becoming even. We can infer that this result is brought about by our geometry construction rule 3, which tries to eliminate long periods of walking experience through excessively narrow or wild spaces. Judging from this analysis result, it seems that this rule favours a space with subareas of homogeneous scales. But it remains to be discussed whether this is a preferable outcome. In fact, a rhythm of compactness and looseness, rather than a homogeneity, is what we expected to produce. This divergence may result from the fact that we set the period of evaluation as 20 ticks, which might be too large to pinpoint subtle variances between subareas, or too small to depict the quality of one whole subarea. Future researches could delve into this point by carefully calibrating this value and matching it with the average amount of time for an agent to transverse a subarea.

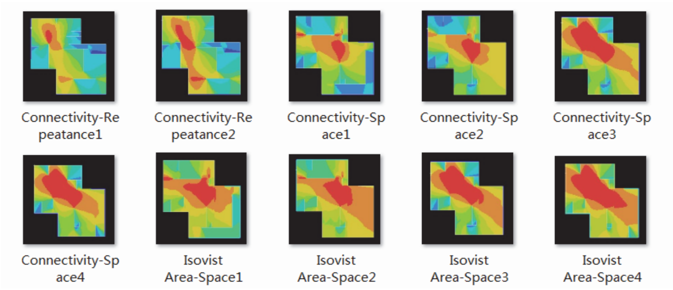

Figure 7. During a series of generation process, isovists in the space are becoming even.

5.3. PROSPECTS FOR FUTURE RESEARCH

One question that remains unanswered in this research is how to generate a complete architecture plan that corresponds to common notions of plan morphologies. We can conclude from section 5 that so far this projection-and-generation method is more apt at measuring than generating, which suggests a necessity for further refinement in generation rules.

According to our existent results, we propose that a distinction between local and global plan morphologies may help to solve this problem. For example, in Figure 6 it remains unknown whether large EIs in Zone 2 results from agents' previous experience in the large foyer (global morphology) or its intrinsic large isovist caused by the horizontal layout of walls in this area (local morphology). For future researches, it is possible to try to apply this method to the two different scales. Some viable local morphology can be predefined and used as raw materials for global-scale generation experiments.

As an exploration of the possibility of space and human experience to co-evolve, this experimental model is reductive to some extent. More factors affecting humans' movement pattern in a space, especially interactions between humans, should be taken into account if the method was applied to generate architecture. The tendency to follow others, for instance, may affect agent's choice of directions when walking. Further experiments can test the significance of such influences and decide whether to include them in the pedestrian model.

6. Conclusion

It is important to point out that this study is still a work in progress and the results and conclusions here presented are still preliminary, although they allow for some conclusions already, mainly regarding the possibilities to generate spaces in response of human activities inside it.

Human's movement is an important tool for measuring spatial qualities. Our research utilized this tool by projecting pedestrian simulation data on the architectural environment, and this projective approach has exhibited a potentiality in revealing spatial qualities that are hard to detect otherwise.

This perception into the relationship between behaviours and space can be applied to generate architectural spaces that afford preferable behaviours. Our research proposed a possible approach to such a generation process, in which space reacted to humans' information in a MAS system. Although detailed algorithms are open to refinement, the new generative methodology introduced in this paper seems promising in solving some of the long-standing problems that hampered performance-oriented design practices.

Acknowledgments

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