BOUNDDED AGENCY
INTEGRATING INFORMED MULTI-AGENT SYSTEMS WITHIN ARCHITECTURAL SURFACES

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ABSTRACT

This paper explores the development and application of informed Multi-Agent Systems (IMAS) as a means of programming spaces generated through the subtraction of built form at both urban and architectural scales. We argue that IMAS are distinct from Multi-Agent Systems (MAS) due to their adeptness at responding to and conditioning complex, data-rich territories that require an open program while also benefiting from top-down constraints that delimit the system’s edges. We demonstrate these claims by unpacking a series of preliminary IMAS experiments and their use in designing a 2013 entry in the 54Jeff competition that makes use of these techniques to reprogram the Grand Rapids Public Museum. We discuss the need for and applicability of these methods within the larger context of contemporary calls for subtractive strategies amidst increasingly complex and compacted built environments.
INTRODUCTION
The shift toward consciously speculative designs has been accompanied by architectural practices that position software as an effective tool for managing and reproducing the complexities at play within designed assemblies. Agent-based models have become particularly popular in this context both due to their open-source accessibility and their ability to mobilize massive numbers of dynamic agents in communication with one another in order to exploit otherwise minute differences between one another. These interactions in turn form unthinkable patterns at a variety of scales. Given the indeterminacy of their effects and the possibilities that they have as intensive population models, they have been broadly appropriated as a contemporary design tool while simultaneously maintaining a degree of widespread doubt regarding their value and usefulness. This research attempts to address these doubts by doubling down on the viability of swarms without necessarily making a claim in advance about their usefulness. By developing a user-friendly agent-based design tool that feeds them with common information assumed to be of inherent value within architectural assemblies.

This paper unpacks the initial development and subsequent use of informed Multi-Agent Systems using the 54Jeff competition entry as reference. We discuss the need for and applicability of these methods within the larger context of contemporary calls for subtractive strategies amidst increasingly complex and compacted built environments.

INFORMED MULTI-AGENT SYSTEMS
Multi-Agent Systems (MAS, also commonly referred to as agent-based models) are computational algorithms that explore the interactions of autonomous agents, programmed to respond to simple conditional statements (Schuetz and Schermerhorn 2005). Agent systems negotiate between other agents and environmental stimuli over time and have the ability to generate emergent phenomena. MAS have been applied to a vast array of scientific studies, from wildlife migration patterns, bacterial mutations, ant colony formations, starling swarming patterns to politics (Panikka 2008) and have been broadly appropriated in art and architectural projects since Processing (processing.org) was made available to the public in 2001. They even go so far as to provide a means of producing speculative behaviors beyond human reason or understanding (Keller and Leitao 2006; Snooks 2012).

However, the primary use of MAS and the accompanying discussions surrounding the architectural applicability of agent-based design is typically limited to specific tasks in an attempt to utilize their embedded intelligence to solve/generate problems of complexity particularly at the scale of the city (Johnson 2002; Leach 2004, 2009). But the implicit dependency on computational scripting to productively utilize agent interactions can leave designers feeling intimidated and ignored thus precluding their usefulness. We have developed a universal design tool aimed at creating a generic platform for user controlled manipulation of an increasingly robust swarming algorithm with the potential to deploy agents across a range of different architectural projects. The intended significance of this tool lies in the fact that it is inherently generic while locally adaptable, allowing users to deploy and stimulate agent systems specific to their design intentions. By increasing accessibility and exposure to MAS we hope to expand the footprint of agent-based designs in architecture thus diversifying their possible uses and applications.

We make the claim that MAS inherently refer to an isolated system in itself and that they can be (and often are) deployed into environmental conditions. However, as is the case in our research, MAS is an insufficient term because it does not account for the codification of non-agents within the computational model. Thus we use the term Informed Multi-agent System (IMAS) so as to describe a hybrid set of different model types between multiple software platforms (in this case, agent based models and 3D static geometries grafted into a single systemic environment). This speaks to the necessity of an integrative capacity for each platform so that it might actively interact with other sets of models, environments and software.

SYSTEM SCALABILITY
Agents are deployed from specified emitter point(s) either generated in the Processing environment or imported as specific x, y, z coordinate information contained within a spreadsheet exported from external 3D modeling software. The design tool can utilize multiple emitters each with the capacity of deploying specific and consistent agent populations or variable populations from different emitters. Multiple emitters can produce agents of the same class, following similar rules of interaction, or deploy agents belonging to a number of independent classes, each class governed by different behavioral logics. The capability of producing simulations with a multitude of different agent classes responding to differential rules of negotiation within the same environment provides an increasingly extensive platform for design potential. For example, one agent class can operate under specific direction to search for structural integrity, while another class can look for network efficiencies, while a third can respond to environmental stimuli and so on. We see this variability as crucial for universal application as it allows for increasingly robust and comprehensive outcomes via infinite stacking of agent classes with varying degrees of interaction.
desirable to achieve a specifically optimal condition, the design tool presents the opportunity to manipulate and influence agent behavior in real-time. This manipulation happens through a GUI that toggles particular visualization and behavioral effects and controls flocking search radii and force through a series of numeric sliders (Figure 1). This provides users with the ability to explore the range of possible effects within a given scenario rather than spending inordinate amounts of time setting up the environment only to realize that it yields an undesirable result. Thus the speed, flexibility and intuitive capacity of the GUI become its primary performance attributes as a design tool.

IMPORT CAPABILITIES
Currently the design tool can receive three types of imported geometries, points, splines and meshes. Points, generated from imported x, y, z coordinates, can operate as discrete geometric entities or in combinations as control vertices for the creation of splines. In addition to their coordinate location, points can be brought in with embedded information that pertains to specific colors, attractive forces, dimensions for subsequent geometry or any other information that can be represented numerically. This encoded information provides a number of opportunities, from influencing agent behavior to driving geometric manipulations. Meshes are imported as STL files using the STL Reader function implicit within the Toxiclibs library. Agents are capable of responding to any morphologically unique mesh, from flat planes, to double curved surfaces, volumes and everything in between. Mesh vertex colors along with texture maps and other information can be imported along with the STL files and this inherent data can be further utilized to drive agent interactions. The combination of geometric primitives as inputs combined with the ability to mesh resultant complex geometries forms the foundational framework for a user-friendly IMAS design workflow. This workflow was used to generate a series of initial tests as proof of concept (Figure 2).

AGENT BEHAVIOR
Given the desire to develop a universally generic and robust agent-based tool, we utilize and build off steering behaviors from Jose Sanchez’s Plethora Library, an “easy-access toolkit [that helps] understand the emergent behavior of complex systems” structured as a sub-library of the Toxiclibs library in Processing (plethora-project.com). Although the tool utilizes an existing agent class, it has the capacity to substitute any other previously developed agent class or further manipulation of the Plethora open-source code. The Plethora Agents utilize Craig Reynolds flocking algorithms which account for rules of interaction as they pertain to separation, cohesion and alignment. Each agent responds to a

IMAGING TIME IN IMAS
The embedded intelligence of IMAS does not lie in one specific moment but through emergent agent interactions over time between dynamic and static geometries. In an attempt to capture time-based patterns the design tool has a number of visualization methods that allow for tracings, assemblies and proximal distances to be understood and exported for further manipulation in a variety of external software. Agents can draw connections between themselves and a variable number of other agents within a prescribed distance, allowing for visualization of agent density and proximity. Agents also have the ability to deposit trails that allow one to trace where the agents have been and to observe what effects differential stimuli produce within the simulation.

ACCESSIBILITY VIA GRAPHIC USER INTERFACE (GUI)
With an interest in making the tool accessible to a broad audience, steps have been taken to reduce the amount of computational knowledge necessary for utilizing and manipulating agent behavior. Keeping in mind that it may not always be necessary or
search radius associated with each of the above variables that can be further controlled through an associated scale value that influences the magnitude of the behavioral forces. The manipulation of search radii and their associated force allows for an infinite number of potential flocking patterns to emerge. Additionally, agents’ movement can be influenced in real-time by manipulating their internal attributes as they navigate through their environment.

Agent behavior is governed by an increasing number of conditional statements currently facilitating response to attractor points, environmental stimuli, threshold conditions, imported geometry and communication between multiple classes. We see this research as the beginning of a much more robust set of explorations that seek to compound larger and/or more explicit data sets into the systems of behavioral interaction.

INFORMED SURFACE CONSTRAINTS

Initial geometry plays a large part in any architectural design process whether representing site constraints, basic massing, individual architectural components, etc. and can be modeled in a wide array of 3D software. However, in order to inform this otherwise unexpressive initial input prior to interaction with agent classes, geometry was run through a Grasshopper definition that would subject the geometry to real-time Gaussian curvature analysis as well as lateral loads in order to produce asymmetrical ly loaded pattern across the surface. Both of these information sets were then independently translated into Processing where a swarm was deployed across the then informed geometric surface. Results were recorded for swarms that behaved across four different scenarios as described in the figure captions (Figure 3), (Figure 4), (Figure 5) and (Figure 6).

While the range of possibilities is literally infinite, geometrically tighter solutions were desired for purposes of structural viability as well as for purposes of formal legibility when responding to subtle differences within the informed surface.

COMPOUND GEOMETRIC CONSTRAINTS

All agent flocking and steering behaviors interact and function relative to geometric inputs. It is possible to constrain the agents to a spline, follow attractor points or migrate along meshes, while still allowing them to interact relative to the prescribed flocking variables (Figure 7).

Agent response to geometry can be further manipulated by increasing and decreasing the associated force the object has on the agent behavior. Imported geometry that exhibits a strong de-
gree of attraction will force agent movement to descend on the geometry rapidly, while a negative force of attraction will act in a repulsive manner. Splines and meshes also have the ability to alter the directionality of agent movement, and agents are embedded with the variable capacity to anticipate varying ranges of potential locations. Agents also have the implicit functionality to simultaneously respond to multiple geometries. The resulting agent behavior averages between their attractive forces, flocking characteristics and agent velocity.

We developed a series of definitions that would visualize these forces such that additional projected layers of geometries (attractor points, traced curves, etc) would be expressed through variations across the base surface. This effectively produced compound geometries, such as surfaces, that expressed the presence of a curve without a curve itself existing within the agent-based model (Figure 8).

The combination of basic geometric inputs, user friendly analytical parametric definitions, and a user-friendly GUI for manipulating agent behaviors yielded a wide array of results that allow designers with relatively little programming or parametric expertise.

PROJECT APPLICATION

In order to test the aforementioned toolset, we applied these methods to an architectural project. Organized by Site: Lab in 2013, the 54Jeff Ideas Competition presented the challenge of "creating compelling visions of the future" for the former Grand Rapids Public Museum that would "define a vision for the building as a public space." Located at the intersection of Jefferson Avenue and State Street in Grand Rapids, Michigan, the building presents a series of complex and seemingly contradictory problems that form a set of related questions:
What to do with an abandoned building that does more harm than good in its present configuration?

What to do with a building that is cherished as a historical object but whose current form negatively impacts the place-making potential of State Street?

How can the project think past the building and address the ways in which State Street can become an inhabitable boundary that bridges between the historical neighborhoods to its North and the medical industrial district to its South?

In synthesizing these questions, a more comprehensive disciplinary mandate for the project emerged: Addressing how 54Jeff might become a catalyst for the reimagining of State Street while preserving its history and autonomy as an architectural project.

Toward addressing the mandate, the building would have to transform in a way that would allow it to reengage the public spaces that it hoped to make at the urban scale without over determining their own use (Figure 9).

CONTEXT

Before simply assuming the title afforded to the building by its address (54Jefferson), 54Jeff was the Grand Rapids Public Museum whose history extends back to 1854 when the Grand Rapids Lyceum of Natural History was first formed, at which point a number of the members lent their cabinets of Natural Curiosities to the Nascent Museum. It wasn’t until 1940, after a number of attempts to establish a more permanent and viable residence for exhibitions, that the Grand Rapids Public Museum building was finally realized (Figure 10).

Given this long history, the premise of modifying or augmenting the building in a substantial way appeared problematic. But the premise of assuming that any individual building should dominate urban development moving forward seemed equally absurd. Despite this rather obvious difficulty, we argued that the building in its current form obstructed a desirable potential of the surrounding area. However, we certainly did not think that the building should be removed. And so we chose to frame the building itself as a curiosity that could be dissected, flayed open and made a spectacle amidst the city that effectively contained it. It is this action that required a new kind of agency to be deployed—capable of both subtracting from and stitching together architecture and its context so that a designed future could be realized. We see such tactics being especially useful in order to preserve the existence of high modern buildings that imagined themselves as absolutely permanent and physically unchanging within cities of indeterminate futures and perpetual change. Rather than taking an all-or-nothing approach to development and/or preservation, the...
dual thrust of subtraction and binding together becomes a chimeric approach that registers the past within its forms without being absolutely constrained by the imposition of permanent and static form. It should be noted that we expect a large degree of contention over this point – and we welcome that debate.

**THE CASE FOR SUBTRACTION**

To achieve the aforementioned mandate, a large subtraction was made from the center of the building thereby splitting the original building into two halves, thus transforming the former museum from a monolithic obstruction between Jefferson Avenue and State Street into an integrative space between them (Figure 11).

The literal fracturing of the original building then provided an opportunity to employ agent-based techniques to both explore the new possibilities of flow and formation afforded by the new diagram of the site. In order to maintain the precision of the subtraction without over-prescribing use, a series of surfaces were inserted allowing for an alternative level of programming to take place throughout the site negotiating between the urban and architectural scale.

**ALTERED STATE**

As an answer to these challenges we proposed Altered State; a multi-scaled, multi-program series of integrated public and private spaces anchored around a community brewery. By reorienting the central hall of the original 54Jeff building to align with the diagonal of State Street, the building becomes able to address the public spaces it has for so long been prevented from serving. By augmenting the flow of public circulation through the original site, 54Jeff is transformed from a hermetic obstruction to a vital and inhabited gateway that connects the State Street District with Jefferson Ave. An IMAS populated structural skin reconnects the two halves of the original building together and demarcates a space that addresses both State and Jefferson at the urban scale and the individuals who inhabit the project at the human scale. A ramp allows for vertical public circulation within the newly aligned central hall to a series of platforms that can be programmed for a variety of different events (Figure 12).

The goal of this proposal is not only to provide a building that can adapt to its community and its evolving interests, but also to influence its surroundings by acting as a vibrant node that enables a revitalization of the entirety of the State Street District.
APPLICATION OF INFORMED MULTI-AGENT SYSTEM SURFACES

The most prevalent type of program in terms of total area in the project was that of open-programmatic spaces. These spaces fell between, across and under the surfaces that formed the masses of the project. So while there was effectively “less” actual interior square footage than there was prior to the proposed subtraction, the amount of activated area within the project was drastically increased. So the question became, “how can the architecture play an active role in activating these spaces without being over-prescriptive or over-generic?” Thus the IMAS surfaces were advocated to address this specific need. These surfaces were selected by identifying spaces that remained unprogrammed during all phases throughout the year (Figure 13).

Three contiguous surfaces form the territory through which the IMAS would be deployed. Each surface in uniquely informed thus generating a varied agent-based result across different programmatic spaces (Figure 14). A series of compound geometries were projected through the base surface and subjected to agent population (Figure 15).

One of the more interesting aspects of the workflow was the process of agent-behavior across a surface over time. While real-time interaction is the best format for experiencing these behavioral patterns, for the purposes of this paper, we produced a sequential diagram (Figure 16).

By emitting agents from the initial curve projection and biasing them toward the underlying structural mesh, a whole series of possible design iterations emerged. The prospect of compounding multiple instances of the same simulation into a single monolithic meshed result is something that we see potential in – particularly when combined with the prospect of multi-material 3D printing.
CONCLUSION & FUTURE WORK

While we are encouraged by the integrative and aesthetic potential of the developed IMAS, we see a great deal of potential to improve the functionality of the designs. Multi-material 3D printing would likely be an appropriate means of physical investigations. The author’s previous research on [Taron 2012, Taron 2012] would provide a viable method for structurally evolving these agent-based formations.

The larger questions raised by the research are perhaps the most pressing. However, in the context of calls to adopt subtractive architectural design methodologies from figures such as Benjamin Bratton (2015) and Keller Easterling (2014) (each with their own respective perspectives), the importance of developing tools and techniques to both facilitate and address void space cannot be understated. The need to approach the demolition of buildings as partial rather than absolute; the challenge of reframing the respect of buildings within the environment by acknowledging and resolving their deficiencies; the premise of designing informed solutions without explicit functional use... these are all problems for design to face head on in the context of a world that may very well already be filled with too much stuff. Architecture has historically been understood (and understood itself) as a constructive or additive discipline. But if it is to truly make use of the built environment for whatever purpose, it must be able to adopt methods of subtraction (and thus binding) into its disciplinary purview. We see this as the context in which this research operates, albeit in a limited but valuable way.

REFERENCES


Taron, J.M. 2012. “Structurally Intelligent Swarms.” *ITcon* 17, Special Issue CAAD and innovation: 283-299.

**IMAGE CREDITS**

All images are the authors’ with the exception of Figure 10 as noted in the figure caption.

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