The Space Re-Actor:

Walking a Synthetic Man through Architectural Space

by

Taro Narahara

Master of Architecture, Washington University, 1997
Bachelar of Science in Mathematics, Waseda University, 1994

Submitted to the Department of Architecture
in Partial Fulfillment of the Requirement for the Degree of
Master of Science in Architectural Studies
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Signature of Author: ______________________________
Department of Architecture
May 24, 2007

Certified by: ______________________________
Takehiko Nagakura
Associate Professor of Design and Computation
Thesis Supervisor

Accepted by: ______________________________
Julian Beinart
Professor of Architecture
Chair of the Department Committee on Graduate Students

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Abstract:

Spatial qualities in architectural design cannot be fully evaluated solely by observing geometrical constructs without reference to inhabitants placed inside. However, imagining what happens to those inhabitants and appreciating their movement is difficult even for trained architects.

This thesis proposes a computational method for visualizing animated human reactions to physical conditions that are described in a synthetic architectural model. Its goal is to add a sense of place to the geometry, and augment the representation of its spatial quality for designers and audience.

The proposed method introduces a walking scale figure in a geometric model.
Through agent-based computation, it moves inside the model and displays various behaviors in reaction to spatial characteristics such as transparent surface, opaque surface, perforation and furniture. The figure is assigned a psychological profile with a different degree of sociability, and reacts to proximity and visibility of others in the same model.

Today's advanced computational design tools can produce complex forms and sophisticated visualizations of light, materials and geometry. But they are not suitable for helping people to quickly study and understand a spatial design as it would be inhabited. The proposed method lays a foundation for developing a new kind of software that overcomes this shortcoming.

Thesis Adviser: Takehiko Nagakura

Title: Associate Professor of Design and Computation

The Readers of this thesis are

Terry Knight
Professor of Design and Computation
Massachusetts Institute of Technology

Kostas Terzidis
Associate Professor of Architecture
Harvard Graduate School of Design

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Without meeting with Professor Kostas Terzidis, I could never reach where I am now. His unique philosophical insight in architecture, algorithm, and complexity will continue to inspire me.

Finally, I would like to sincerely thank my parents for their limitless support and understandings.

Contents:

To my parents

Chapter 1

Introduction: Turning Geometry into Place

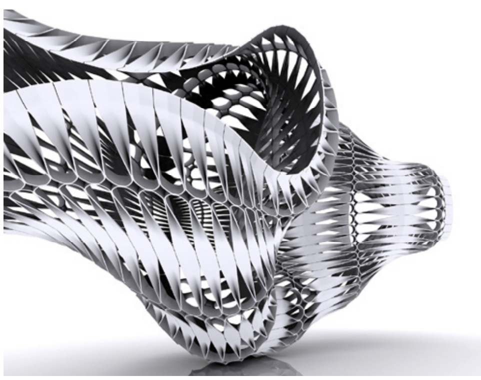


Figure 1.1:
Today's advanced computational design tools can produce complex forms, although they are not suitable for studying a spatial design as it would be inhabited.

As architectural projects become increasingly more complex in their formal manifestation and functional requirements, new methods are sought to address the complexities caused by multiple usages and constraints involved with them. Contemporary designs by today's leading architects are often filled with their signature expressions, and some of their design decisions seem to be executed based on their individual sensitivities and intuitions. Architects tend to underestimate the importance of the role of people inside their buildings; they are often not fully aware of the behaviors induced by the spaces which they design. The existing analytical means of architectural representations – plans, sections, elevations, axonometric drawings, and perspective – are not sufficiently capable of visualizing the psychological behaviors of people. Furthermore, today's advanced computational design tools can produce complex forms and sophisticated visualizations of light, materials and geometry. But they are not suitable for helping people to quickly study and understand a spatial design as it would be inhabited.

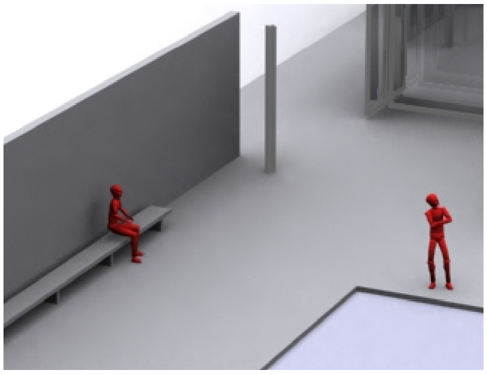


Figure 1.2:
Scenes from the Space Re-actor.

The paper seeks to find a tool with which to capture human reactions in architectural spaces in an animated format. By suggesting another layer of architectural quality hidden behind the constructive forms, this paper aims to bring the designers' attention back to a man (figure) on the stage, and the eyes of a user. (the person on the stage and seeing through his or her eyes) By walking a synthetic figure through architectural space, this tool will visualize the psychological response to architectural elements in motion.

The difference between typical architectural representations with figures and the tool I propose lies in the presence of autonomous behaviors embedded in the figures. Firstly, in the next chapter, I will clarify the particular reactions that I am investigating and hope to represent with this tool. Human response to and interaction with architectural elements is manifested in such media as film, video games, and evacuation simulations. I will try to capture psychological reaction to architectural elements which other media have not been able to capture.

In chapter three, I will further discuss the implementation of the autonomous behaviors and details of reactions that I am using for visualization experiments. This new tool accords some level of cognition to figures from the outset of the process, and beyond the basic cognition of the environments such as collision detections, figures in the tool have some level of psychological response to certain architectural materiality – opaqueness, transparency, and so on. The key notions to achieving autonomous behaviors – randomness, comparison between analytical approach and simulation, and concurrency (use of agent-based computation) – will be discussed in this chapter.

Figure 1.3:
The Barcelona Pavilion (1929)

In chapter four, I will explain the tool, the Space Re-Actor, actually works. I will follow this by describing the series of experiments in which the Space Re-Actor was used. Starting from the basic concept and rules I used for the tool, I will also briefly explain the user interface and mechanics of the software. Series of real architectural projects by Mies van der Rohe including the Barcelona Pavilion (1929) are chosen for the experiments to see how mere geometry (the model) can turn into place (the scene) with the use of the Space Re-Actor.

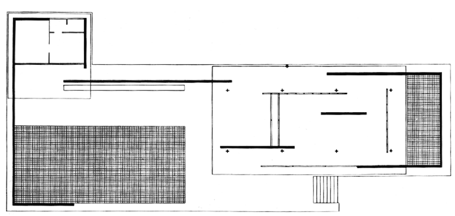
In the final chapter, I would like to discuss the tool's relevance to our practice. What we can really gain from a "walking figure" in architectural space will be critically questioned again in this section. The development of this tool owes a great deal to the various techniques used in behavioral simulations, and many aspects of the tool related to simulation. However, later I will argue that the Space Re-Actor may more properly be considered as the first instance of a new category I am calling "enactment software."

I will also discuss potential applications of the tool, which may include feedback loop into the system is one attempt to extend the tool's functionality as a heuristic generative system. Beyond the mere conceptions of a space, how this tool can potentially become a generative design tool will be further discussed in this section. Potential of human intervention, implementation of behaviors into the generative design system can be a challenging topic to discuss.

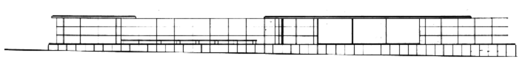
Chapter 2

Background: Means of representation

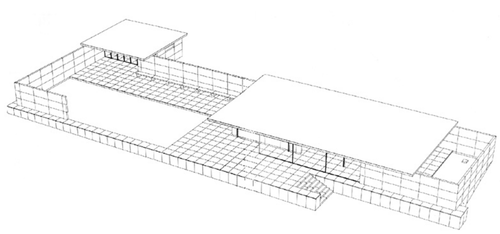
Over the history of our architectural practice, we have established many different means of architectural representation. The conceptual sketch, plan, section, elevation, axonometric drawing, perspective drawing, and animation, including walk-through, are all methods of representation. These methods of representation are used based on the demands of various phases of projects. Conceptual sketches are used to communicate initial gestures and schematic ideas without going into too much detail. Plans, sections, and elevations are all analytical methods of building representation. They can be used with various levels of detail in different stages of a project's development. Sections and elevations are often prepared with figures to indicate the scale of spaces. My studio instructors and even the principal designers in my professional office, always ask us not to forget to add scale figures into our section drawings. Axonometric drawing is basically a bird's-eye view of buildings. It is extremely helpful to capture the overall spatial organization of buildings, and it can represent a slice of buildings to reveal their internal structure. As we move into perspective drawings and animations, the representations are becoming closer to what we experience at eye level. Walk-through animation is literally the simulation of what we would see with the proposed buildings. All the above means are used in successive stages of projects in the order given above, from concept sketches to animations.



Plan



Elevation



Axonometric

Figure 2.1:
The Barcelona Pavilion by Mies van der Rohe

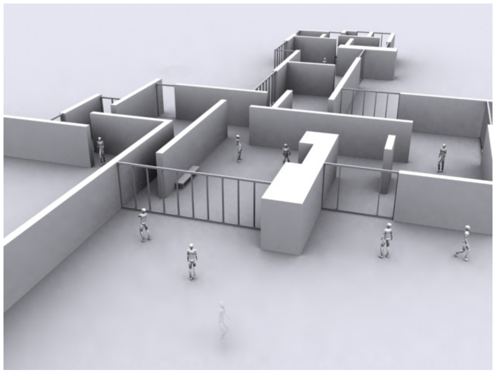


Figure 2.2:
A Scene from the Space Re-Actor.
Proposing an alternative representational tool.

Scale-ness

The tool that I am proposing can be positioned somewhere between axonometric drawing and animations, but the presence of autonomous behaviors embedded in the figures makes a unique difference. The most obvious contribution is the scale-ness of the representation. Simply by adding the scale figure into the 3-D models, observers can gain the sense of scale and physically relate themselves to proposed spaces.

4-Dimensionality

This tool differs from conventional axonometric representation with figures because of its four dimensional qualities. Here 4-D means space and time (x, y, z, and t.) The scale-ness in 3-D space can present the physical size of objects described in x, y, and z coordinate systems. Similarly, the scale-ness in 4-D can present the speed of objects in motion (along the time axis). This quality can be in constant velocity, acceleration, deceleration, or shivering (oscillatory) motions. In addition to the physical scale of the spaces, the user can literally view the time that it takes to move from point A to B in their 3-D models. This four dimensionality of the tool makes it slightly differently from conventional static representations.

Figure 2.3:
Mies communicating his ideas through his scale models.

Behaviors

The difference between typical architectural animations with figures in motion and the new proposed tool lies in the presence of autonomous behaviors embedded in the figures. Typically all the figures in architectural animations are controlled, prepared, and inserted afterward, on top of their 3D models in a top-down manner. For example, most of the walking figures merely follow the paths that were drawn and reinterpreted by the designer on their 3D models, and their motions are post-rationalized by the makers (observers) of the presentations. There are some levels of discontinuity between the motions of the figures and their surrounding architectural environments since they are results of reinterpretations by the observers who reside outside the environments. The new tool attempts to omit this final tweaking process by according some level of cognition to these figures from the outset of the process. These cognitive capabilities include collision detection, obstacle (walls, etc.) detection, cognition among others, and cognition of the attractions in architectural environments. Re-Action to the architectural spaces, including the reaction to the different materiality of the architectural elements, is the most unique features implemented in this tool. (I will discuss this further in the chapters four.) Since these cognitions are directly embedded in the figures on the stage sets, these reactions are directly derived from the architectural spatial conditions around them, and not from the re-interpretation or the post-rationalization.

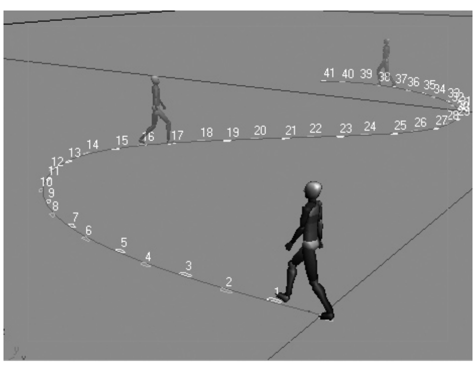


Figure 2.4:
Animation requires path generation; Re-interpretation of the space by animators.

Figure 2.5:
Casa Malapante by Adalberto Libera.

Background: Re-Actions

The reaction that I am proposing in this thesis is based on psychological reactions to surrounding architectural spatial conditions. In the following paragraphs, I would like to compare the Space Re-Actor with other media such as video games and evacuation simulations, to clarify the particular reactions that I am investigating in this study.

Film / Cinematic Representations:

Cinematic representations also have the 4-dimensional qualities. This 4-dimensionality allows creators to sculpt events in motion. This particular characteristic produces major differences between cinematic representations and typical photographic representations we can often find in architectural monographs. (Figure 2.5) The example from Casa Malapante in the figures shows these differences fairly clearly. Pictures in architects' monographs, especially bird's eye views, treat buildings almost as precious lovely objects, and sometimes designers' appreciations for the forms intentionally hide the presence of people from the views. Anyone presenting works in this particular ways are almost producing scale-less aesthetical qualities of their own. Furthermore, recent advances in digital technologies allow architects to fairly easily achieve more complex formal manifestation by using readily available CAD soft-ware.
(Figure 1.1)

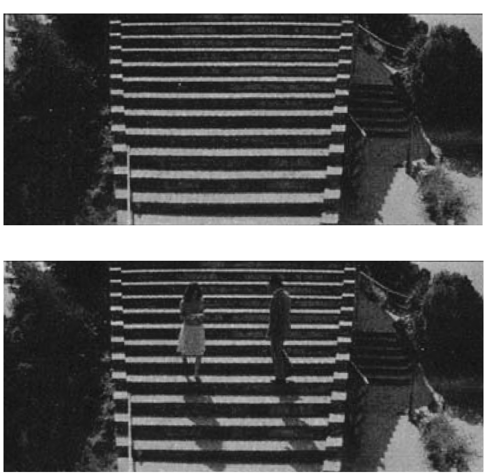


Figure 2.6:
Casa Malapante with or without actors (Chatzitsakyris, 2006).
Scene from Jean-Luc Godard, Le Mepris (Contempt 1963).

However, going too far in these directions has some risk of designing ill-functioning buildings. Architects tend to underestimate the importance of the role of people inside spaces. There is so much we can do with formal manipulations, but too much obsession with this formality often leads architects to forget the protagonists of the spaces – people, whom they are designing for. Just by observing the forms with any existing methods, it is extremely hard to tell whether their designed components actually contribute to the performance and use of the buildings or not.

Figure 2.7:
Cinematic representation offers a sense of physical scale and depth. Scene from Orson Welles, Citizen Kane (1940)

Cinematic representations offer several obvious advantages. The most obvious benefit is that they give sense of scales to space. As soon as we have actors on stage sets, conversation will start, which evokes a sense of physical scale and depth in front of our eyes. (Figure 2.7) Ability to render the event in motion is one of the unique differences in cinema. The camera works in films are mostly driven by the events that occur in the scene and help us to emotionally connect ourselves to the events in the scenes. These emotional projections possibly alter our stance from observers to participants of the scene. In films, the camera can be also set to our eye levels to record the protagonist's experiential views. This virtual layer of objectivity latent in cinematography can be a great potential representational method for any other creative activities.

This conceptual shift from observer to participant is always unconsciously (or consciously) executed in the mindset of many architects during their design processes. Good architects always have strong virtual visions of what they are designing in their plans, sections and elevations. We cannot design fully functional and aesthetically meaningful buildings only from observers' point of views. For example, when Eero Saarinen designed the entry sequence for the Administrative Center for Deere & Company, Moline, Illinois, 1957, he asked his colleagues to push him in a dolly (wheelchair) to check the curvature of the approaching drive-way and appearance of the buildings from the entry sequences.

Figure 2.8:
The Entry Structure project, Mori Art Center, by Gluckman Mayner Architects (2003).

(1)	$R+T=43.2 \sim 44.5$	Kinder
(2)	$2R=T$	
(3a)	$2R+T=S$	
(3b)	$2R+T=61 \sim 63.5$	Kinder
(3c)	$2R+T=60$	
(4a)	$R^2+T^2=S^2$	
(4b)	$\sqrt{R^2+T^2}=33$	
(5a)	$R \times T=450$	
(5b)	$R \times T=450 \sim 485$	Kinder
(6)	$R \div T=\tan(R-3) \times 8°$	J. Parker
(7)	$T=5+\sqrt{7 \times (9-R)^2+9}$ $R=9-\sqrt{(1/7)(T-8)(T-2)}$	E. I. Freese
(8)	$T-R=12$ [1)]	Lehmann, Engelmann
(9)	$R \fallingdotseq 18$, $T \fallingdotseq 28$, $Q \fallingdotseq 32°40'$ [2)]	

Figure 2.9:
R: riser, T: tread, S: stride, Q: slope. Various Tread and Riser Ratios (Nihon-kenchikugakkai, 1994)

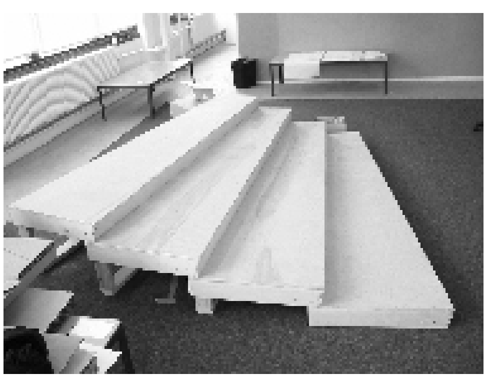


Figure 2.10: Full Scale Mock-up of spiral staircase. Adjustable in height and width.

Full-Scale Mock-Up

Besides the proportions and aesthetical values, functionality and levels of comfort can be also studied through this notion of shift between observer and user. From 2000 to 2003, working with the Gluckman Mayner Architects at the Mori Art Center, I created a unique three-dimensional project called "Entry Structure." Designing the elliptical spiral staircase—conically reducing the radius from the center as you go up—was one of the most complex tasks I have ever undertaken. This staircase will be used for major entry circulation sequence for the museum, and achieving an optimal design that can simultaneously satisfy the codified information, functionality, comfort level of steps, and the designer's aesthetic intention were essential.

There are a few formulas to calculate optimal tread and riser ratio based on knowledge-based approaches, although our spiral staircase was too complex in its geometry to evaluate the ratio merely from locally defined conditions. (Figure 2.9) Our team's solution at the time was to create a partial actual size mock-up of the spiral stair and evaluate its comfort and functionality levels by "walking" actual people with various heights and physical strengths. (Figure 2.10) This approach was maybe not the most economical or prompt solution, but it definitely told clearly what was right and wrong. The riser height was adjustable by shims, and tread length was also adjustable by sliding them over each other. What was critical to us was difference in tread length at the inner and outer radius. By checking different combinations of dimensional constraints, the mock-up helped us to find the preferred sizes from the feedback of actual people (users) beyond the simple numbers from the codes or references.

Figure 2.11a:
Complex form of the Spiral Staircase, Entry Structure (2003)

Although the Space Re-Actor's aim is not merely about the analysis of functionality in space, this idea of feedback and evaluation loop system using actual humans gave me inspiration for my research's idea of a "walking man."

Besides the staircase, translucency of the glass cladding was also evaluated through the use of full-scale mock-up. Glass panels with three different translucencies – ceramic dots frit pattern with 20, 40, and 60 opening percentages – were installed for the designers and clients evaluation. In this case, mock-up was used for rather qualitative purpose.

Figure 2.11b:
Full Scale mock-up to evaluate translucencies of glass panels, Entry Structure (2003)

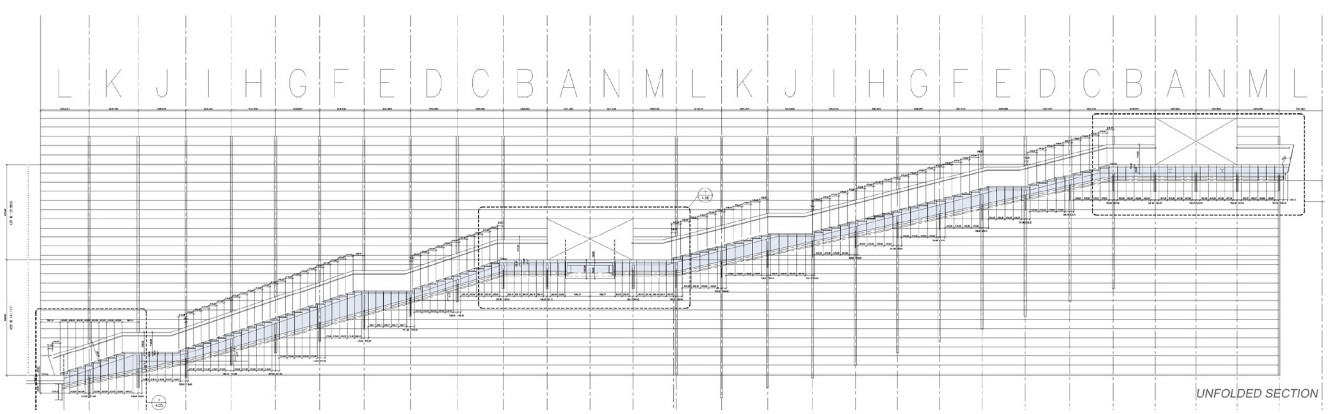


Figure 2.11c:
Unfolded section of the Spiral Staircase for the construction, Entry Structure (2003)

Video Games (Action games)

Figure 2.12: Game "Tomb Raider 5"

Video games have some level of automated reaction and responses in their characters. Reactions from the objects in their virtual environments – walls, missiles, fire, cannonballs, enemies, basketballs, etc. – are implemented in their characters. Basic cognitions such as, Collision detections, Wall repel behaviors, Avoidance of Enemies, etc. are installed in most of the action-based video games. In addition to these reactions, many contemporary games have superior graphic representations achieving cinematic qualities which I have mentioned above. Players of the games can easily project their minds upon the characters which they are controlling. Furthermore, in recent days, some film directors have created their movies nearly one hundred percent inside the virtual world adopting the same graphic technologies used in game creators such as motion captures. These parallel evolutions of cinematic representations and game technologies are about to produce a new level of communication means. These readily available graphic technologies are promising vehicle for architectural representations as well.

The critical difference between the proposed Space Re-Actor and video games lies in their concepts of Reactions. The reactions that I would like to investigate with this tool are based on people's psychological responses from various architectural elements– materiality, spatial conditions, width, height, density, scarcity, etc – which are different from those of video games. Many action based games challenges particularly users' reflex response for avoidance or detection of obstacles. Automated characters in the background of games are also responding to those, but they do not include any psychological interpretations.

Evacuation Simulations

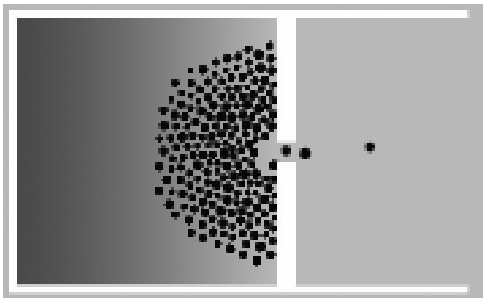


Figure 2.13:
Simulation in Helbing's model (Helbing et al, 2000)

Evacuation simulations are dealing with psychological responses of people and have quite similar modeling approaches to that of Space Re-Actor. They use similar environments for simulations using agents-based computer models. However, their studies of behavioral responses are under fairly specific circumstances – emergency conditions, and this fact separates my studies from theirs.

The first comprehensive academic research on crowd behavior was done by Gustave Le Bon at the end of 19th century, and the following is the quote from his book, The Crowd: A Study of the Popular Mind.

> *"We see, then, that the disappearance of the conscious personality, the predominance of the unconscious personality, the turning by means of suggestion and contagion of feelings and ideas in an identical direction, the tendency to immediately transform the suggested ideas into acts; these, we see, are the principal characteristics of the individual forming part of a crowd. "*
> *"He is no longer himself, but has become an automaton who has ceased to be guided by his will. "*
> *(Gustave Le Bon, 1896, The Crowd, p19)*

Many evacuation simulation models are based on the premise that the crowd behaviors follow certain patterns under the special circumstances. Some studies indicate that people's responses start to become simpler and more straight-forward under emergency conditions (Quarantelli, 1954).

- Tendency to move straighter path
- Tendency to follow others
- Tendency to choose paths which are Immediately Visible

These studies have much more systematic and quantitative approaches than the Space Re-Actor. The reactions that I am interested in are mainly psychological responses from spatial qualities in our day-to-day lives, and this study differs from those of evacuation simulations in this regard.

While many techniques and methods have been widely tested to evaluate the efficiency of real-life systems such as traffic simulations, congestion pricing, and fire evacuation simulations, very few methods have been actively tested to model and evaluate spatial qualities based on human behavioral patterns. Numerous studies based on the context of emergency conditions, such as way-finding problems in fire evacuation situations, and mathematical tools used in operations research are effectively used to describe and analyze the conditions. The potential of using these methods in the analysis of spatial qualities in our day-to-day lives is an issue yet to be addressed. The integration of the quantitative analyses and qualitative judgments is a challenge. Various data from knowledge-based qualitative studies of spatial planning will provide valuable research for modeling human behavioral patterns. Informing designers about the potential interactions between the space they are designing and human behaviors will constitute a promising and expedient interactive tool for architects.

Chapter 3

Methodologies: The Road to Autonomous Behaviors

I started this project by simply questioning, how randomness, probability, and the ever-changing human mind and behavior can affect our design strategies, and how they can possibly change our design practices. The Space Re-Actor: Walking Synthetic Man was first realized by adopting notions and techniques from the following concepts: randomness, analytical vs. simulation, and concurrency in agent-based modeling. Beyond the simple mechanical applications, these techniques give us interesting insights and inspirations about our problems in architectural space. In the following chapter, I would like to explain above issues not only in technical terms but also in conceptual terms.

Interpreting Randomness:

"Randomness" is becoming one of the key words for designers. It seems to establish aesthetical values of its own and has almost gained an identity in our design market these days. After all, having seen all the signature expressions invented by various design ideologies from extremely personal ones to ones that represent phenomena of national or religious scale, we seek to find new expressions from outside of any "self." Randomness has its roots beyond our intentions, motivations, or manipulations. It is simply "random."

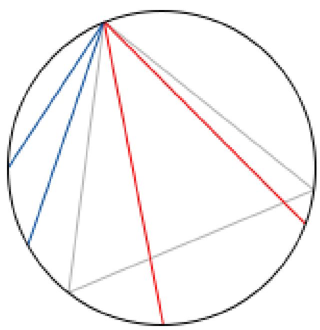
Figure 3.1:
Action painting by Jackson Pollock. www.worth1000.com/web/media/32675/pollock

The aesthetical representations of randomness are commonly introduced by the form of Action Paintings, such as works by Jackson Pollock. It is not my aim to go into the philosophical aspects of his paintings, but "Is it really random?" is my question. The drippings and trajectories of his paint (spattering) are somewhat derived from his body motions. His body motions are, of course, constrained by his own skeletal configuration to some degrees. The landing coordinates of each paint drop are somehow the results of controlled randomness with the stochastic nature of aerodynamic movements involved in the process. The argument here is that the Randomness can be "controlled" and defined variously, based on different interpretations.

For most audiences, the word "random" probably refers to a uniformly distributed randomness over all the possible choices in the given situation. Defining the "randomness" by using the patterns on the grid of LED panels with the chances of each LED to be ON or OFF normally considered to be fifty percent, this will produce the appearance of patterns that would be perceived as "random." But this is probably not the only kind of interests to us. For example, one can go home from his or her work by walking, bus, metro, taxi, or one might have one in billions of chance of struck by lightening. The probabilities for above each case are not equally distributed. Probability of choosing one over the other is influenced by many contextual elements surrounding the decision makers (agents), and biased toward their tastes and mindset. Later this notion has become an important technique to achieve autonomous movements for the Space Re-Actor.

Randomness is an ambiguous term, and the following example from Joseph Bertrand, called "Bertrand's Paradox," represents this point fairly intuitively. "Determine the probability that a "random chord" of a circle of unit radius has a length greater than √3, the side of an inscribed equilateral triangle." (Figure 3.20) is the problem given by Bertrand (Larson, 1981). There are possibly three approaches to the solution of this problem based on different interpretations of the word "random."

Figure 3.2:
Case 1: The Chord's end points are random.
Probability = 1/3

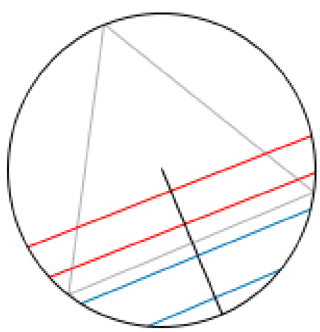


Case 1: The Chord's end points are random.

Any chords are defined by two points intersecting the circle. Without loss of generality and the symmetry of the conditions, we can fix one end point and move the other along the circumference of the circle. So the probability is one-third of the circumference of the circle. (Figure 3.2)

Probability = 1/3.

Figure 3.3:
Case 2: The Distance from the center is random
Probability = 1/2

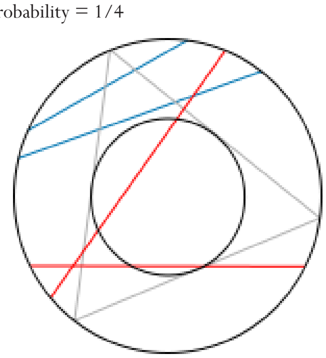


Case 2: The Distance from the center is random.

Any chords are defined by the distance from the center to the mid point of the chord and the rotation of this distance vector around the center. So the probability is one-half of the radius of the circle. (Figure 3.3)

Probability = ½.

Figure 3.4:
Case 3: The Mid-point of the chord over the area of the circle is random
Probability = 1/4

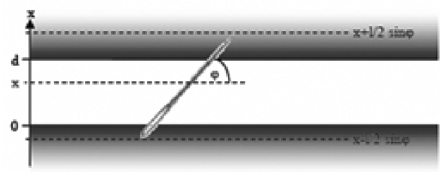


Case 3: The Mid-point of the chord over the area of the circle is random.

Any chords are defined by the location of the mid-point of the chord over the area of the circle. If this point is within the inscribed circle of the equilateral triangle, the chord's length is less than √3. So the probability is geometrically the areas of the smaller circle over the original circle. (Figure 3.4)

Probability = ¼.

All of the above three results are "correct" corresponding to their definitions of randomness in each scenario. The resulting probabilities are different because of the different interpretations of the word "random." The methods of random selection are defined differently in all three cases. I will omit rigorous proof of these probability assignments here (though these could be derived visually intuitively), but this aspect of randomness is especially important when autonomous motion and decision making are implemented. The probability of choosing one motion among all possible next moves is not uniformly distributed in many real-life scenarios. People's choices are often biased toward one over the other. When a person is about to make a decision about whether to go right or left in a museum exhibition space, he will probably choose left if his favorite paintings are awaiting him in that direction, but we cannot one hundred percent deny the possibility of his choose to go right. In such cases, randomness is not necessarily uniformly distributed, and it can be interpreted in a certain way by allocating the bias toward certain events. The use of Probability Mass Functions (or Probability Density Functions) with weighted distributions of the occurrences of the events will technically achieve the mathematical description of this phenomena. For example, use of exponential functions is widely accepted to simulate queuing studies as probability distribution functions (such as Poisson's distribution). Randomness is utilized to represent the various possible events that could possibly take place inside the proposed design spaces.



$$P = 2l/[\pi d]$$

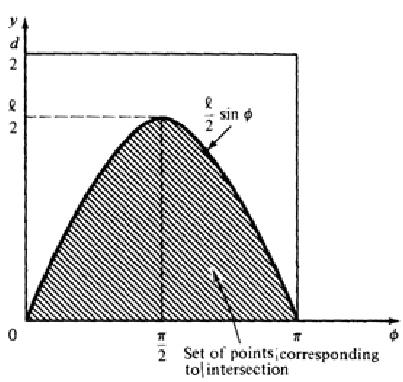
<u>Derivation by Geometrical Probability</u>

$$f_\Phi(\phi) = \frac{1}{\pi} \qquad 0 \le \phi \le \pi$$

$$f_Y(y) = \frac{2}{d} \qquad 0 \le y \le \frac{d}{2}$$

$$f_{Y,\Phi}(y,\phi) = \frac{2}{\pi d} \qquad 0 \le \phi \le \pi, \quad 0 \le y \le \frac{d}{2}$$

$$P = \int_0^\pi d\phi \int_0^{(l/2)\sin\phi} dy \, \frac{2}{\pi d} = \frac{l}{\pi d}\int_0^\pi d\phi \sin\phi = \frac{2l}{\pi d}$$



<u>Figure 3.5:</u>
Analytical Approarch to Buffon's Needle problem.
Derivation of the Probability by Larson R.

Analytical Approach or Simulation:

Two distinctively different attitudes toward problem solving exist in our world – the analytical approach and the simulation approach. In almost any field of studies, not only engineering but also social science, economics, and architecture, those two different attitudes exist. The analytical approach is much more deterministic and mathematical in terms of its methods and results, whereas the simulation approach is more or less "trial and error" type of heuristic process. Usually simulation approaches take effects where there no deterministic established problem solving methods are available or unknown.

Buffon's Needle Experiment:

The following well-known experiment called "Needle-throwing" by Buffon in 1777 is a good example clearly displaying the above two different problem solving approaches. Suppose one has parallel strips with two alternating colors, which are equally spaced – same width (Such as the American flag). Then, start throwing needles randomly, aimlessly on to the surface. Finding the probability that the needle falls onto both of the colors of the surface (red and white stripes of the flag) – intersecting with one of the parallel lines – is the problem. One classical solution to solve this problem is mathematically using geometrical probabilities (by considering random variables and joint probability distribution). To make a long story short, one can deterministically find out that the probability is equal to 2l / πd (where l = length of the needles, d = depth of the strips.) In this case, without committing any trials, you can purely mathematically gain this regulating threshold value in top-down manner. Some of the regulating numbers in architectural spaces are also given in this top-down manner such as width of the corridors for wheelchair access, etc.

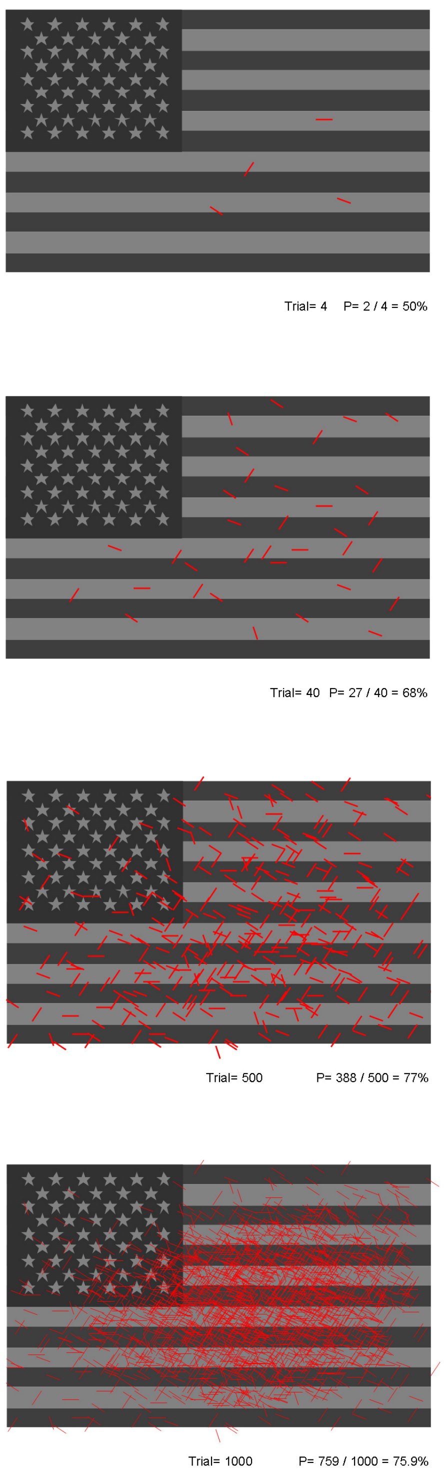


Figure 3.6:
Monte-Carlo Method for Buffon's Needle problem.

(I will show the step-by-step process of how to gain this result at the end of this section. This method uses only a basic notion of probability mathematics, yet the result is quite amazing. Buffon obviously did not use the American flag for his initial experiment at the time.)

The other obvious approach to solve the problem is simply throwing as many needles as one can, and record the results of success over the number of trials. If one do it four or five times, one will not gain reliable results, but if one do it one million times, one's result gets closer to the optimal. (This approach is also known as a simple Monte Carlo method, and combining the two results from the above two approaches, it is used to gain the estimation of pi = 3.1415926…) This approach suggests two important facts. First, in cases where you do not have any analytical means to find the solutions such as the above mathematical probabilistic methods, this simulation approach becomes always valuable. Secondly, to achieve meaningful results from the simulations, we almost have to have the computational power to go through millions of iterations to gain meaningful results.

The Buffon's Needle problem has two ways to reach a solution, but many problems in our real-life situations do not have two ways to approach the solution. Many problems in our day-to-day scenarios do not have a deterministic method to reach the clear-cut solution. One of the most famous problems classified in this category is called the Traveling Salesman's Problem – given a number of cities on a map, to find the shortest path to visit every city without skipping or duplicating the cities to be visited. When the number of cities to visit exceeds fifty, it is known that very few formula or analytical methods are available, and the "trial-and-error" type of heuristic algorithm is a faster way to search for the optimum solution. Another more intuitive example involves packing. When you are packing a large trunk or storage space with numbers of boxes with various sizes, there is essentially no deterministic way to find the best packing solution inside the given space. However, by doing some trials, one will find it better to start with the boxes with larger sizes. Then filling the gaps with smaller boxes will yield the better solutions faster. This method does not give us a perfect packing solution, but guarantees decent optimal solutions faster.

Simulation in Architecture

In architecture, many spatial problems are also indeterministic. Solutions to particular design problems are usually constrained by multiple criteria and are far from obvious. Normally, architectural design has multiple evaluation factors, and this fact prevents it from having simple straightforward equations or methods to reach solutions. Moreover, this ambiguity and invisibility of spatial qualities tends to hide the actual problems from designers' eyes. Aesthetic values may scarcely ever be quantified or objectively evaluated, but even mere functional aspects of architecture are hard to evaluate. For instance, architectural codes such as the Universal Building Code (UBC) and Americans with Disabilities Act (ADA) respond to constituent parts of dimensional constraint in architectural spaces. (Figure 3.7) However, for a building as a whole, whether or not the end products of assembly of all locally constrained parts are efficient and comfortable, are very difficult to predict before actual user involvement.

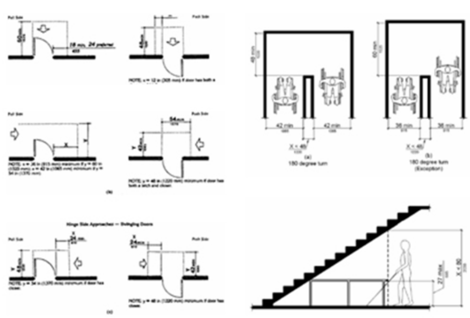


Figure 3.7:
Dimensional constraints from Americans with Diasabilities Acts (ADA).

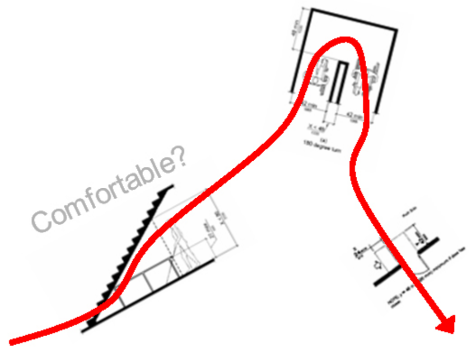


Figure 3.8:
Dimensional constraints from Americans with Diasabilities Acts (ADA). Compornents in sequences.

The example from the last chapter, based on my experience, designing the Entry Structure staircase, also illustrated this point. Width, turning radius, tread length, riser height, landing length, interval of required landings, and handrail height of the staircase are all constrained by regulating numbers from codes, and the codes give us some optimal solutions in local conditions to achieve better functionality and accessibility, although possible combinations of all those constraints in sequences will create entirely different criteria of spatial qualities and comfort. It is difficult to predict whether or not the designed components in sequences contribute to the performance and actual use of the buildings. Even if the design conforms perfectly to the required regulations, it does not guarantee the best flow in the spaces. A simulation approach can be more promising for checking the global organizational aspect of design. A "walking actual human" was our group's solution to check the level of comfort at the time. Another possible approach can be using a synthetic figure based on human behavioral patterns to test the performance of space. Various data from knowledge-based qualitative studies of spatial planning will provide valuable resources for modeling human behavioral patterns. Slight variations in behaviors implemented in the human model can iterate through the possible consequent patterns, and trial-and-error simulation will provide us some insight into possible motions, reactions, and activities between people and architecture before realization of the physical space.

Concurrency: use of Agent-based Computation

Concurrency, or synchronization, has become key words for the implementation of the autonomous behavior of synthetic figures in my projects. Use of a multi-agent-based modeling environment allows me to render the events induced by the decisions of multiple individuals. How to achieve reactions among figures and architectural components in real-time synchronized fashion was a challenge, and the agent-based technique is suited for modeling the settings where many chain reactions between different events are likely to take place. A multi-agent model is used to simulate natural and social phenomena, and is capable of simulating complex systems growing over time.

Going back to the last discussion about analytical versus simulation, interpreting the human behaviors with sole analytical mathematical equations is very difficult due to its complex emergent phenomenal aspect.

In agent-based computation, user can model behavior (give instructions) to numbers of individuals (agents) and this system is capable of controlling them in concurrent fashion. It is particularly effective in order to observe how individuals' local behaviors can potentially affects global emergent patterns or collective behaviors from the interaction of many individuals.

Aim of the thesis is not the development of multi agent system itself out from the scratch. Basically any object oriented language settings allow us to design agent-based modeling environment using the class structures. The essential concept of the agent based model – achievement of the concurrency and synchronization among the agents' behaviors – is the main characteristics that I seek for the development of this project, and the use of the agent based programming environment allows myself to focus

Figure 3.9:
Relationship betweenVision and Density

on coding the behaviors of the synthetic figures. In this project, I used NetLogo as a programmable modeling environment. The system is a pixel based system – similar to the logic of a two-dimensional cellular automaton, thus color coding scheme works quite well. This system allows users to access individual models as Java applets inside a web browser, and does not force users of the tool to have the modeling and programming environment itself. (See footnote below)

Pedestrian Crossing 1: Lane Formation

The first step for my research was to understand pedestrian movement by modeling a simple program that simulates pedestrian behaviors. (The ideas studied in this exercise are later applied to the movement of figures in the Space Re-Actor – particularly the implementation of detections and repel or seek behaviors for figures) Studies of pedestrians walking in a crosswalk have done by many scholars (Helbing D), although my interpretation may not be exactly alike in terms of algorithms.

The aim of this exercise was to reinterpret known human behaviors under certain circumstances as the simulation model by the use of algorithms. The basic behaviors of each pedestrian are fairly simple – they all want to cross the road. The problem for them is to avoid the people walking toward them and not to slow down their walking pace unnecessarily. The following behaviors are observed by many past studies relating to the density condition of real pedestrian movements. (Figure 3.10) (Katoh 1980).

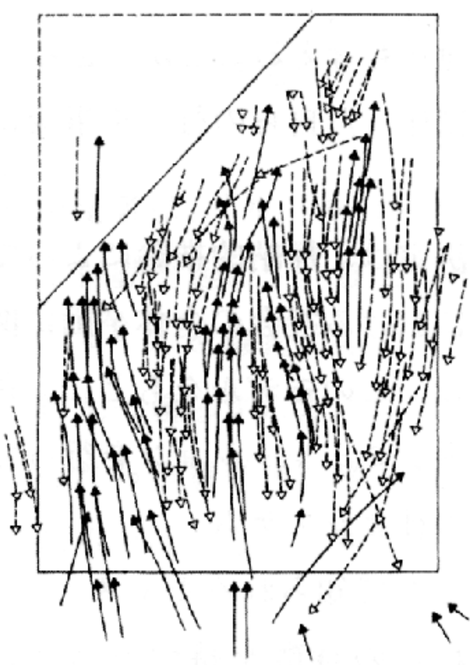
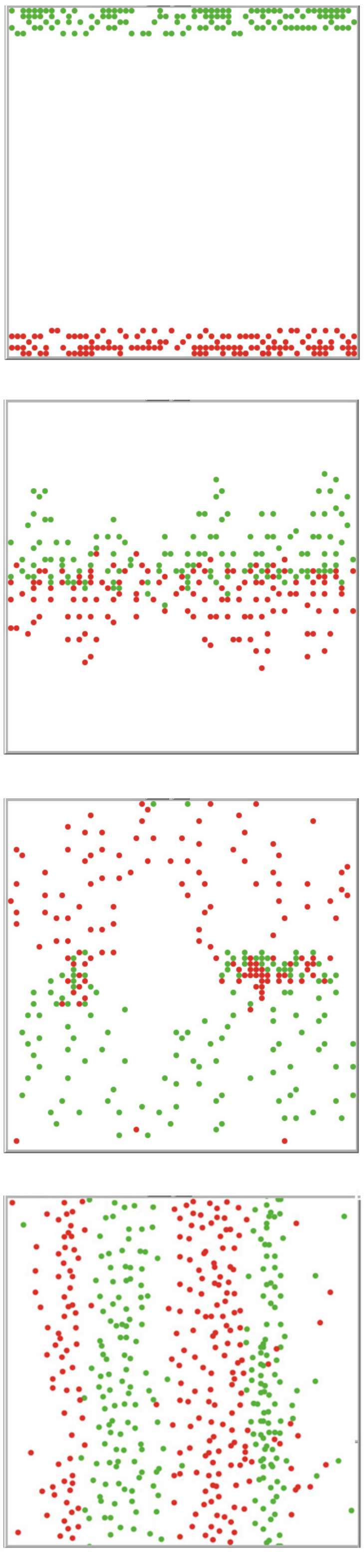


Figure 3.10:
Lane Formations observed at the intersection in Tokyo, Japan. (Katoh, 1980)

Footnote: NetLogo was authored by Uri Wilensky in 1999 and is in continuous development at the Center for Connected Learning and Computer-Based Modeling. (http://ccl.northwestern.edu/netlogo/docs)

Figure 3.11:
Emergence of the Lane Formation.



- Pedestrians pay attention to their immediate neighbors and avoid collision with them. Adjust walking speed based on the density condition around them.

- When density is low, pedestrians tend to keep distance between the other pedestrians in front and back. Then pay attention to the distance between their left and right sides.

- When density is high, pedestrians tend to reduce (compress) distance between their front and back.

- Pedestrians overlook the flow around them, and follow the direction where more people are moving in the same direction as they are heading.

(Density here refers to the density in terms of the local conditions around the pedestrian, not the overall density.)

The last characteristic is the most interesting one, and introduces the idea of the visions of the modeled pedestrians. This vision allows the modeled human to read motion of the other people around itself, and make proper judgments for its next move. Extent of this vision has an inversely proportional relationship with density conditions around the modeled human. When the person is surrounded by many people, he or she possesses a smaller field of vision, so his or her decision will be based more on local, immediate neighboring conditions. When the density is low, the person has more ability to overlook the movement in macro scale and consequently recognize groups of people moving toward the same direction in more spread out large. This behavior and algorithm that I have interpreted and implemented in this exercise are similar to those of flocking behaviors.

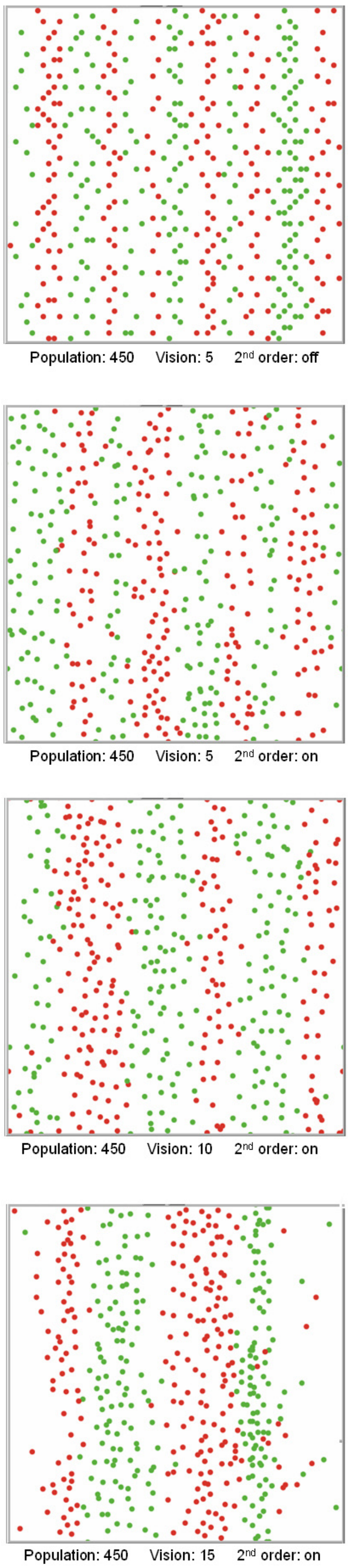


Figure 3.12:
Lane Formation on varied conditions.

The "Lane Formation" is the most fascinating emergent phenomenon we can observe from this experiment. Each pedestrian's embedded behavior is simply avoiding others blocking their way in local neighborhood conditions, yet the global collective behavior that emerged from those simple behaviors shows these self-organized characteristics of a crowd. They are obviously minimizing the collisions among them to reach more efficient steady states by gradually forming lanes by following each other. This phenomenon is recorded in many real life locations such as crowded pedestrian streets crossing in the city of Tokyo. (Figure 3.10)

Based on various populations (density), condition of the pedestrians' vision (fields of view), and all the rules that applied, I have recorded the emergence of lane formations in different sizes in width, numbers and distances between them. In general, the overall density needs to be above certain threshold values to observe lane formations. In this exercise, I used a 30 x 30 grid of hypothetically 45 to 50 cm which is about the average width of a normal person's footstep. In population below 100 (overall density < 0.55 people-per-m2) I do not observe much lanes forming since the pedestrians have almost no need to avoid many others. In an overall density above 0.82 people-per-m2, I started to recognize some clusters of pedestrians walking toward the same directions. It is an issue of what precisely defines the "lane formation." However, the main aim of this exercise is to understand the concept of this phenomenon, so whenever I observe more than two lanes of pedestrians flowing into the same directions, I decided to interpret them as lane formation. Next, I fixed the population at 450 (density close to 50%) and observed the difference with the various fields of vision (2.5m, 5m, 7.5m) and rules (2nd order rules On or Off) that applied. (Figure 3.13) The rules that applied in the pedestrians' behaviors

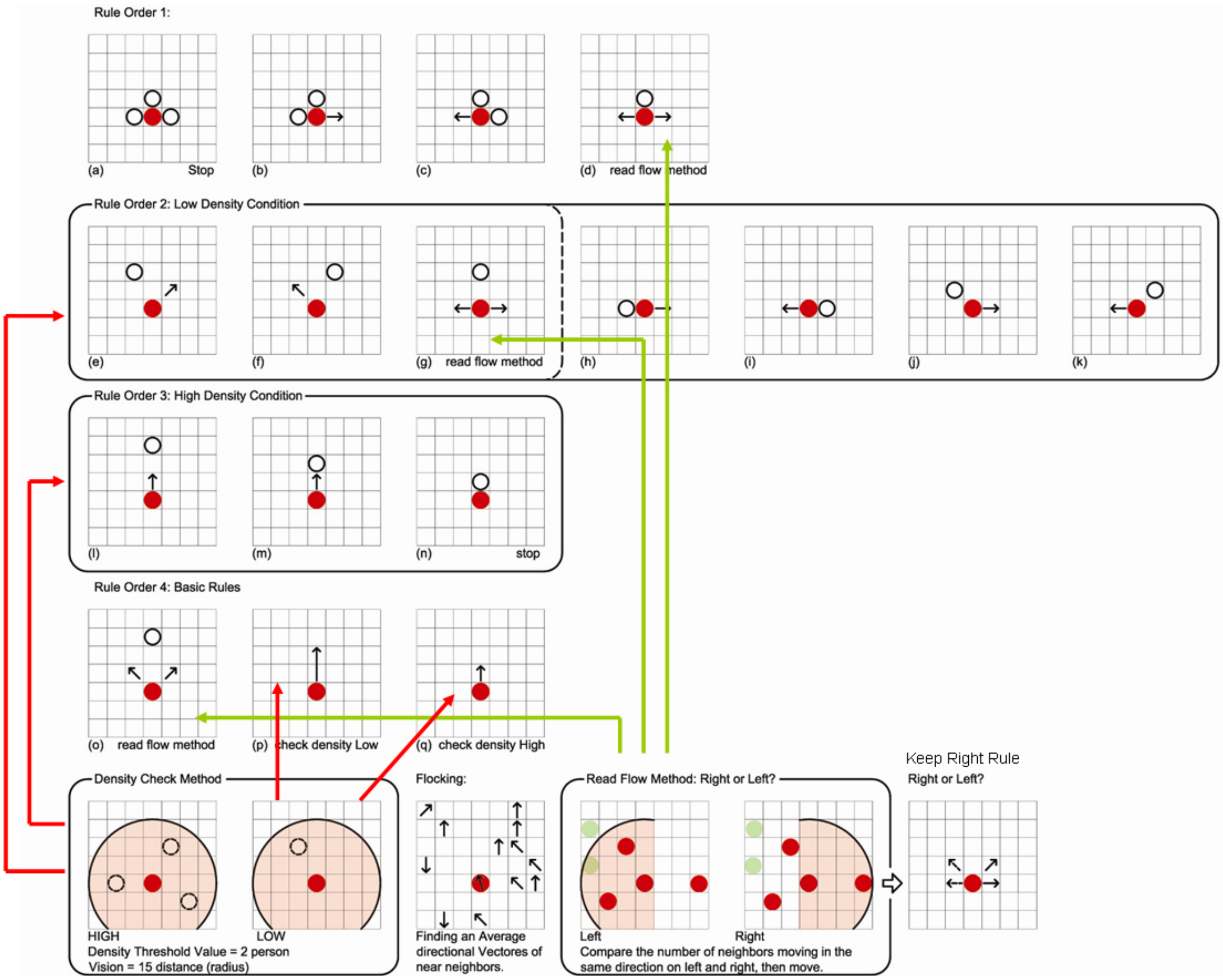


Figure 3.13:
Pedestrian Movement Rules

and algorithms have an order of applicability starting from their immediate neighboring conditions (Moore neighborhood) to their surroundings. Some rules (rule order 2 and 3) are turned on and off based on each pedestrian's local density conditions.(Figure 3.13) I found lane formation can be observed with or without additional rules, but they would affect the sizes and numbers of lanes. In this experiment, applying more rules in addition to the basic rules, agents gain better capabilities to sense the surrounding conditions, and they form more efficient lane flows. Applying more rules gives the agents behaviors more responsive to the different conditions. In conclusion, the more sensing capability pedestrians have, the wider lane widths become. Thus, the numbers of lanes also decrease, and eventually become two lanes – up and down directions.

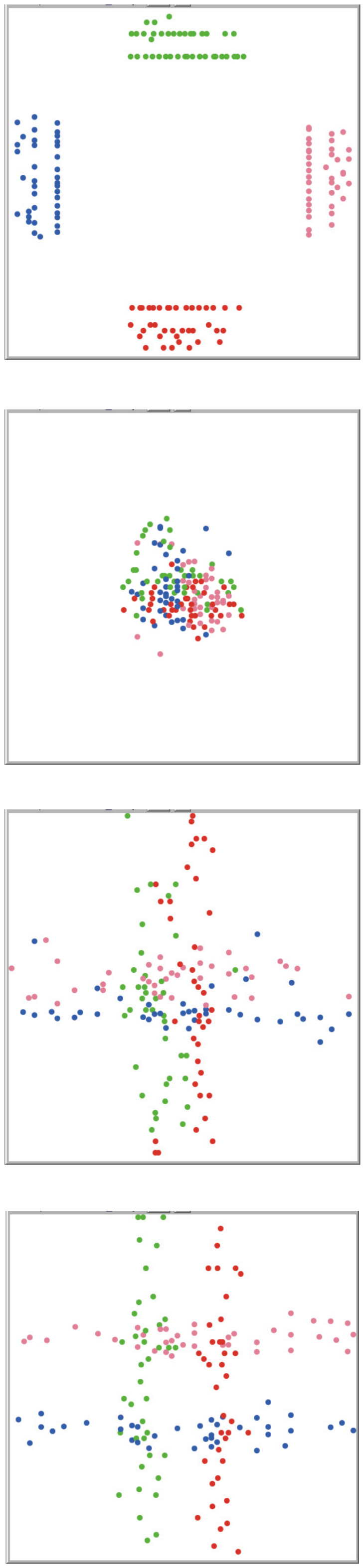


Figure 3.14:
Emergence of the Pin-wheel Formation.

Pedestrian Crossing 2: Intersection

Study of an "Intersection" adds another level of complexity to the above study of pedestrian crossing. Four groups of pedestrians are walking in different directions toward the intersection, and the basic behaviors of pedestrians are the same as the above conditions. This time, I had no prior information from any sources about the possible results of this case study and was quite personally excited about seeing the possible emergent behaviors. In this experiment, it was easily predicted that there was no way to perfectly avoid all the collisions between the agents' groups moving in different directions.

Figure 3.14 shows the resulting configurations from the model of intersection. Pedestrians form a pin-wheel like formation instead of lanes this time. This is also self-organizing collective behavior to minimize collision among them. In this case, avoidance of collision at all locations is not possible. Instead, the pin-wheel is their effort to minimize the points of collision down to four areas. Figure 3.15 shows two possible orientations for four lanes' flow directions. From the diagrams, it is comparatively clear that internally steadier formations evolve to balance the physics of flows. The above two exercises only implement locally defined individual behaviors, yet the resultant global behavior indicates self-organization among them.

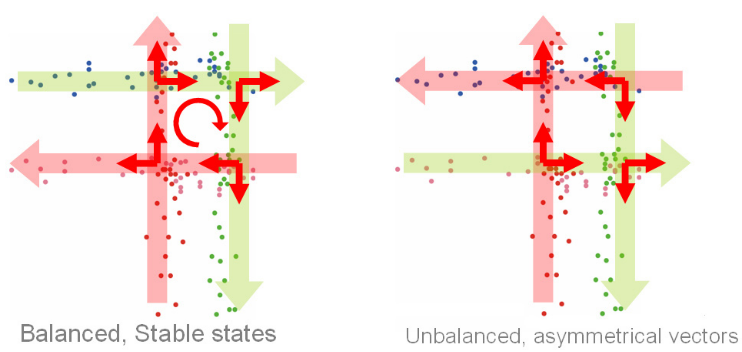


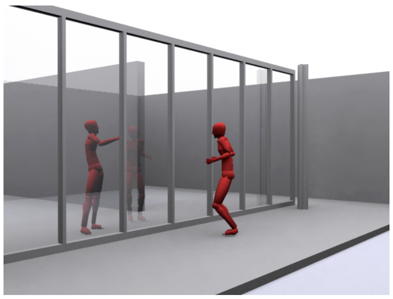
Figure 3.15:
Two possible directions in Formation.

Chapter 4

The Space Re-Actor

In this chapter, I will introduce series of case study of projects by Mies van der Rohe using the Space Re-Actor along with an explanation of the tool's functionality and user interface. Then I will report and analyze the results that I have obtained from the experiments. The tool's purpose will be introduced through the series of analysis on case studies using the existing buildings such as the Barcelona Pavilion. Both built and un-built works by Mies are selected for the case studies. The spaces designed by Mies are relatively loosely defined in terms of the programs and the specific usages of each individual spatial compartment, thus results of human responses are less predictable, and they are considered to be suited for the study.

The Barcelona "Pavilion"



The German Pavilion at the International Exposition in Barcelona (1928-1929) by Mies van der Rohe, usually referred to as the "Barcelona Pavilion" is the first building on which the functionality of the Space Re-Actor will be tested. The building type, a pavilion, was chosen because as a building type, a pavilion does not force any specific objective on the people visiting the building. Visitors' behaviors will be in direct response to the building's architectural features such as water features, benches, and sculptures, as well as to the transparency, opaqueness, or texture of the surface materials. They begin by wandering around the building and gradually find their ways toward what naturally attracts them. They do not have a specific purpose, such as shopping, eating, or working inside this building type, and conceptually this building type allows us to ignore any external reasons for visitors' behaviors other than the direct influence from their surrounding architectural conditions. Hence, the visitors' behaviors are induced by the architectural elements present, and this condition is well suited for solely concentrating on evaluating the spatial conditions.

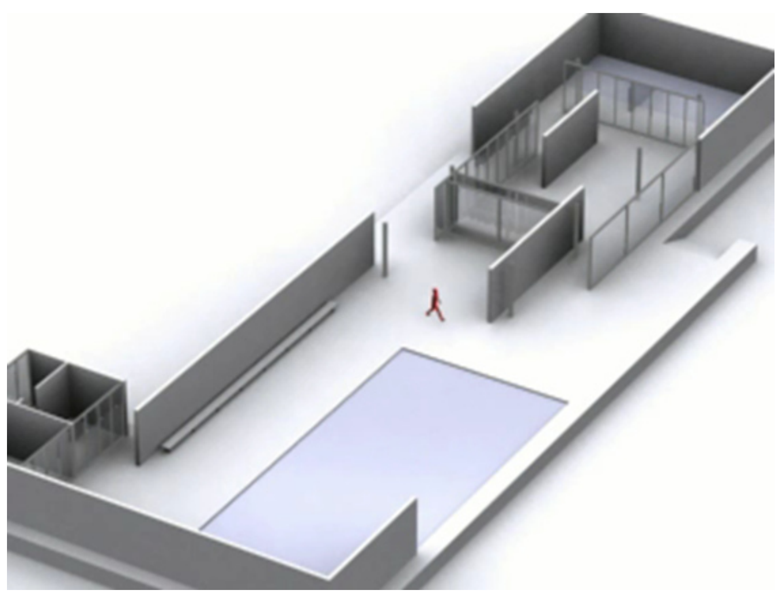


Figure 4.1:
Scenes from the Space Re-Actor

Re-actions:

The Space Re-Actor allows users to color-code the architectural elements to assign particular characteristics to the materiality and features intrinsic to architectural spaces. The first version of the Space Re-Actor focuses on four psychological reactions within the environment. The following is the selected four reactions that I considered for this experiment.

Water Features:

Figure 4.2:
Re-Action 1: Attractor-based Reaction
Water Features, Sculptures.

The Barcelona Pavilion has two water ponds as major architectural features. They attract visitors' attention, and the visitors may halt for a moment to enjoy the views. Some other elements, such as sculpture and marble walls, also belong to this category of the attractor. Spatial allocation of these elements inside the overall composition by definition reflects the master designer's intention and motivation to shape people's circulation and experience. The Space Re-Actor allows users/designers to revise and update the plan information by directly drawing on the plan to assign different qualities and characteristics to attractors. How the specific placement of those attraction features can manipulate the visitors' behaviors and contribute to the overall experience of the pavilion are the questions to be explored by seeing the real-time reactions of walking figures. (Attractor based reaction)

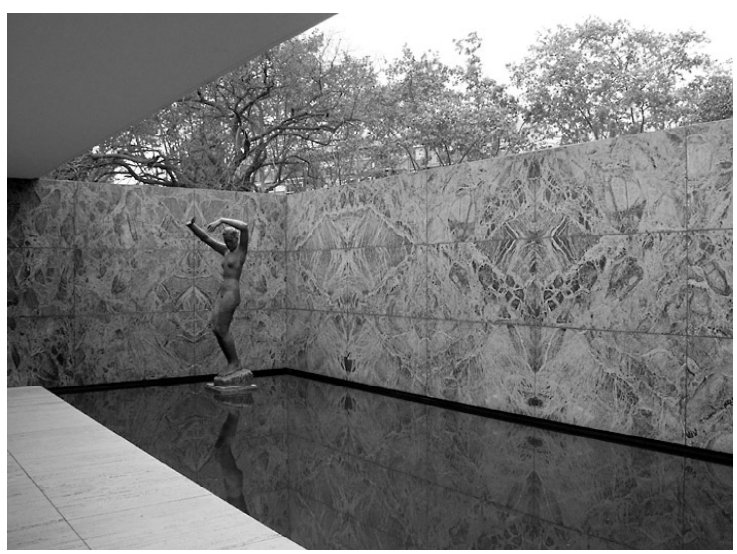


Figure 4.3:
Water Features and sculpture in the Barcelona Pavilion

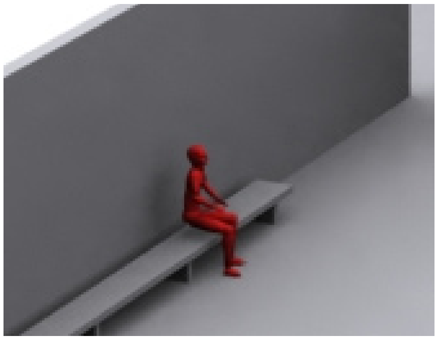


Figure 4.4:
Re-Action 2: Agents' Variable-dependent Reaction. Benches, Furniture. (above)
Sitting people at the Barcelona Pavilion (right)

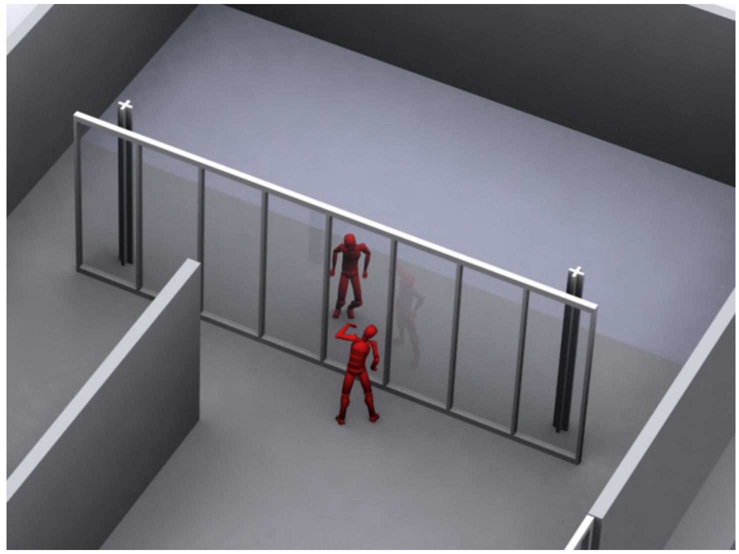
Benches, Furniture:

Depending on a visitor's activity level, she or he might find comfort by sitting on the benches. Figures have an internal variable to measure their activity level (energy level) to check whether they feel like sitting or not. This type of attractor will be conditionally applied based on the internal variables of the figures. The mechanics of these behaviors will be described in detail in the following sections. (Agents' Variable-dependent reaction)

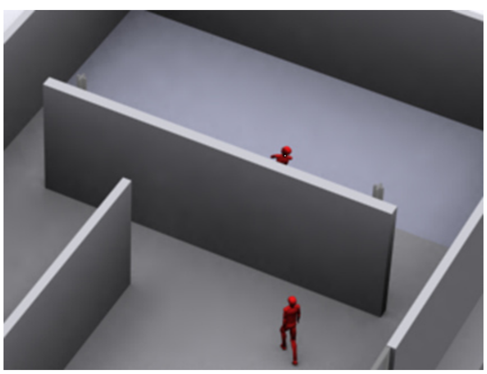
Figure 4.5:
Re-Action 3: Interaction Agent - Agent Reactions (above); Conversing People (left)

Interaction between people:

Besides the simple avoidance and collision detections introduced in the pedestrian crossing examples, interactions between the visitors are considered. Having two different categories of figures, sociable and shy, the tool can start to render an event in the scene. Heterogeneity among the agents governs the variations in interactions among the visitors. Some like to have more interactions with others and some do not. When two sociable people meet within a certain level of proximity on the street, conversation will start, and this begins to add a sense of place to the geometry. (Agents' type based reaction)



Transparency/Opaqueness:



“Can see and can be seen” is an important concept for the behavior of figures. The synthetic figures have vision, and some of their reactions are based on visibility. Better visibility allows them to find not only the attractors but also the others inside the space who could influence their next moves. The tool calculates the visibility at every coordinate point of the accessible space. I will explain this functionality further in the visibility section. (Visibility based reaction)

<u>**Figure 4.6:**</u>
Re-Action 3a: Transparency
Re-Action 3a: Opaqueness
Visibility-based Reactions (above)
Curtain wall (left) Marble walls (right) of the Barcelona Pavilion.

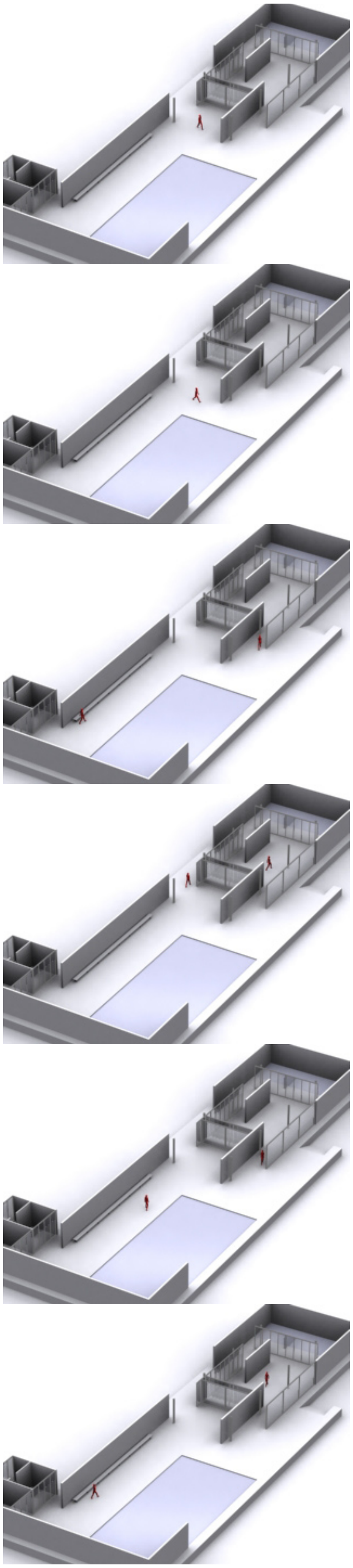


Figure 4.6 a:
Animated Sequences.

Mechanics of Realization:

Before going into the results and discussion of the tool's output, I would like to explain the functionality, user interface, and the general work flow of the Space Re-Actor. I will also explain the techniques that I have used behind the scenes.

The input of the tool will be the space designed by users in three dimensional model and pixel-based plan formats. The three dimensional model will be used as a stage set for the final animated representation. The pixel-based plan will be used for the agent-based computation process. Users are recommended to color-code their floor plan to assign the above-mentioned spatial characteristics and qualities according to their design intentions. At the moment, the tool has six selected pallets for the qualities user can choose and assign, but conceptually speaking, it can expand as user needs. The results from the computation will be exported into visualization software environment to achieve superior representational qualities. This final process will alter the conventional flat seemingly mechanical simulations into cinematic representation in true four-dimensional scale.

Pixel-based Floor Plan (Discrete vs. Continuum):

The past examples from the pedestrian crossing studies are adopting discrete floor grid system in order to increase the computational speed. The idea was to dicretize a floor area into cells, and each cell represents open area, obstacles, and other elements. People moves from cell to cell based on the rules described in the last chapter. There are always critique about how this discrete representation can manage to grasp the smooth flow of actual human movements and behaviors.

In order to achieve more architectural descriptions into the user inputted plans, the Space Re-Actor allow user to adjust the granular resolution of the input plan. Eight to ten pixels per one meter is descent resolution to describe required fineness of spatial elements to execute the simulations since the thinnest required components in the plan – thickness of framings for the glazing – is about five to eight centimeter. A physical size of the figure is also relatively set to the resolution of the plan and is represented by buffer zone around its centroidal location.
Production of this pixel based floor plan can be done in any image editing software, such as Adobe Photoshop, or directly exporting vector-based conventional CAD software files.

Autonomous Synthetic Figures:

The figures are one-hundred-seventy-five centimeter tall (about the height of the author) and possess walking speed of four kilometers per hour. In addition to the collision detection algorithms that I have implemented from a series of pedestrian crossing examples, synthetic figures have more important technical implementations.

Since this building is a pavilion, I set the rate of their entry to the pavilion (arrival rate) to fifteen persons per hour. This rate is a typical average arrival rate for a medium-size exhibition space (not a peak hour, but a more average rate). To make this rate more realistic, I used the Poisson process with mean arrival rate of fifteen visitors per hour. Many people are appearing, most likely about every four minutes, but Poisson distribution will allow me to include the chance of, for example, two or more people entering close together. (Similar to the discussion at randomness section, probability or likeliness of occurrences of events can be modeled by the use of various probability distribution functions.)

Variables:

I now begin to explain the internal variables for the synthetic figure. The listed below is the major variables possessed by the figures.

- Vision
- Memory
- Heterogeneity
- Energy

Vision:

The figure has vision that enables it to recognize the surrounding physical conditions that are described in a synthetic architectural model. Walking figures need to identify the "types" of elements ahead and the "level of visibility" around themselves. Each figure has variables to store the information about direction, distance, and types of element ahead of them. (Figure 4.7) Based on this information, figures will make decisions about which direction to go and how to respond to the elements. The agent-based computation system, NetLogo, is a pixel-based environment, and the following elements are color-coded to make them recognizable to the agents. In other words, cognition of the various materials is done by color assignment inside the software. The Space Re-Actor's interface allows its users to directly draw on the plan and assign qualities and characteristics to the elements in a real-time manner. (Figure 4.8) One can draw new partitions, windows, furniture, and other attractors in desired locations to view the difference in potential behaviors.

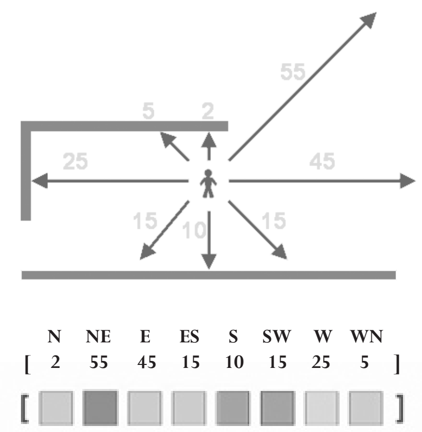
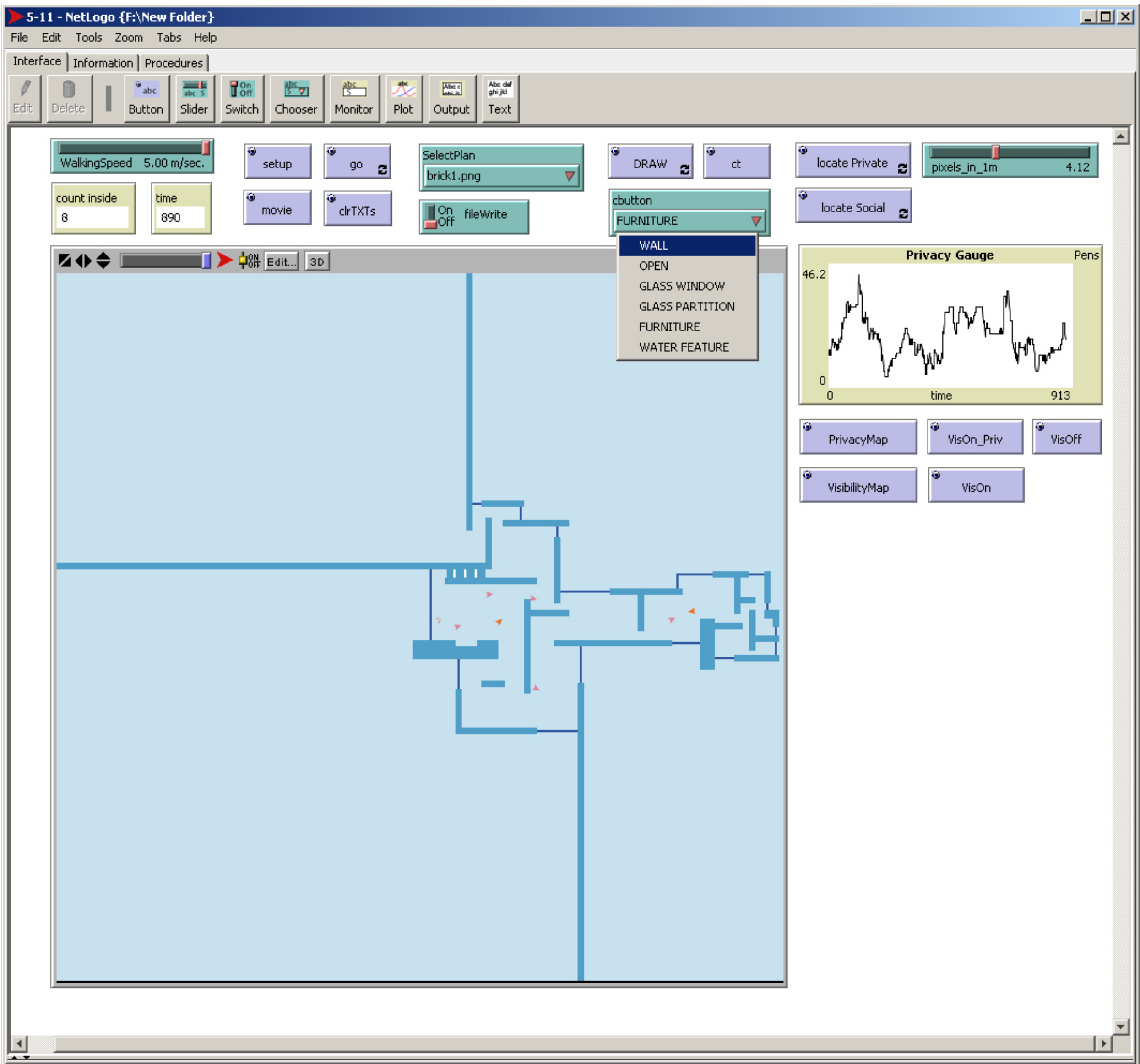


Figure 4.7:
Agent's Vision:

- Solid Wall
- Open Space
- Exterior Glazing
- Glass Partition
- Furniture (Bench)
- Water Features

Figure 4.8:
User Interface of the Space Re-actor



WalkingSpeed:
Set agents' average walking speed

fileWrite:
Send agents' behaviors into .txt file format

Movie:
Record QuickTime movie of screen shots

SelectPlan:
Import plan options. Plans can be made in any garaphic software.

Draw/cbutton:
Select architectural elements, such as wall, glass window, benches, and so on, then one can draw them directly in plans.

locate Private/social:
Insert agents with varying degrees of sociability.

Privacy Gauge:
Measure average degree of privacy.

pixels-in-1m:
Adjust resolution and scale of plans.

Another important aspect regarding vision is to identify the level of visibility at each coordinate inside the space we are investigating. Agents will measure the distance from their locations to the closest visual obstacles in many directions around themselves. The finer the interval of the directions you have, the better the resolution you gain in this case. I began from eight directions around the figure (Moore's neighborhood), and give some hierarchy to the choice of directions which figures can take based on the proximity to the objects ahead. In addition to the color schemes mentioned earlier, this technique will help agent to evaluate their choices of moves and behaviors. How they decide among choices will be discussed in the choice heuristics section.

Inside the agent-based computation environment, computing the above-mentioned visibility for every step agents take requires burdensome calculations and slows down the simulation. Particularly when the aim of the simulation is qualitative visual representation to evoke the sense of place in an animated format, rather than the quantitative results in a numerical format, a smooth flow is essential for the purpose. The idea introduced by the Space Syntax Group, Visibility Map, executes all the calculations prior to the simulation and restores the visibility information as variables attributed to the location rather than to agents (Turner and Penn, 2002). This approach minimize the time that it takes to compute while simulations are running.

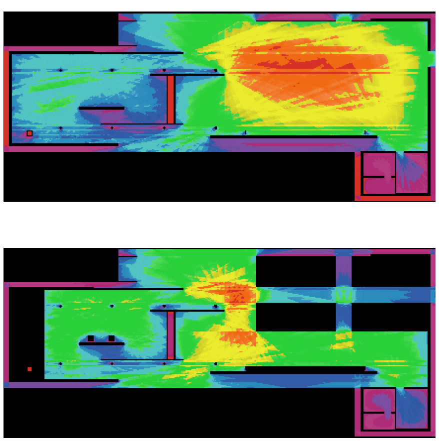


Figure 4.9:
Visibility Map based on the notion introduced by the Space Syntax Group.

Memory:

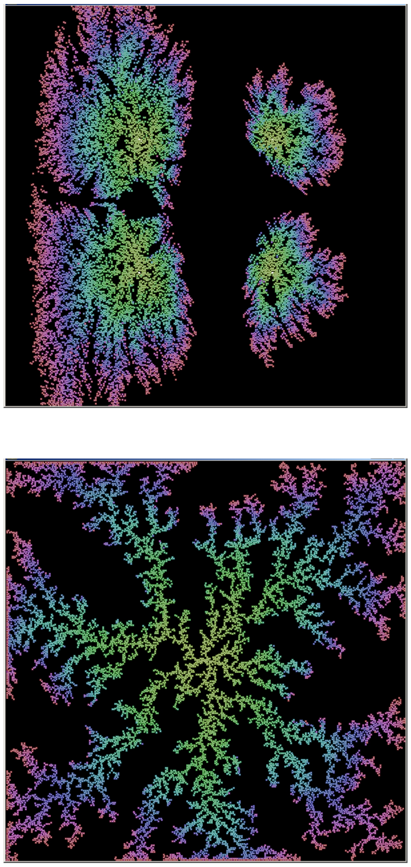


Figure 4.10:
The Diffusion Limited Aggregation using random walk. (by author)

Figures also have memory of where they were in the previous two hundred steps in the past. This memory prevents them from repeating the same responses excessively right away. To simulate the natural flow of walking movement is a challenge throughout my study. I began by interpreting the Diffusion Limited Aggregation (DLA) in physics and coded several different random walk patterns, then my interests have moved to human walk. Starting from a pure random walk, what makes a trajectory of movement more natural and human-like was an interesting issue. Some level of understanding about the past locations helps to accomplish a better smooth trajectory of the motion. Conditionally comparing the available options for the next moves with where they are coming from, they can make more sensible judgments. Later, I realized that assimilating the natural walk was not all about adopting the sophisticated algorithm. Slight adjustment and tweaking of dimensional constraints often dramatically changes the impression of the movement. These dimensional constraints are not registered by a constant value, but always changes relative to the figure's surrounding conditions. This seems to suggest that we human possesses personal perceptible dimension around us relative to the surrounding environment. However, further investigation needs to be done in this area.

Heterogeneity:

Figure 4.11:
Interaction between sociable figures.

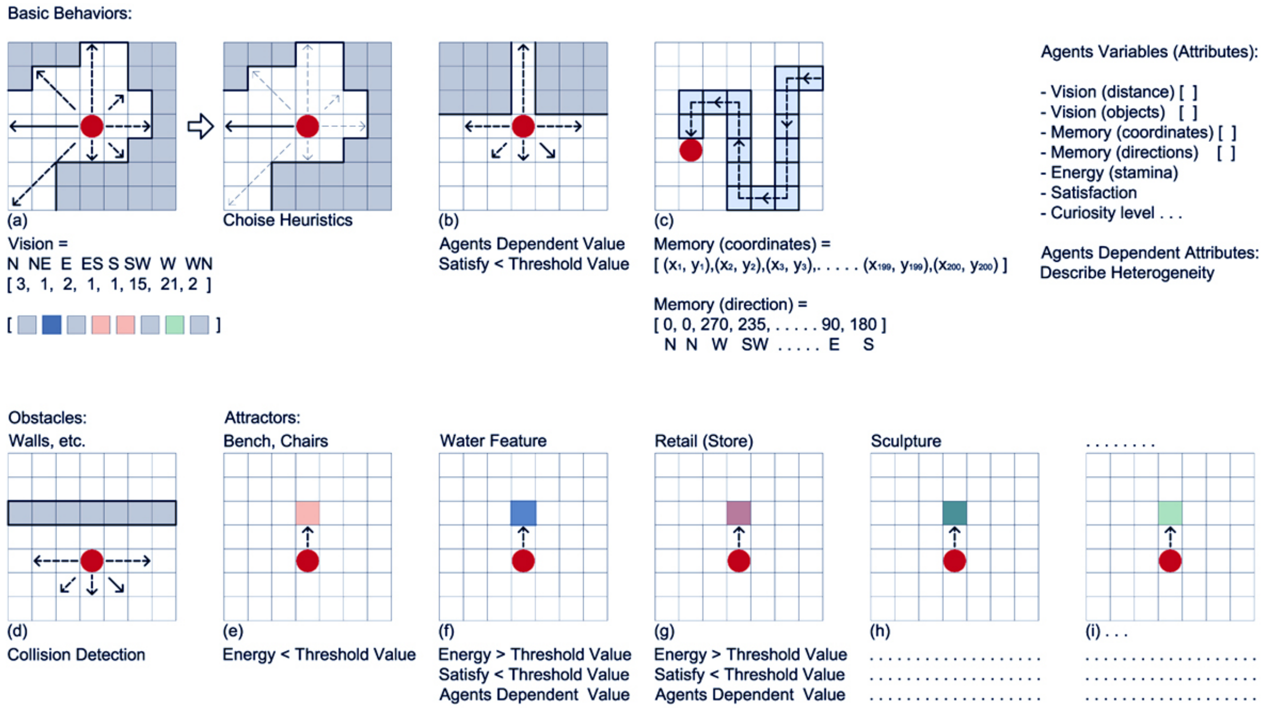
Heterogeneity among the agents is another important variable for the realization of the spatial quality for designers and audience. With this technique, their motions will be influenced by their individual characteristics. Each one has vision which works as a sensor to check the surrounding environment. Many of them have tendency to avoid stepping into the narrow path ways, but some of them do. What if they are architecture manias who want to check the every corner detail of the Mies's building? This part of the variance in individual characters is defined proportionally stochastically selected, for example one in five people randomly selected will choose the behavior. Another heterogeneity implemented for the experiment is "social" and "private" characters among the agents, and this characteristics will dominate the degree of above-mentioned interactions between people. The tool's interface allows users to be able to select which agents to be located in the scene.

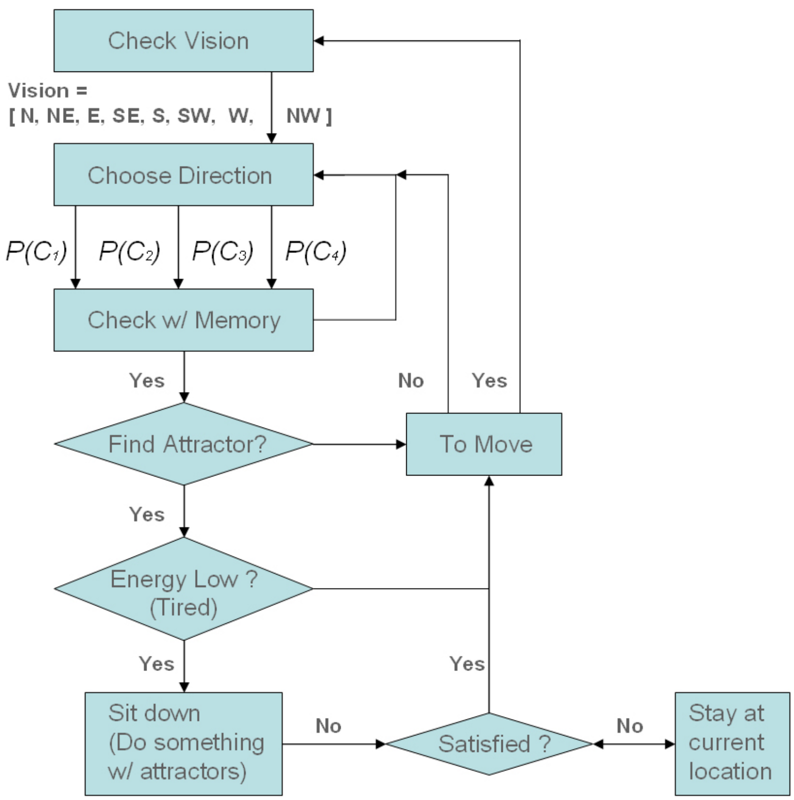
Energy:

Energy level governs the stamina and level of activity of the agents on the scene. For instance, if the energy level is lower than a certain threshold value, they will start to seek the place to rest (furniture: Bench). After regaining the energy, they will go back to respond with the normal level of curiosity to other attractors.

Choice Heuristics:

Figure 4.12 shows the states-transition diagram of the agent decision making process. A series of choices are chained and branched out from the current states of the figure, and this process is called choice heuristics. When figures have multiple choices, they will choose based on situations from their surrounding environments, their internal variables, and the different probabilities with which possible next states are weighted. Likelihoods of one behavior over the other can be expressed by directing randomness to a certain manner. In the "Interpreting Randomness" section in chapter 3, I mentioned the unevenly distributed probability for the occurrence of events in many real-life situations: for instance, one can go home from his or her work by walking, bus, metro, or taxi, and one might have one-in-billions chance of being struck by lightning. Their chances of occurring are not uniformly distributed. For the sake of simulation, these differing probabilities are interpreted and applied to the figure's tendencies to select one state over the others. The interpretation of the events' likelihoods should ideally reflect patterns of human behavior in real-life. Choosing one specific probability mass function (PMF) for the purpose will enforce one particular interpretation into simulation, and this is always a critical issue for researchers. The aim of these exercises is to render the potential events and scenes of the building ideas, which had been left simply as states of geometry; to turn the results obtained into universally valid quantitative results is not the ambition of these experiments. The scope of reliability of results obtained through behavioral simulation is a critical bone of contention for researchers, and I will discuss this topic further in the next chapter.





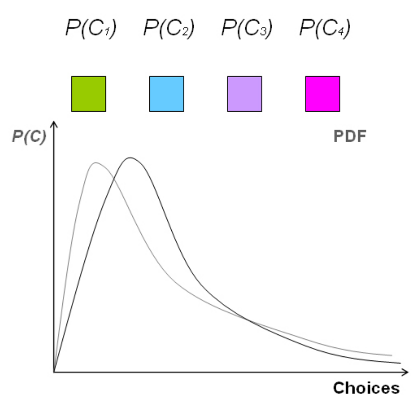


__Figure 4.12:__
Simplified Diagram for agents' stochastic decision making process.
States Transition Diagram for agents. (partial rules)

__Figure 4.13:__
Probability Mass (Density) Function
Events are weighted with different prob.

Loss Aversion:

In the area of behavioral economics, provocative research has been undertaken regarding human cognitive and emotional biases in the quest to understand economic decisions. “Cognitive bias” here means distortion in the way humans perceive reality. Describing behaviors and providing some rationale for each decision making process of agents are critical parts in the computer simulations. The work of D. Kahneman, A. Tversky, loss aversion has shed light on our tendencies in decision making. Suppose one has a chance of winning one million dollars or losing one million dollars (having to pay it), and the probability of the two events occurring is equal. Assuming one does not have enough money to pay the penalty right away, which would mean one would be in big trouble in case of loss, one will be much more likely to avoid losing one million dollar than to try to gain it. In other words, we are more conservative against loss. Our utility function is not symmetric for gain and loss, although the probability shows fifty-fifty chances. This point seems trivial, but becomes extremely important concept for describing human behavior in the form of algorithms or mathematical formulas for studies in economics. Although the level of the implementation of human behaviors in this experiment does not include such phenomena as loss aversion, such sophisticated findings are extremely important for describing human behavior for future simulations.

Note: The diagam in figure 4.12 represent an interesting resemblance to states-transition diagram - Markov chains - used in queuing theory.

Toward Superior Visualization:

Two aims of simulations:

Problem Solving Approaches

- **Analytical**
- **Simulation**
  - **Quantitative**
  - **Qualitative**
  - **The Space Re-Actor (enactment software)**

Figure 4.14:
Various problem solving approarches.

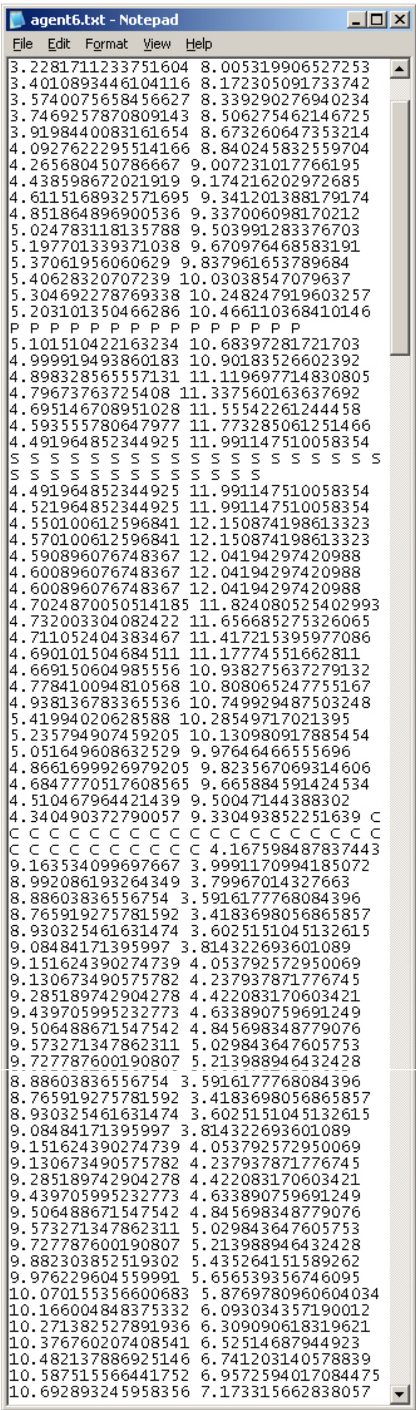
Broadly, simulations involving the movements of crowds fall into two categories. One category aims to validate results quantitatively and finds the correspondence to real-life observations of particular conditions. Usually simulations of this type derive quantitative information from the simulated phenomena. The other aims to achieve high quality representation of events to communicate ideas by tapping the viewer's subjective experience. (evoking the viewers' sensibilities.) In this case, the results may not always provide definite scientific quantitatively comparable data, but they help users' judgments about specific events or spaces by providing qualitative information. Sometimes, it is not so much a matter of subjectivity or objectivity of the resulting images. Rather the issue here is whether by visualizing one case of interpretation about particular events or spaces, viewers can share and discuss the same interpretations of the events, the "same target." Multiple viewers can share the same output so that the arguments between the viewers become more objective. There can be many different interpretations of the same events, but without visualizing one instance of interpretations, the targets are incommensurable. This approach may not always lead to quantitative results, but providing a cinematic representation of spaces will enable us to initiate and develop the discussion about the latent characteristics of the issues on the table. With aesthetic matters, no one evaluative judgment is uniquely correct. Architecture, in particular, is an activity of design, and there is no singularity in its evaluation process.

The Space Re-Actor definitely belongs to the latter category of simulations. In many cases, whether a particular location in proposed spaces should be activated or not is totally dependent on designers' decisions, and the animated results will present a potential realization of places that may suggest better ideas to designers. By allowing users to map and assign different attractors in different locations, the Space Re-Actor will be able to provide different interpretations of the same spaces. One may think that visualization is mere interpretation of the simulation results, but, for this project, the output form – being realistic three dimensional representations – is highly important because of the qualitative nature of architectural design.

Encoding and Decoding of Text files:

Results from the agent-based computation of the Space Re-Actor will define all the behaviors and movements of the figures. In other words, all the intelligence about the autonomous behaviors is acquired from the simulation program developed by the author in the programming environment in NetLogo. In order to achieve physical three dimensional qualities in representation, all these behavioral information will be once translated (encoded) into text files to export the information into superior external visualization environment. 3d Studio Max release 8 is selected for the final visual representational platform due to its high-end rendering capabilities, and its availability among the architects and students. Furthermore 3d Studio Max R.8 comes with CharacterStudio which provides standard (pre-made) bipedal character skeletons.

Figure 4.15:
Text File describes agent's coordinate points and corresponding behaviors in ASCII codes.



```
agent6.txt - Notepad
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3.4010893446104116 8.172305091733742
3.5740075658456627 8.339290276940234
3.7469257870809143 8.506275462146725
3.9198440083161654 8.673260647353214
4.0927622295514166 8.840245832559704
4.265680450786667 9.007231017766195
4.438598672021919 9.174216202972685
4.6115168932571695 9.341201388179174
4.851864896900536 9.337006098170212
5.024783118135788 9.503991283376703
5.197701339371038 9.670976468583191
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10.587515566441752 6.9572594017084475
10.692893245958356 7.173315662838057
```

This biped figure is used as an actor inside the Space Re-Actor's environment based on the results acquired form the agent-based computation.

The encoding of the simulation results will be done by the following manner. The figure's motions are generally categorized into two: "walking" and the "reactions." Information about the figures' walks will be translated into the coordinates points of the figures, and the reactions are translated by sending a certain ASCII code character flags corresponding to the specific behaviors. For instance, in this exercise, the correspondences to a certain movements are the followings.

"S" = Sitting

"P" = Parking (halting at one location, viewing something in scenes, and so on.)

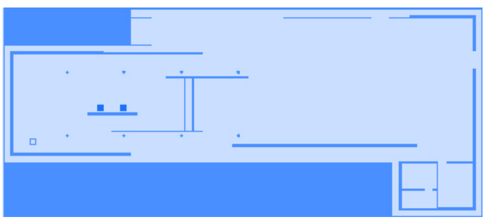
"C" = Talking (conversing)

The decoding of the text files – interpretation and translation into the 3d Studio Max environment – is done by 3d Studio Max script written by the author. This is relatively a mechanical procedure compared to the above-mentioned agent-based one. Taking all the coordinates information from the agents' walk, the script will first turn them into series of spline curves in plan, then generates footsteps along the spline curves for biped figures. While taking the numerical coordinates data from text files, it is simultaneously counting the numbers of steps that it takes to move the figures from one place to the other to adjust the time-rug between two environments. Whenever the script received the flags: "c", "s", and "p", it will insert the motion file with the corresponding behavior at a certain moment, durations, and locations. Some of the motion files are originally created from motion capture devises and are realizing natural human motions as close to the reality. (http://www. charactermotion.com accessed 5/7/2007) Series of motion files are collected by the max script to create Motion Flow diagrams. This process is similar to the mixing of sound tracks, although every operation is invisibly executed by the script.

Figure 4.16:
The Barcelona Pavilion color-coded plans

Option 1: Existing scheme

Option2: Ponds with cross-walks.



Option 3: No water features

Results:

The animated result from the tool brings a sense of place to the geometry by displaying the figures in motion. By observing the scales and numbers of footsteps that it takes to move figures from the entry point to the benches, viewers can obtain a sense of both speed and physical three-dimensional space. The viewers' interpretation may vary, depending on their various sensibilities, and may not always bring perfectly objective results or universally valid quantitative results. The tool's result offers a starting point for initiating viewers' evaluations of the spaces and helps users to quickly study a spatial design that is inhabited. Whether or not the tool itself is offering valid evaluations of the spaces is a critical issue. In other words, the validity of the tool's results may depend on the level of intelligence that is implemented in the figures, and this issue may lead the discussion into the debate about behavioral simulations in general. I would like to bring up this issue again in the discussion section.

The critical part is whether the tool has managed to capture the particular movement patterns unique to the composition of the space or not. I tested the tool with three different floor plan variations of the Barcelona Pavilion: one with its original existing condition, one with the small four ponds with cross walks instead of one large pond, and one without pond and without some of the original partitions (fairly open). (Figure 4.16) The latter two plan schemes were modified by the author in order to gauge the behavioral differences in varying conditions. Figures definitely chose to walk different paths and reacted to the different elements depending on the plans that I applied. The trajectories of the figures' walk in a duration of fifty hours were recorded based on four kilometers per hour as a known average walking

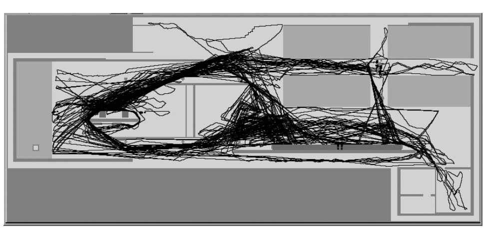


Figure 4.17:
Recorded trajectories of figures

speed. (Figure 4.17) (Synthetic figures vary their speeds based on their responses, although their base walking speed needs to be assigned.)

With the second plan – a pond with crosswalks (a large pond split into four smaller ponds) – I recorded that the figures spent more time wandering around the ponds area than in the other two variations. This also caused more interactions between the figures on the location and activated the space around the attractors. Differences in movement patterns from different configurations are observed.

In the third case, where there is no pond and no significant attractors mapped in plan, figures can not find any objective from the plan and continue to wander around aimlessly. They seem all equally scattered around the site; hence there are fewer interactions between them.

Privacy Mapping: Spatial Hierarchy

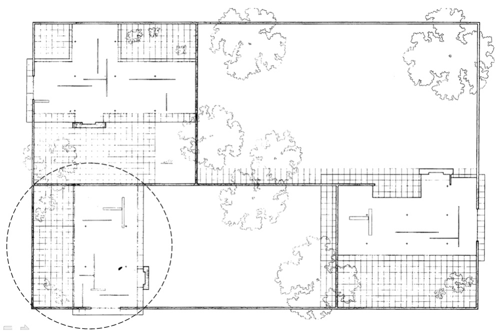
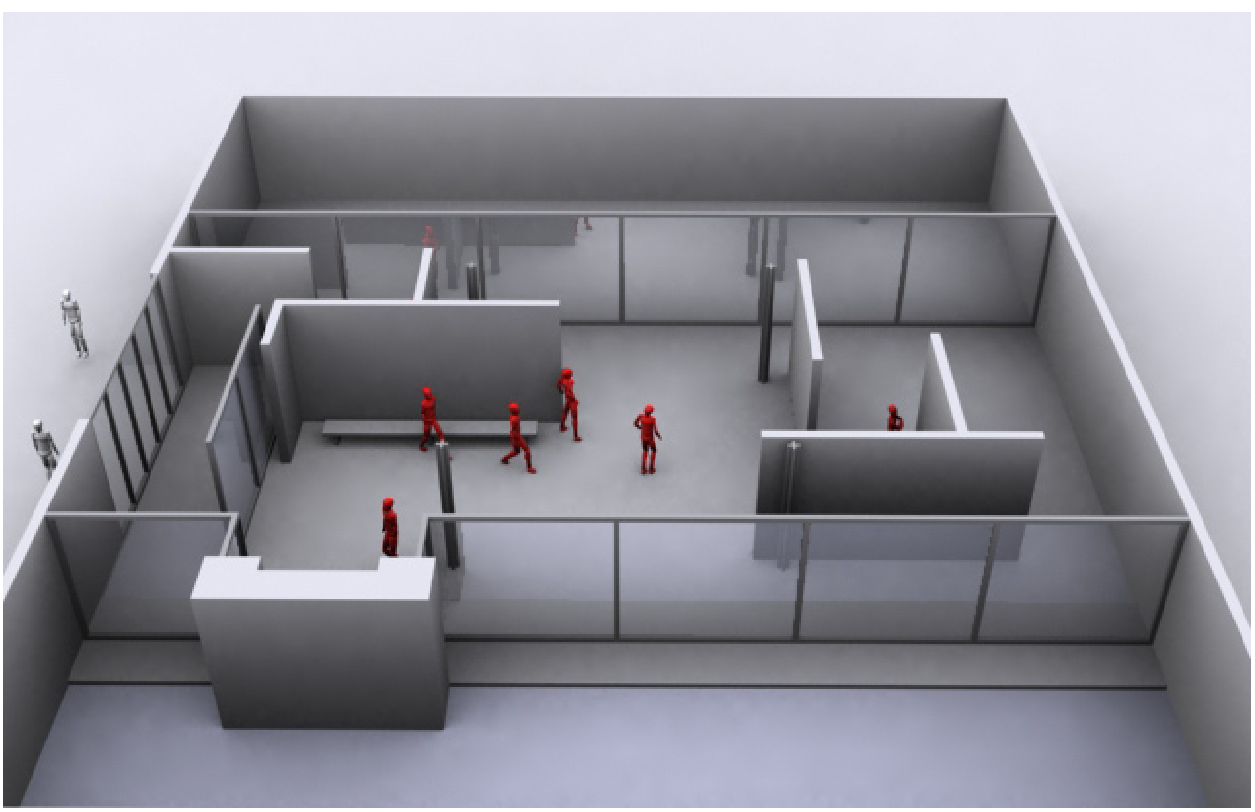


Figure 4.18:
The group of court house, 1931

In 1931, Mies designed the group of Court "Houses." This project was never built, and Mies left only a few traces of geometry. The rectangular site is surrounded by brick walls around its perimeter to provide privacy and form enclosed open courtyards for each house. To test and sculpt the hidden spatial qualities left behind by Mies's sketches, I decided to use the Space Re-Actor for one unit of the court house. Unlike the Barcelona Pavilion building type, "House" suggests another type of approach to utilize the benefits of autonomous figures. In building types such as museums, exhibition spaces, and pavilions, their spatial components and displayed objects are the main cause of the motions and responses of the people, while residential projects represent different characters and objectives to the people inside. I propose "Privacy Mapping" for this exercise to test particular aspect of spatial conditions.

Figure 4.19:
The Original plan with 7 occupants.



The Agent Location Measure:

Privacy mapping is a concept for gauging the level of privacy inside the space. I based the concept on two proposed criteria: level of exposure to the exterior environment (public) and the numbers of others who can see within the house. The first criterion can be simply calculated by projecting invisible rays 360 degrees around every point within the house. Areas of visual exposure to the exterior in elevations (in this experiment, it was in 2-d) are calculated using trigonometry, and it is simply the sum of these areas from the entire surroundings that indicates the privacy level of this coordinate point. (Figure 4.20 & 21) This measure is independent of the agents' information and is highly influenced by the transparency (materiality) of the walls and partitions inside the house. Any change of the materials and their locations may affect this location-based measure. This provides agents information about spatial hierarchy based on the privacy.

Figure 4.20:
Privacy mapping on brick country house, 1932

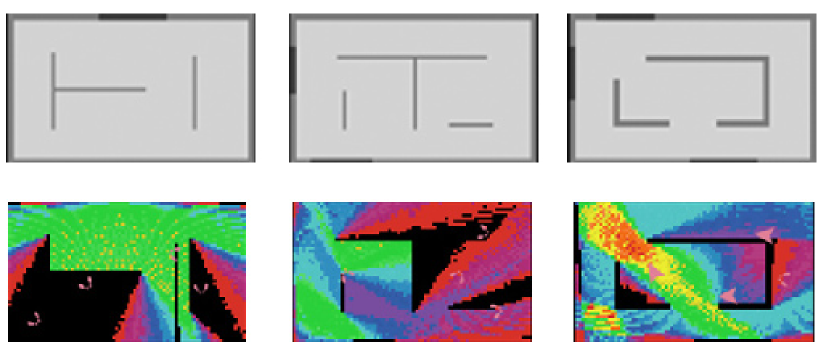


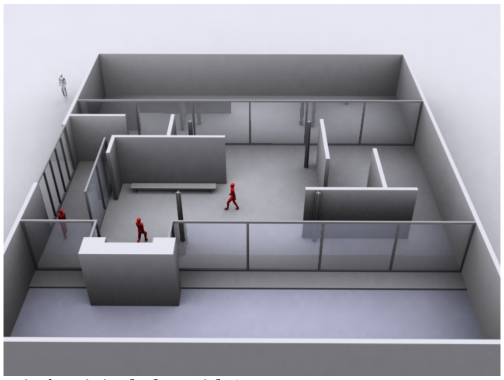
Figure 4.21:
Examples of Privacy mapping on simple plan schemes.
Privacy level, from red being high to purple, being low.

Plan Options:

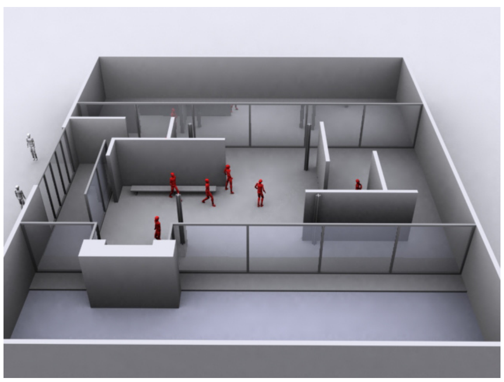
In this experiment, to test differences in behaviors comparatively, Mies's original plan was modified, and four different settings for the experiments were prepared.

- Mies's original plan with only a few (three) occupants.
- Mies's original plan with as many occupants as it can hold.
- The original plan is further divided into three smaller compartments.
- Two sides – north and south walls – become transparent glass walls.

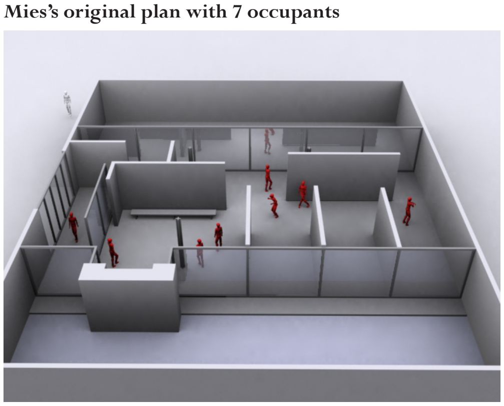
The above four settings produce different privacy mapping conditions. The tool's function visually demonstrates the intensity of the exposure to exterior environments by colors: from red, being high to purple, being low. Figures seek to move toward more private zones based on this score.



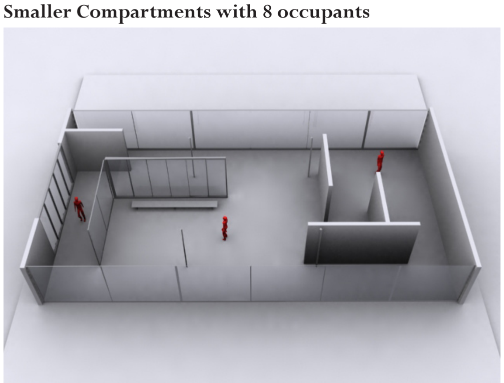
Mies's original plan with 3 occupants



Mies's original plan with 7 occupants

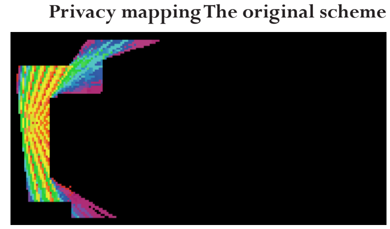


Smaller Compartments with 8 occupants

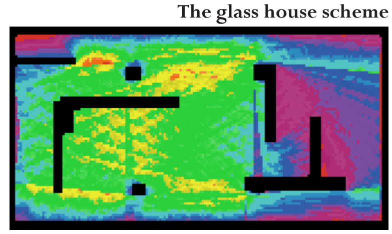


Glass house scheme with 3 occupants
Figure 4.22:

Figure 4.23:
Privacy mapping The original scheme



The glass house scheme



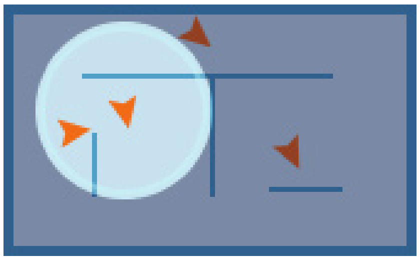


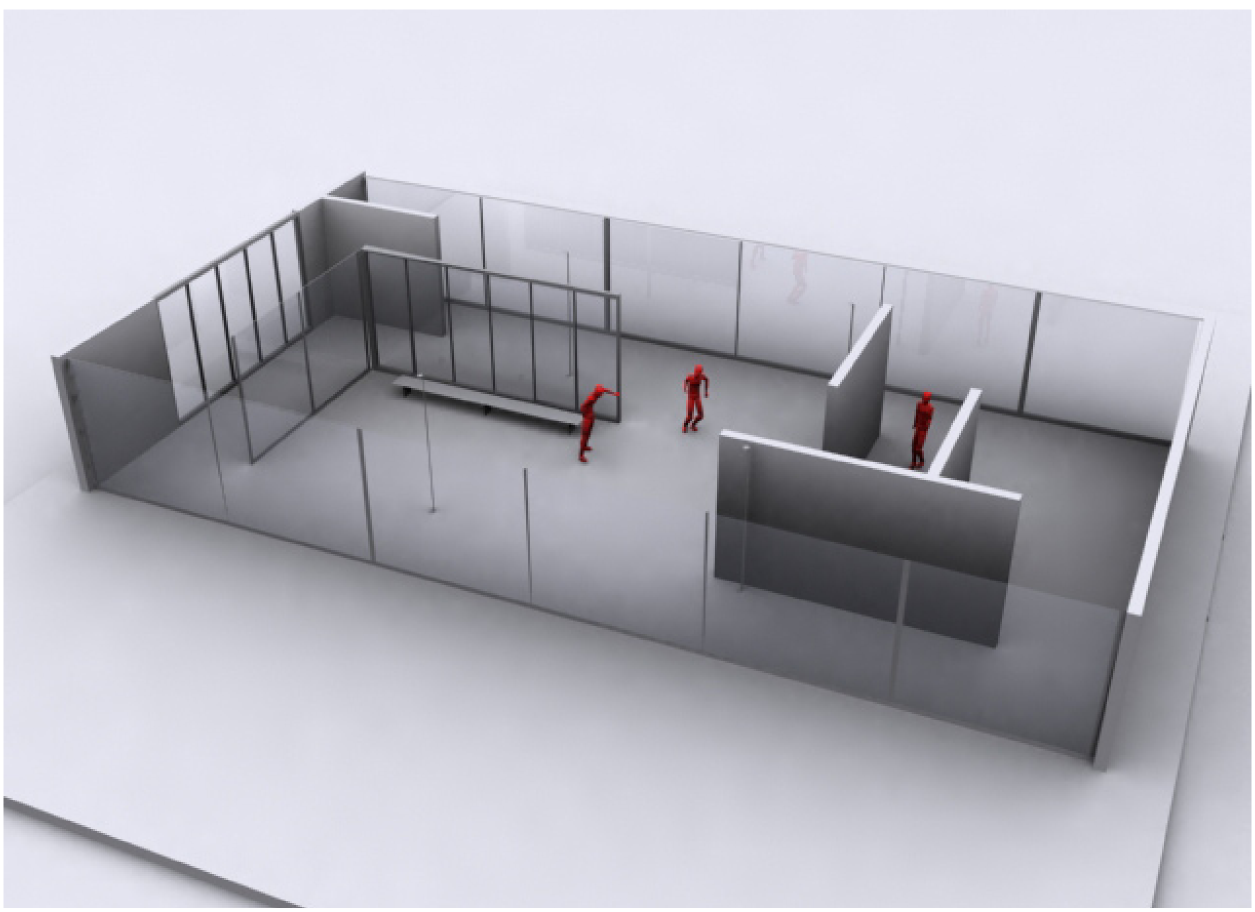
Figure 4.24:
Personal Space around agent. Plus-or-minus four feet in radius according to Hall.

The Agent to Agent Measuer:

Another criterion that I proposed is to measure privacy based on how many others are seen. When the density of the space is higher, people are likely to be seen by others, and this value will indicate the capacity of spaces that can maintain a level of privacy. Similarly, two plans with the same floor area and density may represent different privacy values according to the partitions and overall composition of the plans. On the contrary, this criterion is not always restricted to the current position of the figures. If someone happens to move within a certain proximity to the current individual, this can cause an increase in this value regardless of the physical spatial conditions.

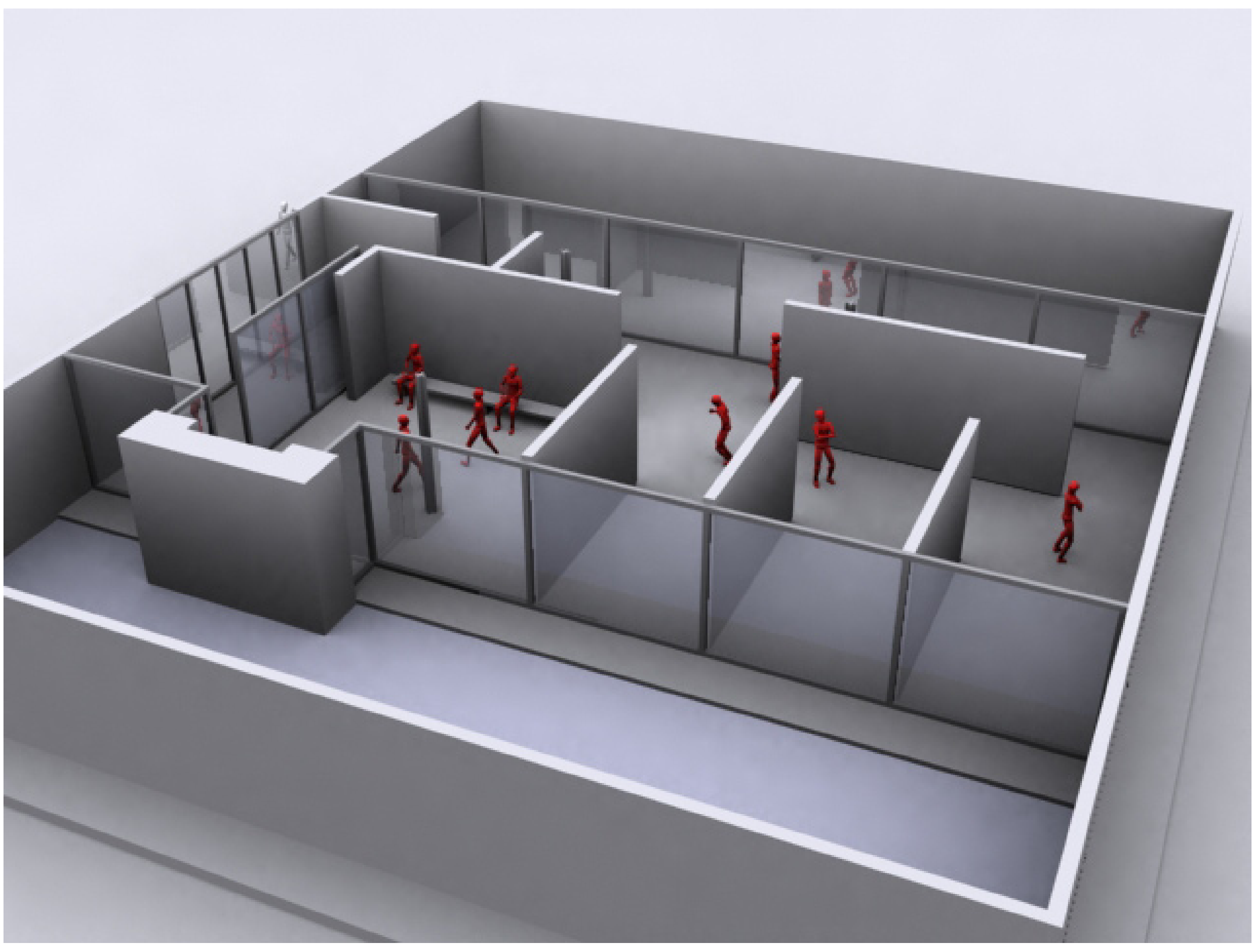
The derivation of the numerical figure is as follows. Each person inside the house checks the numbers of people in their potential visible range. In this exercise, I include anyone around the figure, even though some are not directly in the figure's current field of vision. Normally humans have maximum 180-degrees of forward-facing field of view of which plus-or-minus 140-degrees are actively visible using both eyes. In terms of privacy measurement, without directly seeing each other, someone being close within a certain range will cause changes in their senses, and whether or not they are facing each other as not considered for this measure. As long as there is no spatial discontinuity between two individuals, they are considered to be potentially visible to each other. The proximity, or distance between them, is an important privacy factor here. The relationship between the distance around oneself and one's perception of others has been introduced the studies such as Proxemics by Edward T. Hall and Personal Space by Robert Sommer. In "The Hidden Dimension," Hall suggests that two-and-a-half to four feet is considered to be "personal distance" which maintains a small hypothetical protective sphere between oneself and others. This dimension also varies, depending on one's cultural background, and is hardly ever objectified. It is an interesting idea to test the spaces with the different cultural dimensions possessed by various social groups. As a starting point of this study, any numbers of others within the dimension from Hall's studies, plus-or-minus four feet in radius as a threshold value, are counted as people who can greatly influence one's sense of privacy. Any others in visible areas outside of this distance are considered less influential; hence, those values decrease in inverse proportion to the distances from oneself. Values for every figure in the plan at each step are measured, and the averaged value of these shows the current state of agent-dependent privacy value.

Figure 4.25:
Glass House scheme with 3 occupants.



The above-mentioned two criteria are measured at every step, and whenever they fall below threshold values, the figures will stop. When all figures stop seeking, this will end the process, and this means that everyone found some degree of privacy around them inside the space. Two threshold values used to evaluate privacy are four meters for the location-based measure and less than one for the agent-dependent measure. (This does not allow anyone to be in the personal dimension.) I understand that this experiment's setting is extremely simplified compared to possible real-life scenarios, and it produces only one aspect of qualification. However, I have recorded different results from the above different plan variations, and this suggests that the plans' different characteristics affected the behaviors of inhabitants inside.

Figure 4.26:
Compartmentalized scheme.



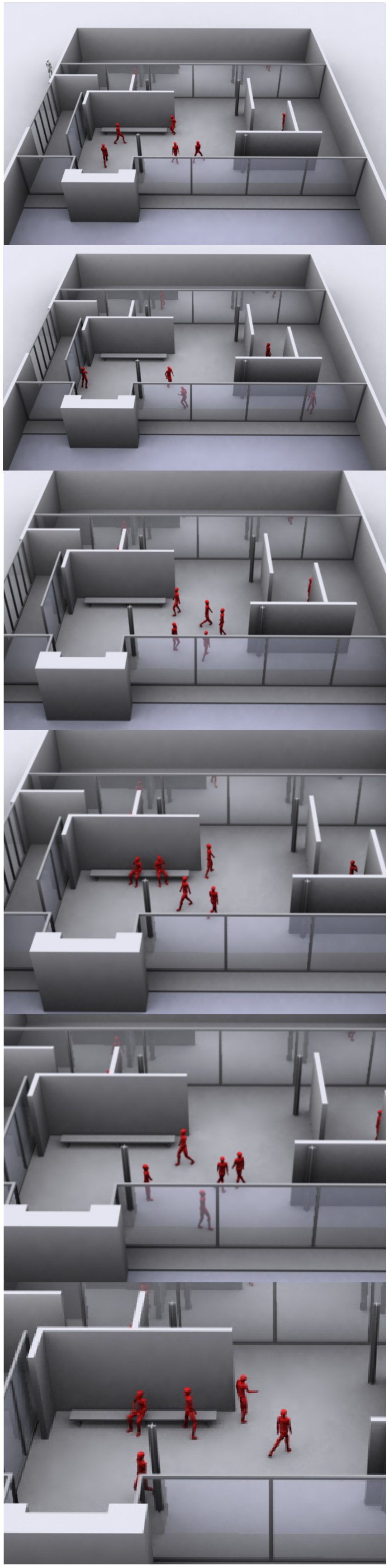


Figure 4.26 a:
Animated Sequence: The plan w/ 7 occupants.

Results:

In the original plan, with the insertion of a single occupant, a figure walked away from the glass window close to the entrance, which is the only area that is exposed to the public street, and it did not take very long for the figure to find a private spot. The original design by Mies is screened from the outside world by brick walls to maintain fairly private interior conditions. When the occupants are increased to three, they do not seem to have any problem finding their personal separations. After sitting on the sofa and having conversations, they walk for a while to find the spots easily. One by one, I increased the numbers of figures inside the house, and at seven people in the house, the house seemed obviously over-crowded, and they started to spend more time to find the private spots. Observation of the size of the house relative to the figures tells that this activity did not look like a residential activity any more. Even if one found a decent private spot, another one still looking for a spot intruded on figure's personal distance, and they both needed to start the search all over again. It took 29 seconds for three occupants and 147 sec. for seven occupants. Over the eight people, I rarely saw the end in their activities. If I did not see the end after 300 seconds, I terminated the simulation. If I did not see them stop in over fifteen trials, I considered that the case did not converge.

The plan with smaller compartments demonstrated higher tolerance for number of occupants. The plan split one large space into three 200 square feet spaces, which is closer to the size of the residential compartmentalization seen in Japanese conventional apartment layouts. The plan managed to have eight people inside, and they all found their spots in 95 seconds.

The last plan with north and south exposure by the wide glass windows barely showed the convergence. With the three

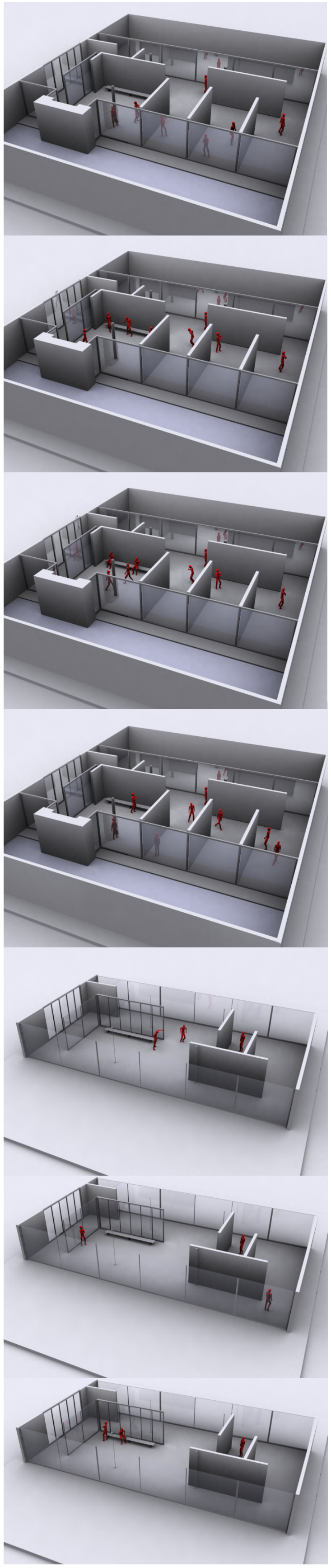


Figure 4.26 b:
Animated Sequence: plan scheme 2 and 3

occupants, it took 102 seconds to see them all stopped, and the plan barely accept any more occupants to see them stop.

The fact of others being inside the same space adds another layer of complexities to this exercise. As I indicated earlier, figures' behaviors are not always constrained to follow a single pattern. They each have some level of internal stochastic decision process so that they may act differently in every run of the simulation. In addition, at every successive moment, the conditions around figures are constantly changed by others executing their responses, close together, which also cause their next decisions to differ. The iterations of these decision processes eventually lead to an unpredictable domain simulating the complexities that potentially exist in our real lives.

Although I recorded different times for convergence and different capacities for number of people in each case, since these experiments were based on one particular aspect of privacy, the time duration that it takes for all the figures to stop may not establish reliable significant meanings in real-life scenarios in strict sense. But these time measures are primarily not what I am interested in gaining from the tool. Rather by visualizing the figures' behaviors, viewers can gain a sense of space. For instance, viewers can gain a conception of the space by seeing how crowded the figures are, or how relaxed they seem. In the same way that, conventional rendering software can assign materials such as concrete, steel, or brick to generic geometrical primitives to display possible realizations of the building's appearance, this tool allows users to render the events and behaviors from a particular generic geometry chosen by the users. I will discuss this issue further in the next chapter.

Brick Country House Project, 1923

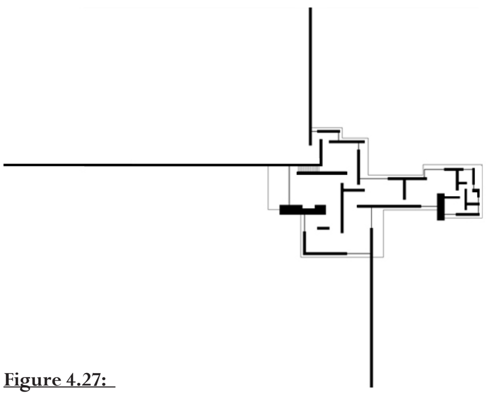


Figure 4.27:
Mies left us a trace of Geometry.

In 1923, Mies left only the trace of geometry for his design of a brick country house. Mies rarely showed the presence of people in his drawings; instead, he left us the perfect compositions. Finding out what types of quality this pure compositional masterpiece would have possessed with the presence of people is an interesting quest for me. My attempt is to add a sense of place to his geometry. Using my learning from prior experimentation with the Barcelona Pavilion, which was actually built and also simulated by the tool, I run the Space Re-Actor on this brick country house building. "Is this really a house, or a pavilion?" is an interesting question. The scale and behaviors of the figures may sculpt the building's hidden characteristics. This building (or composition) is one of the climaxes of Mies's early career, and this crystallization of geometry almost refuses to accept any presence of inhabitants as an additional extra component to his geometry. In contrast to Mies, another master architect of our era, Le Corbusier, had included many traces of people in his drawings. A notion such as the Modulor indicates his relentless effort to integrate human dimensions into his spatial conception. Testing the Space Re-Actor with these two different spatial conditions and comparing the results would be an exciting future exploration.

Figure 4.28

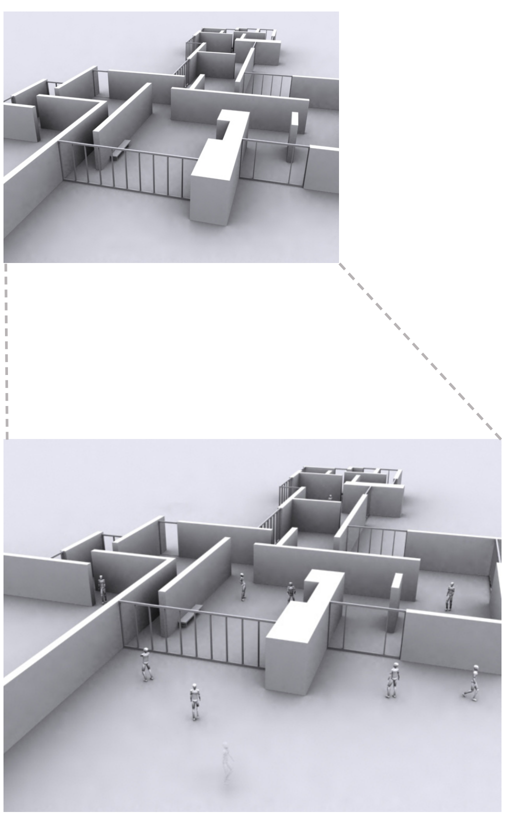


Figure 4.28 and .29 show some image clips from the results of animated representation by the Space Re-Actor.
This time, I would like to leave them for the reader/viewer's interpretations.

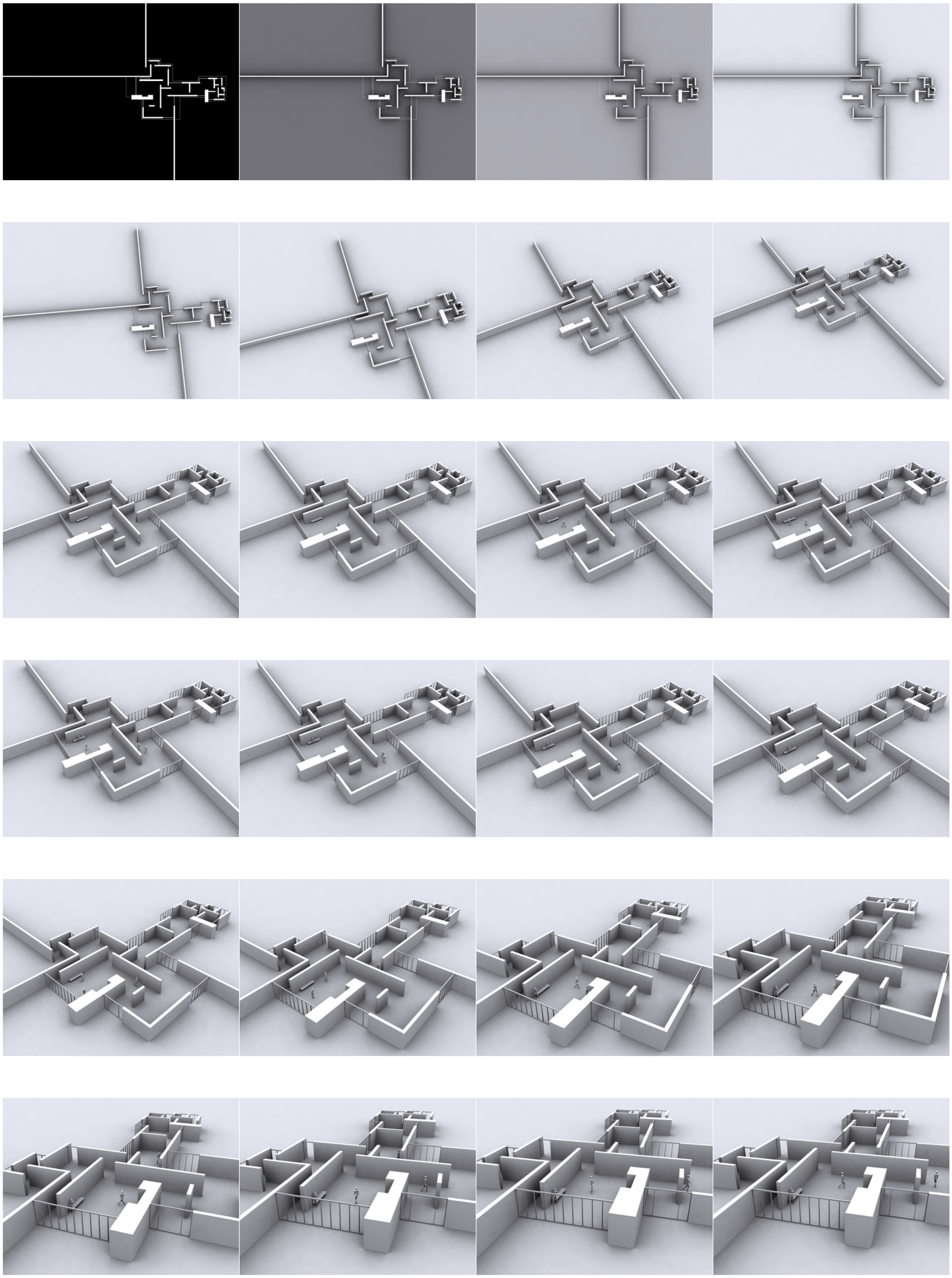


Figure 4.29: Animated Seaquence 1.

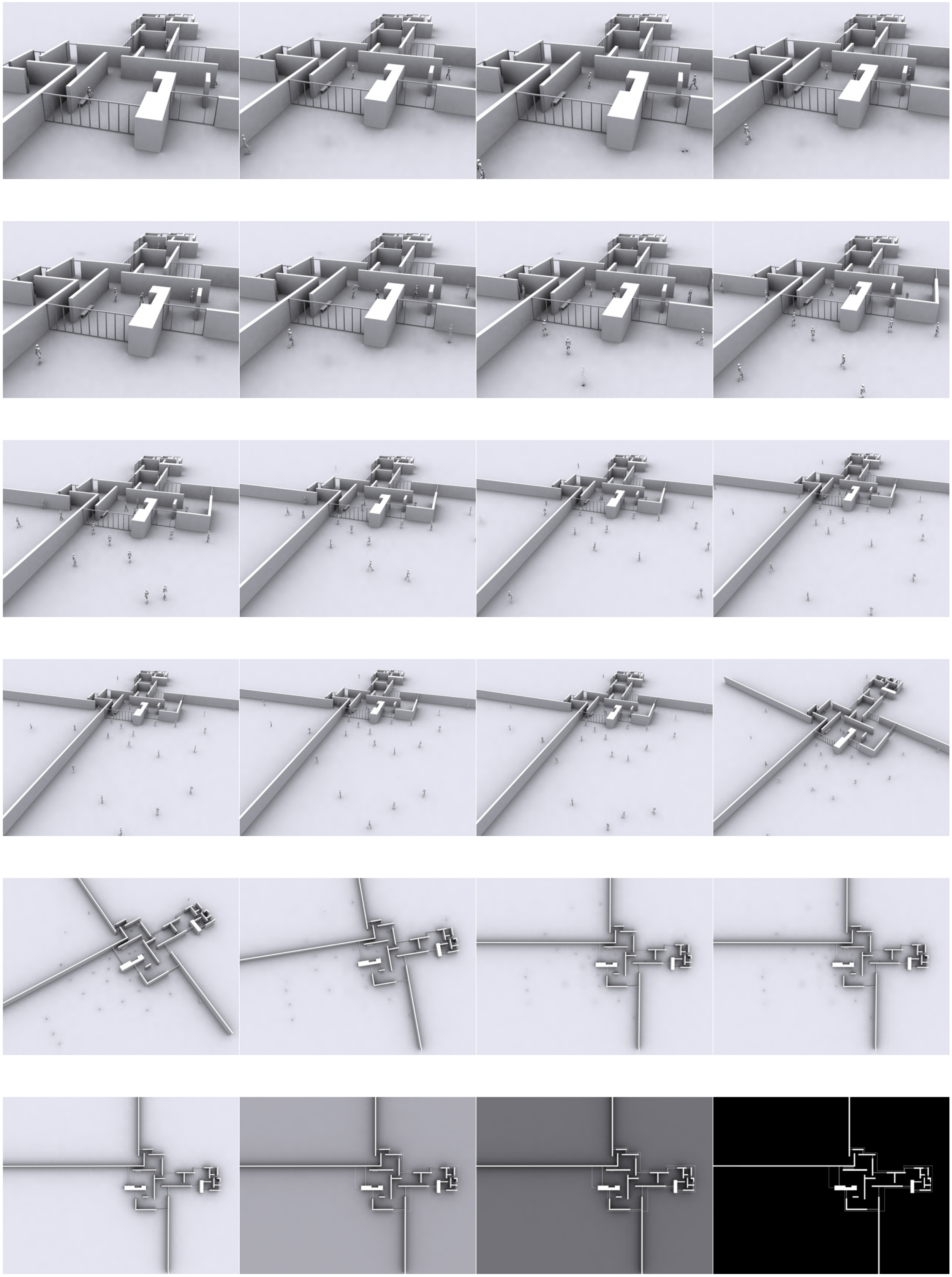


Figure 4.29: Animated Seaquence 2.

Chapter 5

Discussion and Critique:

I understand that describing the people's (figures') behaviors computationally is a controversial issue here. That "an Agent-based model can never perfectly duplicate human social interaction" is a perennial critique and a genuine problem for the computer and social scientists involved in behavioral simulations. Simulations are always based on premise that human beings will behave in certain ways under specific conditions. Even though possible behaviors are incorporated from actual events and scenarios, there is no proof that the behaviors include all possible occurrences. To be realistic, how far we can rely on knowledge-based judgments is a critical issue. The scope of reliability of results obtained through behavioral simulation is a critical bone of contention for researchers, not only in computer science, but also in operations research, social science, behavioral economics, and so on.

Through considering the results that I have obtained from the series of experiments using the Space Re-Actor, I began to realize that the importance of the tool lies in the effort to integrate "human involvement" into a spatial design. Behavioral aspects of the spatial design have yet to be addressed well in any existing design tools. Today's advanced computational design tools can produce complex forms and sophisticated visualizations of light, materials and geometry. But they are not suitable for helping people to quickly study and understand a spatial design as it would be inhabited. The proposed method lays a foundation for developing a new kind of software that overcomes this shortcoming.

The tool's results offer a starting point for initiating users' conceptions of a space and help them to immediately study a spatial design as inhabited. Having seen more than eight people frantically searching for comfort in the residential building suggests to us that the size and the layout of the building do not offer a satisfactory level of distance between the occupants. A space seems to exhibit different characteristics according to the numbers of occupants, their objectives inside the space, and the proportions of groups with different degrees of sociability.
As I indicated earlier in the section comparing analytical approach to simulation, one may be able to obtain discrete numerical data about people's comfort levels as they depend on the density of a space per unit area through analytical means, but comfort and other characteristics in particular spatial layouts and conditions can be more fully grasped through the use of simulations. Aggregation of all the architectural components, such as doors, partitions, windows, staircases, and furniture in specific layouts can be understood through the use of "enactment software" such as the use of a synthetic figure in the Space Re-Actor.

Spatial qualities in architectural design cannot be fully evaluated solely by looking at geometrical constructs without reference to inhabitants placed inside. The consequent emergent behaviors of people induced by characteristics of spaces may be impossible to predict, and indicate another layer of spatial qualities beyond the visible, formal, and aesthetic. A method for informing designers about the potential interactions between human behaviors and the spaces they are designing will constitute a valuable tool.

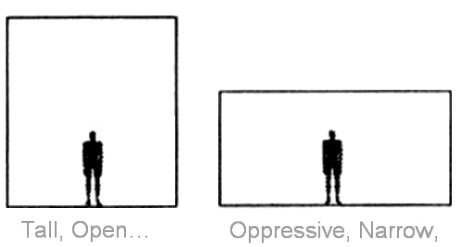
Whether the tool is offering valid evaluations of the spaces is a critical issue. The validity of the tool's results may depend on the level of intelligence that is implemented in the figures, and this concern may lead back to the debate about behavioral simulations in general. However, it is also debatable whether the Space Re-Actor belongs to the established category of simulations. How it differs from simulation may be possibly answered by the presence of "acting" by synthetic figures on a stage. The key to the future development of the tool will definitely lie in the improvement of the figures' cognitive capabilities. I list the potential future extensions to the current stage of the Space Re-Actor in the section that follows.

Extension to True 3-D Environments:

Although the final output of the current tool is represented inside the three-dimensional environment with realistic figures, the original agent-based computation environment is still in two-dimensional space in a pixelated world. This fact limits the tool's application to a space with a single floor level, and spatial characteristics that are affected by height are not interpreted. Technically, this improvement can be done by extending the same principle into the three-dimensional voxel-based world. This may exclude the translation process by the visualization rendering environment and build a better cohesion between behavioral computation and representations. Run time – time that it takes to execute the behavioral computation – will be a concern because of the burdensome calculation from additional dimensional expansion of fields, though the pallets for the spatial descriptions will increase.

Volumetric perception of a space is one potential psychological aspect that can only be possible by the adaptation of a truly three-dimensional environment. How one can feel broad, narrow, wide, open, secluded, oppressive or closed is deeply related to the volumetric quality of a space, and the sole square-footage of a space description almost never conveys the perception that one has imagined beforehand of actual involvement in spaces. One way to register this human evaluation is directly learning from the existing physical examples and data of psychological responses from actual human beings. This approach may establish a knowledge-based commensurable platform for such evaluation. In contrast, what interests the author more is rather than inventing the evaluation system, offering a platform for conception for users as if they were actually experiencing spaces

Figure 5.1:
Volumetric Perception of Spaces



before their realizations. Although I am interested in acquiring human response and behavioral patterns from knowledge-based date based on qualitative studies of spatial planning, evaluation of spaces can be left for the users of the tool. By seeing the events rendered by the presence of autonomous figures, users can use their own imaginations and judgments. This is a paradoxical theme since behavioral simulations will not begin without any knowledge-based behavioral implementation from actual human, but as soon as one selects one interpretation about human over the other, it will no longer possess universally valid objectivity.

Another potential technical extension can be an addition of learning abilities to figures. Current figures do not have the ability to learn and modify their behaviors based on their environment. One way to expand repertoire of behaviors is to provide a plug-in which can help users to prepare knowledge-based behavioral libraries that can extend figures' cognitive capabilities in a user's desired direction, although this will not allow figures to respond to every unique condition that is given by the users at every time of execution. If they have some level of pattern recognition for spatial sequences or behavioral patterns, figures may respond relative to a given specific condition by directly learning from current user input besides the general knowledge given from the outset.

Sculpting the Cultural Dimensions:

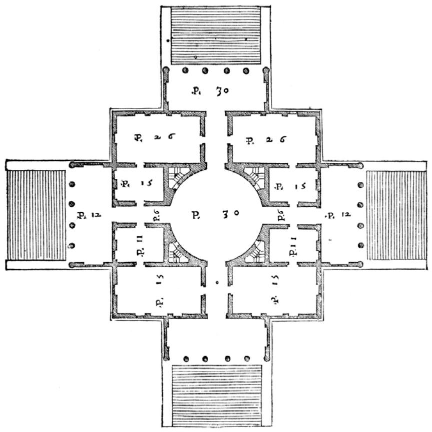


Figure 5.2a:
The plan of Villa Rotonda by Palladio.

The proximity, or distance between people, discussed in the Privacy Mapping section introduces an interesting interpretation about one's personal perceptions of the spaces. The dimensions for a hypothetical protective sphere around oneself and others are highly affected by one's cultural background. Hall's studies indicated that this dimension tends to become larger in the Western world and become smaller from the Middle East to East Asia. Generalization about these dimensions will not be easy since one's protective sphere may change depending on one's momentary psychological states, as well as on the cultural background. However, testing with different threshold values for the dimension may capture the different degree of sociability among the different cultural groups. The differences in spatial organization and characteristics seen in West and East can be considered as a result of accumulation of all these individual behavioral differences in culture.

On the other hand, spatial conditions surrounding users can cause their differences in behavior, too. For instance, many traditional Japanese spatial separations or boundaries are loosely defined by the sliding partitions made of Japanese paper called "Shoji" or "Fusuma," and they contribute to achieving flexible spatial organization seen in Katsura-Rikyu. (Figure5.2b) Aggregations of small compartments can form one large meeting room depending on the use. The translucency of the paper-based wall can introduce different qualities of light, sound, and psychological distance between the inhabitants. These characteristics are partly because the results of tectonics are readily available at the time in this specific region of the world, and this seems to indicate that the spatial characteristics are not all derived from behavioral

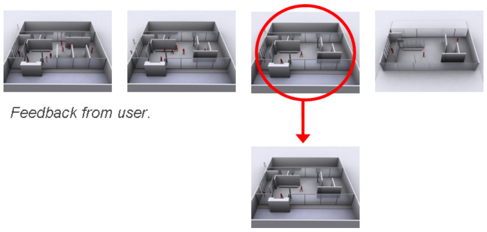
Figure 5.2b:
Katsura-Rikyu: Shoji Partitions

aspects of the local population. The behavioral patterns induced by these spaces may be different from those of the Western world where they have more deterministic spatial separations based on masonry construction. Trials with the use of tools with cognitive capabilities such as the Space Re-Actor may help in understanding and analyzing these qualitative differences through visualizing behavior.

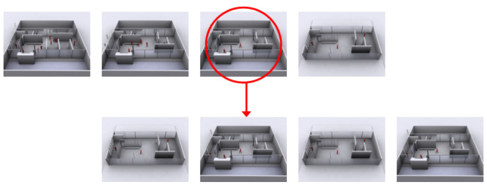
These cultural dimensions in architecture cannot be described without the understanding of human interactions over the thousands of years of their involvement with spaces. Millions of repetitions in use, creation, and evaluation surely guided them to finally find a certain design solution. Whether spaces are forming their cultural dimension or people are forming their regional architectural styles is also obscured by the vast span of time and tremendous collective efforts by people who have been involved in the creation of our culture. But one thing is clear here. Without the implementation of behavioral aspects into spatial study, we hardly ever capture the intrinsic quality of architectural space. Going back to the original statement, today’s advanced computation design tools’ shortcomings can potentially be compensated for by the concept introduced in the Space Re-Actor.

Generative Design with Behavioral Responses:

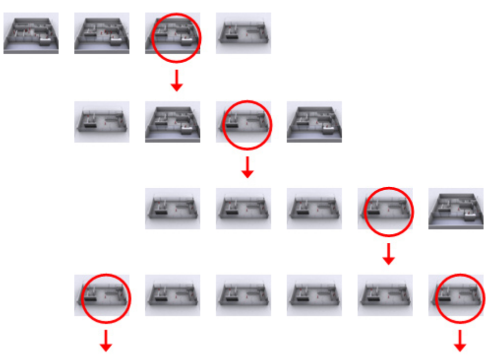
In this section, I would like to discuss the potential aspects of using the Space Re-Actor as a generative design tool. Last year, one of my explorations for generative design became a study of housing unit layout problems using heuristic algorithms such as genetic algorithms. Providing feedback loop based on fitness functions can create iterative selection process based on self-organized internal logic inside the system that is able to search and design without knowing the highest, transcendent solution. This technique is effective, especially where there is no deterministic method available to seek the solutions directly from existing formulas or manual design methods. Introducing this concept into the Space Re-Actor by using user interactivity is one conceptual challenge for the tool. In this case, defining the feedback loop and selection process is the critical factor for this application. The proposed possible conceptual framework is the followings. Users can provide several potential design schemes that they initially prefer. By executing the Space Re-Actor on these plans, users can see the behavioral tendencies and latent scenarios based on the specific behavioral aspects that each user is interested in. Then the selection will be made by the user. Based on the user's selection and preference over the other schemes, the system will provide a next generation of plan schemes. This can be done, for instance, stochastically, generating potential layout patterns derived from the original selection based on the constraints provided by the users before running the Space Re-Actor. Iterating this process over time may lead users to find an unexpected layout that users originally had not conceived.



User Selects One Scheme.



Next generation of plan schemes are prepared based on user's preferences.



Iteration continues.

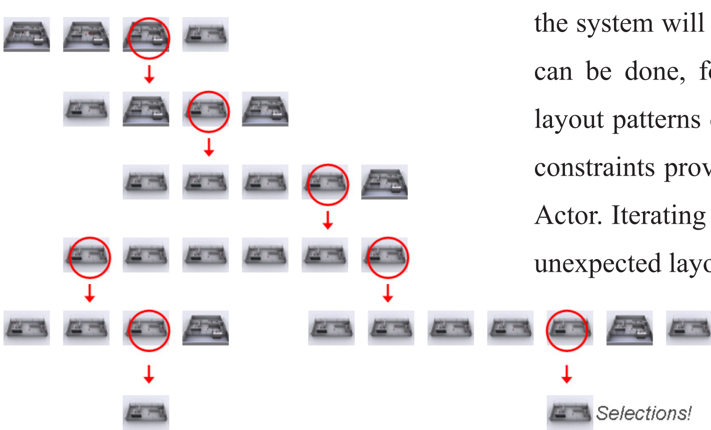


Figure 5.3:
Generative Design system with user feedback

Figure 5.4:
Japanese Sword-smith

Rather than casting and limiting the final form or gesture in a top-down manner before fulfilling all the requirements, step by step, iteration by iteration, this user interactive method can heuristically improve the solution in a bottom-up manner. We can see one such interesting example of design process in the technological innovations and development of Japanese swords. Typically, sharper the sword gets, more brittle its gets and vise versa. Over the thousand years of proceeding by trial and error, Japanese sword-smiths were able to develop highly sophisticated processes that produced swords which could simultaneously maintain their sharpness and endurance. To satisfy those conflicting constraints, Japanese sword-smiths have gradually developed the methods to distribute the metals with two different properties – a soft and durable iron core and a hard outer skin of steel – in the specific cross sectional areas of the swords. Since there were no computer optimizations available for them to visualize the solution at the time, feedbacks from the users (Samurai) became reliable evaluation factors for their next improvements. Million times of repetitions finally guided them to find a certain design solution. The critical point here is that there were no deterministic ways to search the targets, and none of those sword-smiths knew the solutions in advance. They were neither scientists nor engineers. Their search relied on their experience and intuition, and millions of sword-smiths worked as multiple agents to improve the design progressively over the thousand years of practices.

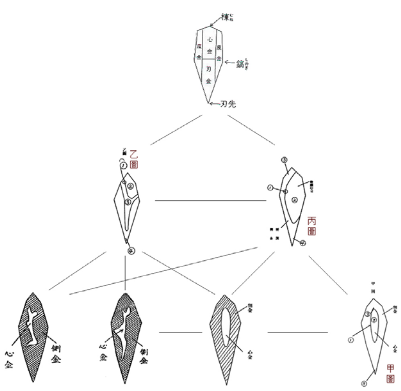


Figure 5.5:
Heuristic process in development of Japanese sword sections.

Generative grammars developed by leading scholars have successfully captured the design languages of many prominent architects. Implementation of psychological behavior and human intervention may add an interesting way to speak within this creative paradigm around "shape" and "grammar." The above-mentioned cultural dimensions may be derived from behavioral implementations. As a novice in this area, I do not feel qualified to discuss these in depth, although I will offer one observation concerning the comparison between existing geometry-based grammar and, so to speak, "behavioral grammar." (I am not rigorously framing this notion, so the argument may be a bit premature.) The fact that many scientists involved with neural-coding are actively using probabilistic approaches such as Bayesian analysis suggests that any study involving our "self" requires some degree of understanding of indeterminacy. Unlike discrete and determinant geometrical operations, behavioral implementation can not be fully described without applying a notion of "indeterminacy." Describing a transition from one state to the other or one formal solution to the other by the decision of a human being may require a probabilistic treatment as is often true in nature.

Epilogue

Albert Einstein famously remarked that, “God does not play dice with the universe.” However, facing apparent randomness in nature, one may sometimes doubt the accuracy of this view. The Space Re-Actor provides animated possible scenarios based on the qualities inherent in architectural spaces. The plausibility or persuasiveness of these results probably depends also on viewers’ own attitudes and perceptions toward the “reality” around themselves. But the tool provides multiple interpretations of the spaces based on the stochastic decision process implemented in the figures, which is meant to reflect the indeterminacy of human behavior.

“Reality,” I believe does possesses indeterminacy. Who knows what types of people are visiting at particular times of the day in Mies’s country house? Every trial of the tool produces different possible events, and the original intention was to identify tendencies in behaviors and actions by seeing series of possible scenarios. What we have witnessed in the several visualization results of the Space Re-Actor may not be certain to occur in reality. However, neither can one completely deny the potential occurrence of such events. One’s attitude toward “reality” will surely influence how we regard this new tool, the Space Re-Actor.

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