'DESIGNING IN' COMPLEX SYSTEM INTERACTION: MULTI-AGENT BASED SYSTEMS FOR EARLY DESIGN DECISION MAKING

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ABSTRACT: This paper presents a novel framework for the integration and development of multi-agent based computation techniques to bridge the cyber/physical divide to enhance early stage design decision-making. Through the development of feedback loops of simulated occupancy behavior with design process, the framework presents a new paradigm for the integration of the building occupant and designer, and the building itself as agents for contributing to optimize building design including space use, visibility, adjacency, geometry and scale. The framework argues for the invention and value of linking of human agency, with computer agency and for incorporating emergent conditions and system interaction complexity in early design decision making. The paper focuses on an initial system design which focuses on transit users of multimodal facilities which brings feedback to the designer to optimize for a subset of identified design criteria. The framework shows that with the use of multi agent based simulations for incorporating more intelligently formalized occupant behavior, designers and engineers can '*design in'* more realistic real world complexity and therefore generate design alternatives more rapidly while demonstrating more efficient spaces in terms of actual versus assumed complex natural and physical system interactions

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Keywords: *Multi Agent Simulation, Design Decision Support, Design Computation, Design Optioneering, Parametric Design, Agents, Spatial Adjacencies, Multimodal Facilities, Autonomous*

1. INTRODUCTION

In design, there are often competing goals such as user satisfaction, and building life cycle costs. The complexity of system-to-system interaction is critical as well as the emergent human behaviors that arise [1]. During a design process the design team works under high degrees of uncertainty due to unavailability of empirical and predictive information or due to the difficulty in predicting implications of early design decisions. The critical challenge is how to design and model a priori architectural stimuli or events in spaces that will have long lasting influence on users' behavior. Habit forming through validated design methods is seen as a method for optimizing building use and overall measures of a buildings' sustainability. It is, therefore, important for a design team to understand what factors may encourage repeat or habitual use of facilities. To address these design complexities, there has been increased research activity, to develop more robust solutions in which we have seen novel approaches in the domain of Multi Agent Systems (MAS)[2]. MAS can be defined as the integration of distributed cross-functional activities [3] to design and model events in design spaces that have influence on users' behavior. MAS can be used either to predict or discover potential design challenges as design teams visualize and interact with data; including spatial and geometric configurations, adjacency and proximity measures, slopes and gradients, time based measurements, structural analysis, environmental system performance measures and more complexly individual and group dynamics.

This paper focuses on developing and presenting a MAS framework for multi modal facilities. Due to the shift in the U.S. away from automobile dependence toward more sustainable mass transit, the design and build of new multimodal transit centers are required. This shift comes with a heightened need to analytically understand the impact and complexity of design tradeoffs. There is a need to input human behavior, perceptions and emotions instead of solely relying on few empirically based guidelines/standards. To provide computational support for early design decisions, this paper presents a framework to simulate agent movements, behavior and satisfaction levels in a 3D model/space within an iterative feedback loop. The objective is to affect design decisions, which take into consideration of users' perceptions about a building. All of these perceptions contribute to building occupants' attitudes and norms, and the favorability of these attitudes and norms in turn contribute to building occupants' intentions to use facilities, such as transit facilities [4]. Specifically, the framework anticipates that design features of multi modal facilities will have emergent properties, with the influence of any one feature on a rider being magnified or dampened by the reactions of others present in the station. This complex design problem requires the design of a multi agent system to simulate social contagion, habit forming, and more simple visualization of crowd aggregation and use.The remaining part of the paper is organized as the following. First, MAS in general and MAS in design decision process are described. Second, opportunities with MAS for multimodal facility design are presented. Finally, a framework for the integration and development of multi-agent based computation techniques to bridge the cyber physical divide through intelligent agent design to enhance early stage design decision-making is discussed.

2. MULTI- AGENT SYSTEMS

MAS tools are increasingly being adopted in design, understood as dynamic task environments, [5] in order to help in effective decision making activities of architecture, engineering and construction (AEC) industry. The activities within AEC industry need to be modeled in a manner that can meet the often conflicting needs, knowledge, domain representation modes and project goals [6]. The MAS modeling process requires socially rational models that is, models that can accommodate such complex social behavior as compromise, negotiation, [7] and contagion in order to realize the project requirements with an increased certainty for desired outcomes.

In the context of this paper, a multi agents system (MAS) deploys agents with clearly defined attributes, objectives, goals, behavioral characteristics [8], and domain knowledge [9] in early design decision-making. An agent can be defined as a proactive, interactive and autonomous hardware and/or software-based computer system that can identify environmental changes and adapt [10] itself to the new environment. Each agent interacts with the changing environment as well as with other agents. Through these interactions, operations designed to achieve the common goals of the system are deployed [11]. All necessary knowledge and resources, databases, operation rules, and the manner of interaction [8], must be formalized precisely for effective cooperation of the agents. Formalizing building occupant satisfaction and mapping them to design features and factors is a challenge being addressed in the proposed framework.

3. MAS IN EARLY DESIGN DECISION PROCESS

Design can be defined as a complex, socially collaborative [12], purposeful human activity [13], that requires effective conflict resolution, negotiation, decision making [14] and attention to cultural differences to create an artifact that meets a human need. The decision making process occurs in a dynamic task environment with often conflicting knowledge, views, goals, expertise and models [14]. This highly iterative decision making process requires real time visualizing of design parameters such as scale, adjacencies and so on thus generating possible scenarios of occupant navigation through space. Conventionally a design process is hampered by design cycle latency due to the inability to rapidly iterate, incorporate domains and share results[15, 16] During a design process, MAS can be used either to predict or discover potential design challenges as design teams visualize and interact with data; including spatial and geometric configurations, adjacency and proximity measures, slopes and gradients, time based measurements, structural analysis, environmental system performance measures and more complexly individual and group dynamics.

4. OPPORTUNITIES WITH MAS FOR MULTIMODAL FACILITY DESIGN

Multi modal facilities are public, community buildings, and transit riders are likely to be influenced by the behavior of others in this setting. A basic principle of social influence is that people tend to like others who are similar to them and to feel most comfortable when similar people are around [17]. As a result, any simulation of transit riders' behavior in stations of varying design must incorporate effects of social influence. In multimodal facility design, design factors such as scale, accessibility, adjacency and spatial configuration affect pedestrian flow and operations including measurements for levels of service, congestion, average walking times, delays incurred at gates and ease of navigation (path finding) [18]. As these facilities assume multiple functions, their complexity from a design standpoint presents challenges such as understanding complex system to system interaction and building occupant to system interaction that must be addressed to achieve the desired functional, performance and formal outcomes. MAS can help a team manage interdependencies and inconsistencies [8] as well as create a robust shared system to simulate and address security, speed, safety, and sustainability concerns; the primary objectives of the research.

Designers can therefore leverage MAS tools, in early decision-making to optimize the factors of geometry, scale, accessibility, adjacency and other design features to favorably affect attitudes and norms which in turn contribute to building occupant's behavior and group dynamics and intentions to use multimodal transit facilities. Scale, path finding, environmental conditions and their influences on transit user behavior are examples of physical world scenarios that trigger designers to collaboratively solve problems in multimodal facility design, in the cyber world in order to optimize multimodal system capacity and overall equations for sustainability. Furthermore, a MAS integrated design approach enables a design team to proactively anticipate situations [11, 19] for example unknown site conditions, unforeseen occupancy patterns and building system utilization and loading, and perhaps thwart under or over designed systems by initiating changes during design a priori.

5. PROPOSED MAS FRAMEWORK AND SYSTEM

In the context of this research, MAS is used to facilitate better comprehension of what a design configuration portends for how design or planning decisions will affect behavior of individuals and groups and therefore a projects' sustainability seen through initial objectives of ensuring safety, security and speed. This understanding leads to empirically tangible outcomes of increased ridership, reduced carbon footprints, reduced urban sprawl, and increased societal gain. This is done by simulating agent movements, behavior and satisfaction levels in a 3D model/space within an iterative feedback loop. These simulations enable collaborative adjustment of assumed and initial conditions through rapid evaluation of design alternatives as the agents not only provide information as to movement and location but satisfaction and contagion levels for defined design criteria.

In order to make progress in the development of a more empirically informed and accurate methodology, the framework designs into the agents the implication on their behavior the most critical design criteria of scale, adjacency/spatial organization, space use, visibility and geometry. The research pre-supposes that by using behaviorally accurate agents, safer, more secure and efficient multi modal facilities and therefore more sustainable built environments will be simulated and more easily tuned in early design decision-making. Safety, a primary objective of all public and shared infrastructures is the condition/perception of being protected from harm/injury. Safety involves the prevention of events that could endanger the health and well being of public, including injury/harm or damage such as disasters (natural or man-made). Security is protection from all aspects of illegal activity and from criminals. Both safety and security exist in objective, explicit, and codified design rules or codes as well as in the subjective perceptions and feelings of occupants in a space.

Scale is a critical factor which effects building occupants' comfort and perception of a space. Scale and proportion independently and dependently affect the environmental performance of a building. In the framework scale is varied through dimensional constraints, areas, volumes, and distances to allow for simulation of design alternatives. These alternatives are analyzed based on occupant behavior, for example crowd flow, queuing and herding behaviors enabling design teams to better understand and respond effectively to the emergent conditions within multimodal facilities. A second factor, adjacency, is a design feature, in which designers program a building's functionality through understanding and testing various orders of space and functional types along with their proximities and geometries. Adjacency has a direct impact on speed and security, for example in locating security booths/devices emergency phones. The framework argues that adjacency/spatial organization must be analyzed and simulated through a thorough understanding of passenger circulation patterns such as unidirectional/free flow, and reverse/cross-flows. Here the design team can visualize potential circulation conflicts thus enhancing early design decisions on occupant interaction and connection between spaces. Through simulations from the MAS, designers can visualize and decipher complex and emergent use of the spaces and explore and alter design decisions for more efficiently scaled and adjacent relationships and therefore create a coherent design that circulates occupants in a logical manner without compromising safety and security. The third factor, visibility, impacts building occupants' sense of safety and security and behavior. The MAS system enables a design team to visualize emergent conditions of building occupants' identifying isolated/secluded areas, potential obstacles, and thus increase passenger confidence through clear sightlines, improved system design including signage, lighting, and acoustics, to allow fluid and comfortable building occupant circulation. The fourth factor, geometry, and its parameters of shape, scale, proportion help determines path finding and complexly levels of building satisfaction as geometry is tied to and impacting the other design criteria.

In order to promote a more incorporative design methodology, the framework is devised for 1) domain integration and 2) a MAS for design and engineering decision making feedback (See figure 1). The system is based on cellular automata, where agents react to the attributes of scale, adjacency, geometry, and visibility. and where these simulated building occupants and their complex behaviors can be visualized.

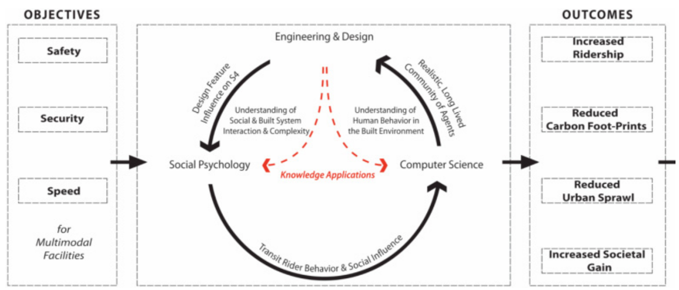

Figure 1: Diagram of objectives, outcomes, general system design, domain interaction and feedback.

The cellular automata consist of an array of cells; each with a finite set of possible states whose purpose is to simulate dynamic processes. In this model, aggregate patterns from individual behavior are developed and then simulated to extract the feedback from the status of the system. Agents are, therefore, queried and used to retrieve information regarding a sense for security, scale, adjacency/spatial organization, space use, visibility, geometry ergonomics and so on, all critical criteria for assessing design parameters which support design performance. This framework can be applied to a large public space, with the assumption that pedestrian destination and route choice can be viewed as the outcome of utility-maximizing behavior, and an aggregate equation of outcomes as contributing to overall definition of sustainability.

6. CONCLUSIONS

The paper presents a framework that seeks to validate a novel design methodology, which is based on the incorporation of MAS technology into design and engineering process in order to simulate and rapidly evaluate design alternatives with 'designed in' real world occupant spatial and behavioral complexity and patterns of use. The design of the agents themselves is novel due to the extension of agent technology through the incorporation of behavioral sciences and due to the application to a complex architectural and engineering problem. Through the application of the system we are bridging the cyber physical divide and where the designer, agents, and buildings all have agency and by definition feeding back to each other. The future work includes gathering human behavior related data that links the design criteria to the use of space and occupant's feelings about the space and implementation of the proposed MAS framework in multimodal facility design through the design studio methodology.

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