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New Directions in Agent-Based Generative Architectural Design

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Abstract

The paper discusses the potential of computer agents in form generation in the early stages of the architectural design process. First it discusses the possibility to simulate human behavior by computer agents and reviews the various directions in which computer agents were employed in architectural design.   Then, it discusses the difference between form simulation and generation in architectural design and suggests ways in which computer agents could be employed in architectural design in a generative manner. The suggested ways are examined by several design case studies. The paper concludes with the advantages and limitations of employing agents for form generation in architectural design.

Keywords: Computer agents, form simulation, form generation.

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Introduction

Computer agents in the context of generative architectural design are virtual entities that simulate pre-defined spatial behavior. As such, the behavior of each individual agent often relates to its adjacent agents, in a ‘bottom-up' organization. Computer agents have been used in architectural design in various directions that generally involve solving complex problems and tracing emergent patterns in complex systems (Hong, mingxi, and Frazer, 2002) (Petrovic, 1999).

Leading directions in using agents in architectural design are the simulation of pedestrian movement in exterior spaces (Sun, 2006)(Turner and Penn, 2002)(Yan and Kalay, 2005)(Dijkstra and Timmermans, 2002), examining people’s flows in circulation oriented spaces such as museums and galleries (Batty, 2001) and examination and optimization of evacuation routes (Zarboutis and Marmaras, 2007).

Computer agents were also used for finding solutions for problems such as collaborative design (Maher et al., 2005) (Anumba et al., 2002) (Kalay, 2004) and programmatic distribution (Ophir, 2009). Less research has been conducted on the possible implications of agents in generative form architectural design in general, and at the building scale of architectural design in particular.

Some examples for this line of research are the “Ecoconguration through agent-environment visual coupling” approach that reached interesting conclusions but did not develop a method to employ it for architectural design (Turner, Morrram, and Penn, 2002) and attempts for generating 3D worlds, which showed promising potential in developing a virtual world but did not discuss the possibilities and implications of these ideas to generative design in the physical world (Gu and Maher, 2005).

The challenge of this paper rests in the examination of the potential and ramifications of employing computer agents for form generation in architectural design. It will embark on briefly addressing the position of computer agents-based form generation within the various modes of generative computer simulation. Then, it will critically discuss the idea of simulating human movement by computers. Finally, it will argue for possible directions and approaches for employing computer agents in architectural design. Each approach is presented and discussed through a design case study.

Simulation as a mode of form generation

The purpose of simulation is usually perceived as a test process. It is an evolution from handbook-oriented calculations to what we know today as the computer simulation algorithms and software (Clarke, 2001). Recent years have seen the accelerating development of a large number of simulation tools and software programs. Indeed, the U.S. Department of Energy lists more than 300 different tools/software programs for simulation of energy performance alone1, and this does not even include all the tools that emerged from the academic world. In architectural design the idea of testing refers to the examination of the level of fulfillment of certain performance criteria by an architectural form. Although simulation is usually connected with performance, the most common use of simulation in architectural design is still for representation (visual simulation and evaluation), which necessitates visual and esthetic performance criteria for evaluation purposes.

Other modes of simulation include: Simulation as part of an empirical evaluation process, which consists of developing a strategy for accomplishing a desired solution subsequent to the test process; simulation as an examination of the behavior of architectural form or space under extreme conditions in order to be able to foresee the point of failure or catastrophe, and simulation as a mode of form generation which is the interest of this text. In other disciplines such as medicine, simulation is also used for training. Simulation process as a mode of form generation is, to a certain extent, an inverted version of the traditional approach to simulation which examines an already existing form.

While modes of simulation act on an initial form in an "after-the-fact" manner, in form generation the computer creates form directly out of performance simulation results. Based on this characterization, it can be assumed that form generation in architecture takes place only at the beginning of the design process while the rest of the process could be regarded as an optimization process which involves multiple simulation and evaluation processes. This would probably be the case for a design process that deals with the design of one element as in some cases of industrial design, or the design of fairly simple structures that, for example, have no internal divisions to secondary spaces. Nevertheless, when it comes to the design of buildings, it is clear that several levels of form generation might take place within the design process, as follows:

1. Generation of initial form/envelope
2. Generation of secondary spaces/division to floors and sub-spaces
3. Generation of building elements (façade, windows, doors, etc)
4. Generation of building details

The above four levels can be compressed into two main types: The first and more obvious has to do with the introduction of new forms, while the second has to do with changing the topology of the existing forms.

In the early ‘60s, the computer was considered to be an intelligent problem-solving machine that would eventually match, and perhaps even supersede, human intelligence. Researchers have developed a plethora of models and theories to automate the design process and optimize its product (Andia, 1999). Some believed that an entire “optimal” project could be computer-generated by translating the designer’s creative work and functional/performance-based criteria into quantitative information. This idea rested on the assumption that because the computer had superior “intelligence”, it would be able to find the “optimal” design. However, it is now clear that due to the ill-defined nature of the architectural problem, generating a complete “optimal” building is not possible. Nevertheless, it can be argued that computer form generation has significant advantages over traditional design when it comes to a small number of criteria and smaller well-defined problems such as the generation of a building’s envelope/initial form or the generation of elements in the building (Grobman, Yezioro, and Capeluto, 2009).

Simulating human behavior

The problem with using computer agents for architectural design is parallel to the idea that human behavior can be simulated to a certain extent by computers. It is clear that the exact nature of human movement in space is not easy to pin down and a total predictability of human movement in a simulation process will probably not be possible in the near future (Batty, 2001). Yan and Kalay (2005) suggested that agent based human behavior model necessitate geometric, perceptual and social modeling. They divide the perceptual modeling to seeing, knowing and finding, and the social modeling to artificial life approach or flocking algorithms, social space, environmental effect and randomness. A close study of these ingredients shows that it is mainly oriented towards constrained scenarios such as walking in a square or sidewalks (Kerridge, Hine, and Wigan, 2001), hospital corridors or evacuation routes. In these scenarios human behavior is rather simple. It could sometimes be perceived in relation to flock behavior where rules of relative position and movement could be defined based on statistical observations (Gehl, 1987). It is clear, however, that in other scenarios in which the space boundaries and movement are less constrained (i.e behavior in an open public space or in domestic internal spaces) the simulation of human behavior is highly problematic. The main problems lay in the subjective nature of the human decision regarding movement in space, which is based on social, perceptual factors. These factors are ill-defined in terms of the possibility to translate it to computer language.

Moreover, examining this issue from environmental psychology point of view discovers that there is a lack in functional theories about basic human behavior such as maintaining personal space and privacy (Sommer, 2002). The lack of research and theories is even deeper when it comes to understand the influence of the Information Technology revolution and the internet on the spatial behavior of people (Stokols and Montero, 2002).

Thus, the idea to simulate complex behavior is still problematic and the possibility to achieve simulative models that would approximate real life) does not seem to be viable in the near future, unlike other empirical performance simulation in architectural design such as structural, acoustic and other empirical fields. Current models that use circulation simulation could, therefore, employ simplified movement/circulation models, which necessitate an argument regarding the validity of the simplification in relation to real life circulation.

Looking from an architectural design point of view, research in this domain has three raison d'etres: the first perceives form generation as “basic science” which tries to develop ways of better understanding human behavior in space in order to be able to use it sometime in the future. Research in this realm would help to close the gap between the current simulation abilities and human behavior in space.

The second direction and the most straight forward one looks for additional constrained scenarios for which rules can be generated to accurately simulate human behavior. It generates simplified circulation models that can be used in a simulation or form generation of specific building typologies and specific cases such as stadiums and hospitals or movement in museum galleries.

The third direction is related to creativity and emergence. It is based on the assumption that the tracing patterns that were generated by a reductive amount of parameters/constraints have also got some potential to generate viable architectural forms. It follows an argument presented by Eisenman (1992) and others about the potential of computers to "release" creativity from the limiting forces of the human eye by allowing it to generate unexpected results. Or, it can suggest that by using the computer for circulation simulation, reductive and inaccurate as it is, one still increases the amount of information they have on the human behavior in space in comparison to not using these tools at all. This line of logic, however, disregards the possibility that the computer simulation is generating misleading data that rules out other possible circulation scenarios.

Computer Agents and the generation of architectural design

As opposed to form generation methods such as cellular automata and shape grammar, in which form is directly generated by the computer algorithm, the possibly to generate architectural form by using computer agents' simulation is not straight forward. While it is quite possible to understand the role of computer agents in simulating human behavior in space, the connection between circulation and architectural form generation is not easy to pin down. Moreover, until recently, developing and testing computer agents' based design methods necessitated a considerably high level of programming skills and extensive processing power which was not abundant in architectural research and practice.

The following sections present and discuss directions and possibilities of using different types of agents in the architectural design process for form generation in the initial stages of the design process. Following a discussion on early attempts to use agents for generative architectural design it discusses emerging possibilities in embedding the use of agents in generative architectural design. The new ideas are presented and explored via a series of experimental case studies in which various types of agents and agents based form generation methods are employed in architectural design.

One of the earliest attempts to use the idea of circulation agents for generative computer based design can be traced back to Greg Lynn's proposal for the Port Authority Bridge competition (Lynn, 1999). Although the particles he used can only be considered as passive agents (since they does not interact with each other or the environment) the notion of using particles movement to generate form was innovative at that time. Lynn suggested tracing the 3D trajectories of particles (agents) for the design of a structure of a bridge. The trajectories of the particles movement in this case were determined by an initial direction and speed input that was defined by the designer, and was influenced by forces (attraction and repulsion) that represented the influence of passing traffic. Clearly, one of the most difficult and important challenges in this realm is the translation of the movement information into architectural form. This process can be image (form) or performance oriented2. In Lynn's case, obviously, there is no precise empiric performance-related logic in the particles movement and the forces that influence the movement. Thus, it promotes image-based ideas as emergence and creativity, and argues for the complexity of the form which is generated by the computer.

A different approach to both form generation and the use of agents was employed by Asymptote in the Broadcast Architecture project design (Lynn et al., 2002). Instead of employing virtual agents the computer was used to trace the movement of real agent (a dancer) in space3. The design method in this case is based on an assertion that a space could be generated in relation to the expected or simulated consumption of space.

Similar to the previous precedents the design process in this precedent is mainly image-based. Although it is possible to argue that the dancer movement embeds by definition performance information, it is clear that the generated form is not trying to produce a functional or performance oriented space. Thus, the movement tracing process in this case is more direct but it still promotes ideas of emergence, creativity and formal complexity4.

As opposed to tracing the movement of a low number of agents, patterns created by the movement of large numbers of people/computers agents have some considerable advantages. The patterns created by the agents' movement could show areas with problematic circulation conditions or redundancies. It is thus used to test or simulate circulation in projects in which circulation plays a vital role as hospital, airport or in public urban space (Batty, 2001), (Xie, Batty, and Zhao, 2007).

In order to promote architectural form generation, the use of the circulation simulation has to be inverted. Instead of examining an already existing solution the designer/computer has to use it in a generative, or "before-the-fact" manner, that is, to use emerging patters from circulation in existing site condition and examine changes in these patterns after introducing modifications or new elements to these conditions.

Turning the use of simulation in design on its head in order to generate building's initial form directly from circulation information would suggest an architectural form which adheres by definition to the defined performance criteria that were used to generate it. Moreover, since it was generate from performance simulation the form would not necessitate reevaluation. Employing this type of design method would be, of course, especially important in projects where optimization of the circulation in terms of traveling distance, duration or simplicity of the movement is central.

Using simple agents in generative computer based design

Using particles as simple agents in generative design has several advantages. The movement possibilities of a simple agent is relatively simple, it consumes small amounts of computer processing power and allows designers to introduce large numbers of agents into the design space. Therefore, it is possible to examine numerous paths and thus increase the odds for patterns to emerge. Moreover, particles modules are now an integral part of design and animation software that are used by architects such as 3Dmax and Maya. It is rather simple to set up and flexible in terms of their visual manifestation. Although the preset modules in the software do not necessitate custom programming knowledge, the integral scrip possibilities allow creating complex scenarios with relatively low time investment and without necessitating custom code.

However, there are also many limitations to the use of simple agents. The main limitation is the fact that simple agents can simulate rather simple movement which does not necessarily imitate the way humans walk or "consume" the given space. Other limitations have to do with the difficulty to control a singular particle and the complexity of the emerging patterns.

A case study design was performed to examine the possibilities within this realm. The case study suggests a method to generate the initial form of a public space based on expected pedestrian circulation. The initial form that was generated in this case was based on the tracing of expected areas of intersection of different paths which would be developed in a later stage into a public square. Figure 1 presents the design method used in the case study. The suggested design method starts with a setup of particles emission sources that are based on a design decision regarding the expected and desirable main circulation axes, and the number and directions particles are to be emitted. Following the initial setup the particles were released to the design space and numerous simulations are performed. The first image, at the most left in Figure 1 shows a single frame from a simulation run where each cross represents a particle/person, while the second image from the left shows a compilation of all the frames in one image (the dark (blue) and light (red) colors represent different times of day). The tracing process that is presented in the third, fourth and fifth next images from the left is based on a completion of all the paths for emerging patterns, which were in this case areas of concentration of circulation path. The initial volumes which are presented at the right hand image in figure 1 represents the initial formal definitions of a design space where the design has to be developed further to take into account solutions for shading, seating and other public services.

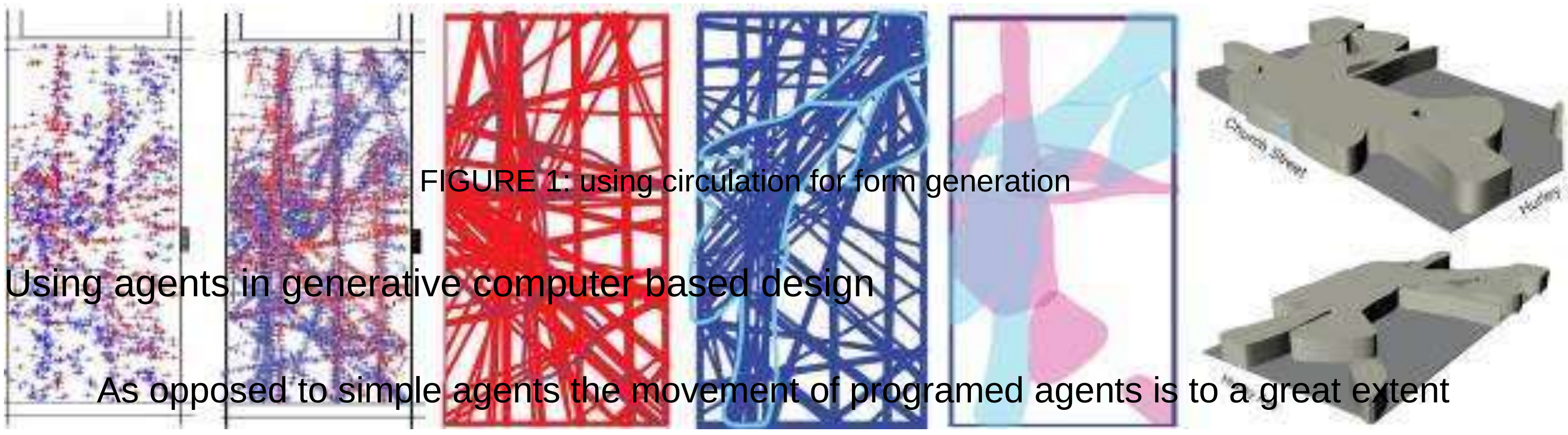

FIGURE 1: using circulation for form generation

Using agents in generative computer based design

As opposed to simple agents the movement of programed agents is to a great extent more complex. It facilitates interaction among agents and between agents and the environment and thus, simulates human movement much more realistically. However, the control of agents’ movement in complex scenarios demands considerable amount of computer processing power. This, naturally, limits the amount of agents that can be used in a single simulation. Moreover, although being able to interact with each other, it is still not possible to truly simulate simple social scenarios such as meeting friends or joining a group.

The design of the exhibition ‘Performalism’ used computer agents for the generation of the initial form of the exhibition gallery spaces5. The project referred to the design of the exhibition as a codified entity which tried to optimize the position of the exhibits in relation to the visitors’ circulation and their viewing angles.   The agents’ movement was influenced by attractors and reflectors, which represented the physical constraints of the possible location of projectors and screens in terms of dimensions and exposure to visitors.

Figure 2 shows the initial setup of a gallery space. The small circles represent the location and radius of deflection of wall screens that necessitate viewers to stay at a certain

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distance in order to be able to view the video. The large circles represent the center of gravity of four attractors located at an initial position of the exhibits of four architectural firms. The attractors attracted agents to come to the center when one enters the radius of influence and thus represent the area of influence from which one can see details of the exhibits.

The initial design method tried to trace patterns from the movement of agents in numerous simulation runs with different parameters in the gallery space. The patterns would then be used to suggest an initial distribution of exhibits and design of the exhibition cases.

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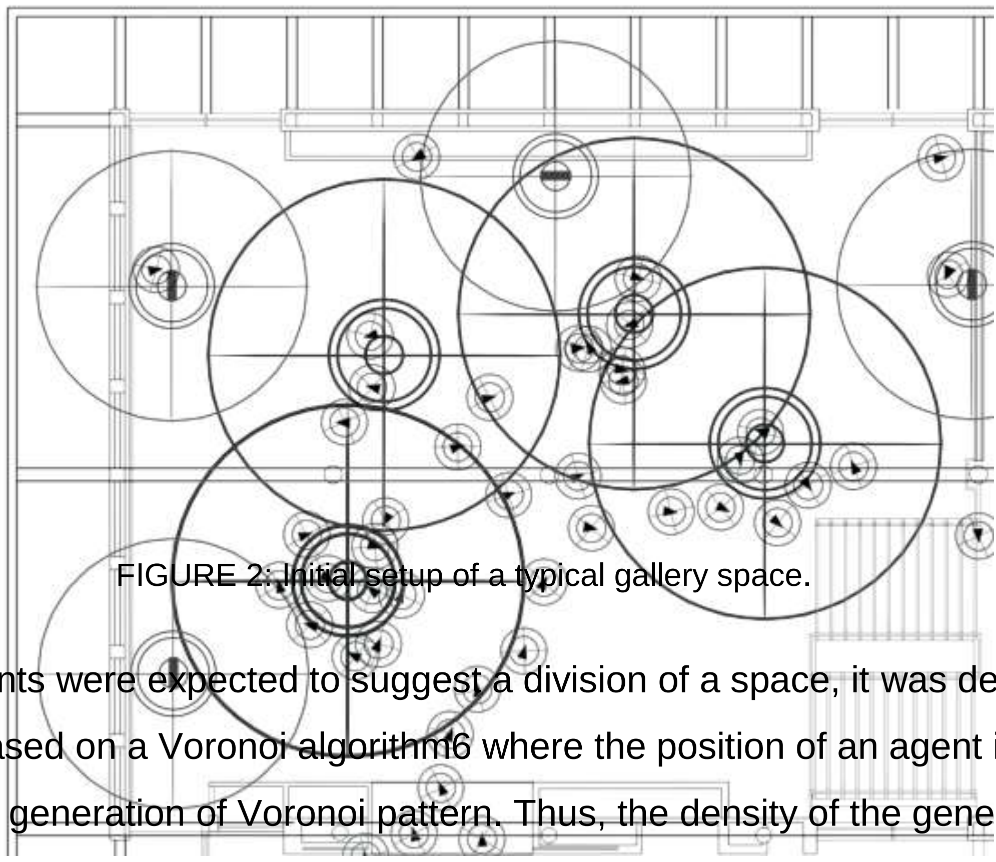

FIGURE 2: Initial setup of a typical gallery space.

As the agents were expected to suggest a division of a space, it was decided to use a cellular division based on a Voronoi algorithm6 where the position of an agent in space is used as an input for the generation of Voronoi pattern. Thus, the density of the generated pattern would be directly related to the amount of points/agents in a certain area and the displays will be positioned in these areas.

The design process used an existing Crowd module in Autodesk's 3Dmax8 software as an interface, and a new code/script, which facilitated the tracing of the agents' position and in real time. In order to trace the entire movement in the gallery space it was decided to use an average of a compilation of all the frames of an examined movement (see Figure 3). The selected average patterns were evaluated in terms of cell density and dimensions, which were