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AGENT-BASED MODELING AND SIMULATION FOR FOOD COURT SEATING DESIGN

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ABSTRACT

Designing a space that is functionally based on the users' behavior is usually executed according to the architect's predictions. The aim of this research is to explore how using behavior simulations of the expected users could benefit the design process and be used to evaluate the design proposals. This paper proposes an experiment to test the usage of Agent-Based Modeling and Simulation (ABMS) in the design assessment of the seating arrangement in a food court. The ABMS framework is applied to a model of an existing food court then develops a score during the simulation that determines the turnover rate of clients. A seating design variation that proposes improvements to the original design is tested against the same behavioral simulation for comparison. The simulation of the proposed design showed an increase in the turnover rate by 12%, its score was 250 versus the 224 for the original design. The framework was useful to the assessment of the design proposals although it still needs some technical development for more accurate results.

KEYWORDS: ABMS, architectural design assessment, behavior simulation.

1. INTRODUCTION

Designing a space requires that the architect should be able to predict how the users would use it, but due to the complexity and the cost of the construction process, the assessment of such qualities are only available after the space is already built and sometimes could even be unavilable. That, of course, is risky especially when the project is of a high cost and depends functionally on the users' behavior [1, 2]. Considering that the most important element of an environment is people, it is of great and crucial importance that the professional designers of the built environment put into

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consideration how people respond to it. To examine the relationship between the environment and people, the focus should be on how the environment's physical stimuli or features affect the behavior of its users [3, 4].

Despite having various tools to help in predicting and evaluating various characteristics of building performances such as cost, structure stability, and energy consumption, architects have no way of predicting the performance of a building before it is constructed and occupied from a user's perspective. Therefore a huge gap occurs between the expected behavior of users and how they actually behave. This leads to inefficiency and users' dissatisfaction problems after the building process is over [1]. Statistical analysis are used to show that the method of human behavior simulations helps in finding unforeseen problems, testing the design solution's functionality and validity, conducting a more efficient experimentation process, and allows relative ease in the solution's determination [2, 5, 6].

The approach used for simulating this human behavior is Agent-Based Modeling and Simulation (ABMS). It is basically used to simulate and model systems that are mainly composed of autonomous and interacting agents. It is a way of modeling complex systems' dynamics, those self-organizing systems often create an emergent order. It includes also models of behavior whether human or otherwise to observe how the agent's behaviors and interactions affect the system. These agent interactions cause the emergence of patterns, behaviors, and structures that were not explicitly programmed into the system [7, 8]. ABMS could thus be used to roughly predict the performance of an unbuilt space in relation to the expected behavior of its users.

This paper uses ABMS to assess the design of the seating arrangement in the food court of a shopping mall. The main questions of the research are: 1) In what ways can behavior simulations of users affect the design of the seating arrangement in food courts? 2) Can ABMS be used to assess different design proposals for food courts? The following sections discuss the literature upon which this research is based, the design and methodology of the experiment and the results respectively.

2. BACKGROUND

This research relies on two main areas of study; environmental psychology and ABMS. Each section discusses briefly the studies that were related and used to design the process.

2.1 Environmental Psychology: The Behavior of People in Built Environments

Environmental psychology can be defined as the relationship between the behaviors and experiences of people and their built environment [9]. The way to examine the relationship between the environment and people is by focusing on how the behavior and emotions are affected by the ambient and physical stimuli/features of the environment [3, 4].

The literature suggests that people choose to locate themselves in relation to prominent architectural features, which have a significant effect on their desire to stay in the place and also affect their emotional comfort [10, 11]. Meanwhile, some scholars propose that people feel comfortable when they are located on the perimeter of spaces or as they get closer to areas that provide psychological protection such as sculptures or fountains [3, 12]. Other scholars showed that, in dining seating arrangements, people are more likely to choose the tables that gave them a greater sense of privacy. These tables are typically placed in close proximity to architectural features like walls or windows [10, 13]. Finally, scholars who studied the relationships between meal duration, spending, and seat features, argue that tables that are placed close to the kitchen or areas with high traffic where far less desirable than other tables. More importantly, while people spend less time at those less desirable tables, they spend the same amount of money that anyone would spend on more desirable ones [13, 14].

The literature thus suggests that the most desirable tables in a dining seating arrangement are located at the perimeter of the dining area, or near architectural features that provide them with privacy and security, and away from the kitchen and high traffic areas. This paper uses ABMS to simulate the above behavior in a food court inside a shopping mall. The following section explores the theoretical foundations of ABMS that relate to the proposed simulation.

2.2 ABMS

The virtual simulation of crowds' behavior, whether they are people or not, is an active scope of research in ABMS. The methods for analyzing crowd simulations could be classified into two categories: The first is the macroscopic method which focuses on the simulated crowd as a whole rather than each agent on its own. The second category is the microscopic method which concentrates on the decisions and behaviors of each agent separately as well as the agents' interaction with each other [15].

One example of the latter method is behavioral models (of humans or non-humans) typically used for the observation of the major effects of the behaviors and interactions of agents. These interactions cause the emergence of patterns and behaviors that were not explicitly programmed in the model [7, 8]. Based on the same study [7], the structure of a typical agent-based model has three elements; 1) a group of agents programmed to simulate certain behaviors and attributes, 2) well-defined relationships and methods of interaction between agents, and 3) an environment for the agents to interact with. The authors argue that the agent's most important and defining characteristic is its ability to act autonomously, which means that it can act on its own without any external guidance. They describe the essential characteristics of agents as follows:

1) Each agent is a unique individual that should be easily identified, recognized and distinguished from other agents.
2) Any agent should be able to make decisions and reactions based on its interaction with the environment and other agents as well (as long as those interactions are related to situations that are interesting to the model).
3) The agent must have a state (similar to the state of a system); this state consists of the needed variables to the agent's current situation.

4) Each agent interacts with other agents and consequently influences the other agent's behavior. This interaction has several protocols for several behaviors such as communications, movement, and response to the agents and environment. The agents can recognize and differentiate the traits of each other.

3. METHODOLOGY

This research uses ABMS in the assessment of seating arrangements in the food court of a shopping mall. The behavior of the expected users of the space is fed to a designed behavioral model then tested against the existing food court. During the simulation a score system is applied to track the turnover rate of tables and the agents are closely observed for emergent behaviors. Afterwards the food court design is improved according to the results of the simulation to test the validity of the behavioral model.

To implement the process of the simulation described above, there are two main features that required development; 1) the physical space, and 2) the agents. The first step was to acquire the floor plan of the food court and produce a 3D model for it. The second step was to encode the behavior of the agents to perform specific tasks. The final step was to run the simulation against the 3D model. To thoroughly explain the design of the simulation, each of the following subsections will discuss a separate feature.

3.1 The Agents

The agents in this simulation represent the actual customers of the food court. They are divided into three roles; the group leader, the shopper and the followers. The leader is the decision maker; who picks the table according to the options in Table 1. The agent's behavior depends on the flow chart presented in Fig. 1.

The followers follow the leader to their seats on the same table, the number of followers change according to the number of agents in the group; a group of four would have a leader, a shopper and two followers while a group of six would have a leader, a shopper and four followers. The meal duration of each group depends on the location of their table. The duration clock starts counting down from the moment they arrive at the table. After the time is up the group leaves the table and exits the food court area.

Table 1. Criteria for preference.
(AF = Proximity to Architectural Features, SH = Distance to Shops)

Most Preferred (Option1)	Preferred (Option 2)	Intermediate Preferance (Option 3)	Less Preferred (Option 4)	Least Preferred (Option 5)
AF1 and SH1	AF1 and SH2	AF2 and SH2	AF2 and SH3	AF3 and SH3
	AF2 and SH1	AF1 and SH3	AF3 and SH2	
		AF3 and SH1		

The choice of tables depends on two factors: the table's proximity to architectural features (AF) and its distance to shops (SH). The proximity to architectural features also has a point scale of 1, 2, and 3 but this time 1 is the closest (best for the client) while 3 is the farthest from the architectural features (worst for the client). On the other hand, the distance to food outlets is assigned a point scale of 1, 2, and 3 where 1 is the farthest from the shops (best for the client) and 3 is the closest to the shops (worst for the client).

The tables are categorized as five options. Option 1 includes the most preferred tables that are the closest to any architectural features (AF1) and the farthest from the shops (SH1). Option 2 includes the tables that are either the closest to architectural features (AF1) and of intermediate distance to the shops (SH2) or those who are of intermediate distance to the architectural features (AF2) and are farthest from the shops (SH1). The same logic applies to options 3, 4 and 5. So as per Table 1 the agent in this simulation checks if any table in option 1 is empty, if not he proceeds to option 2 and so on.

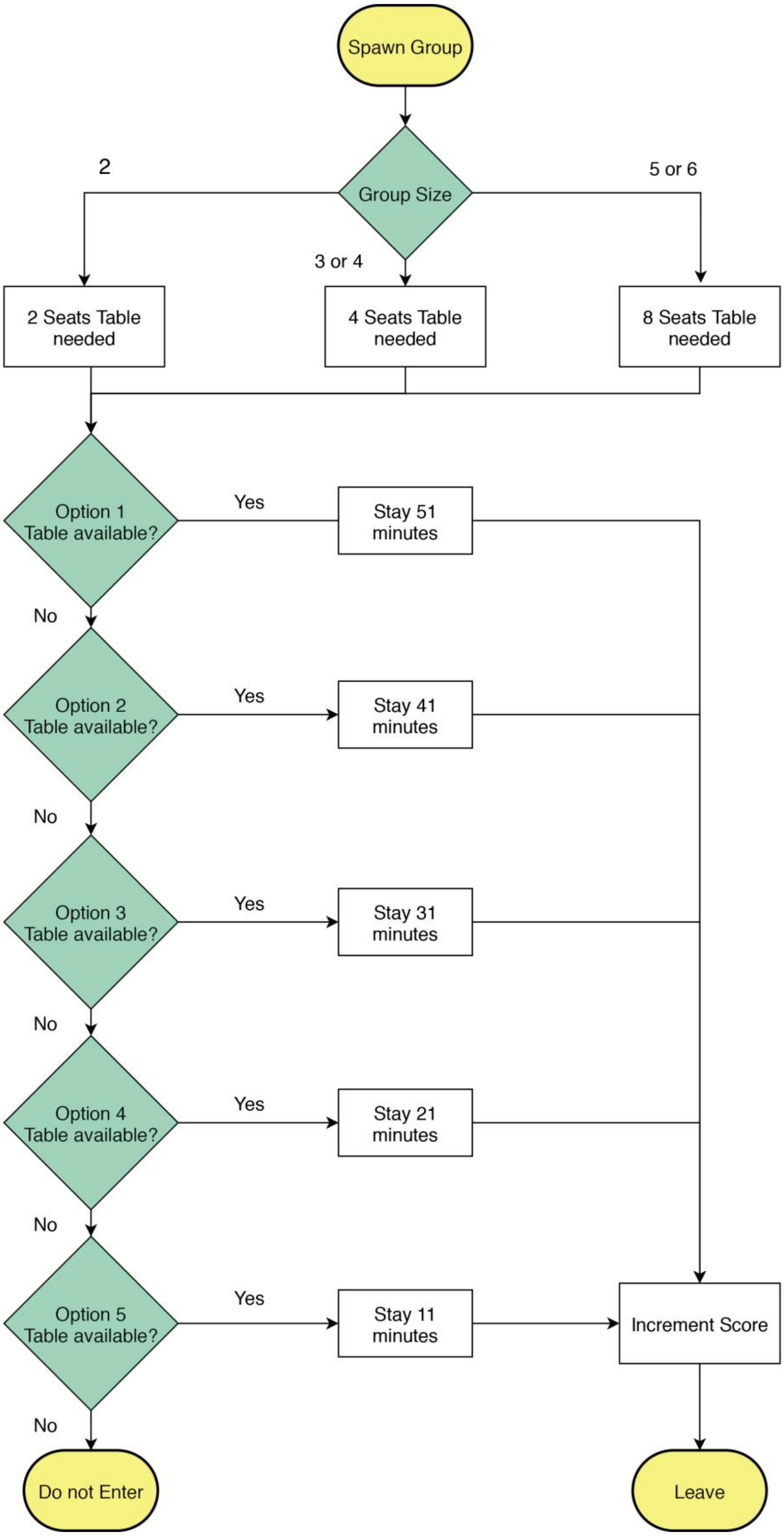

Fig. 1. Flow chart designed for the agents' behavior tree.

The behavior of each agent is technically applied in a games engine: epic games unreal engine 4 (UE4) version 4.19.2 through behavior trees. A spawner is placed in the environment that spawns agents periodically. Each agent behaves according to its own behavior tree which is made up of a sequence of tasks that suits its role in the simulation. Those behavior trees are all controlled by the spawners in the level blueprint. The behavior tree is designed in reference to the flow chart in Fig. 1. When the simulation runs, all agents start spawning and inhabiting the food court where each table has a trigger volume that adds a point to the score each time an agent crosses it, this score is basically the turnover rate of agents within the duration of the simulation.

3.2 The Environment

This section describes the rationale used in encoding the behavior models in the 3D model. It starts by describing the original seating arrangement of the food court as it exists in the shopping mall. It then classifies the tables according to their desirability. Last, it shows the diagram upon which the agents pick their tables in the simulation.

The first step to understand the environment is analyzing the existing plan as shown in Fig. 2. Unlike most food courts, the one chosen for this research is totally enclosed from three sides, this, to a certain limit, restricts the use of the space to eating activities most of its occupancy times. The plan shows the location of shops, columns, the entry and exit zones for the food court, the boundaries of the space, the types of tables and their distribution and the circulation paths for the users of the space.

Figure 2 shows a horizontal projection of the 3D model of the food court. The food outlets surround the seating area from all sides and are only separated by aisles. The two zones for entry and exit are both on the east side of the court. There are four types of tables in the court, which are differentiated according to the number of seats each table affords as shown in the above figure. The food court contains 12 tables for single seats, each table has 10 seats. It also contains 8 tables with two seats, 66 tables with four seats and 36 tables with eight seats. All seats and tables are anchored to the ground and distributed as illustrated in Fig. 2. Those seats and tables have different proximity to the existing architectural features as shown in Fig. 3.

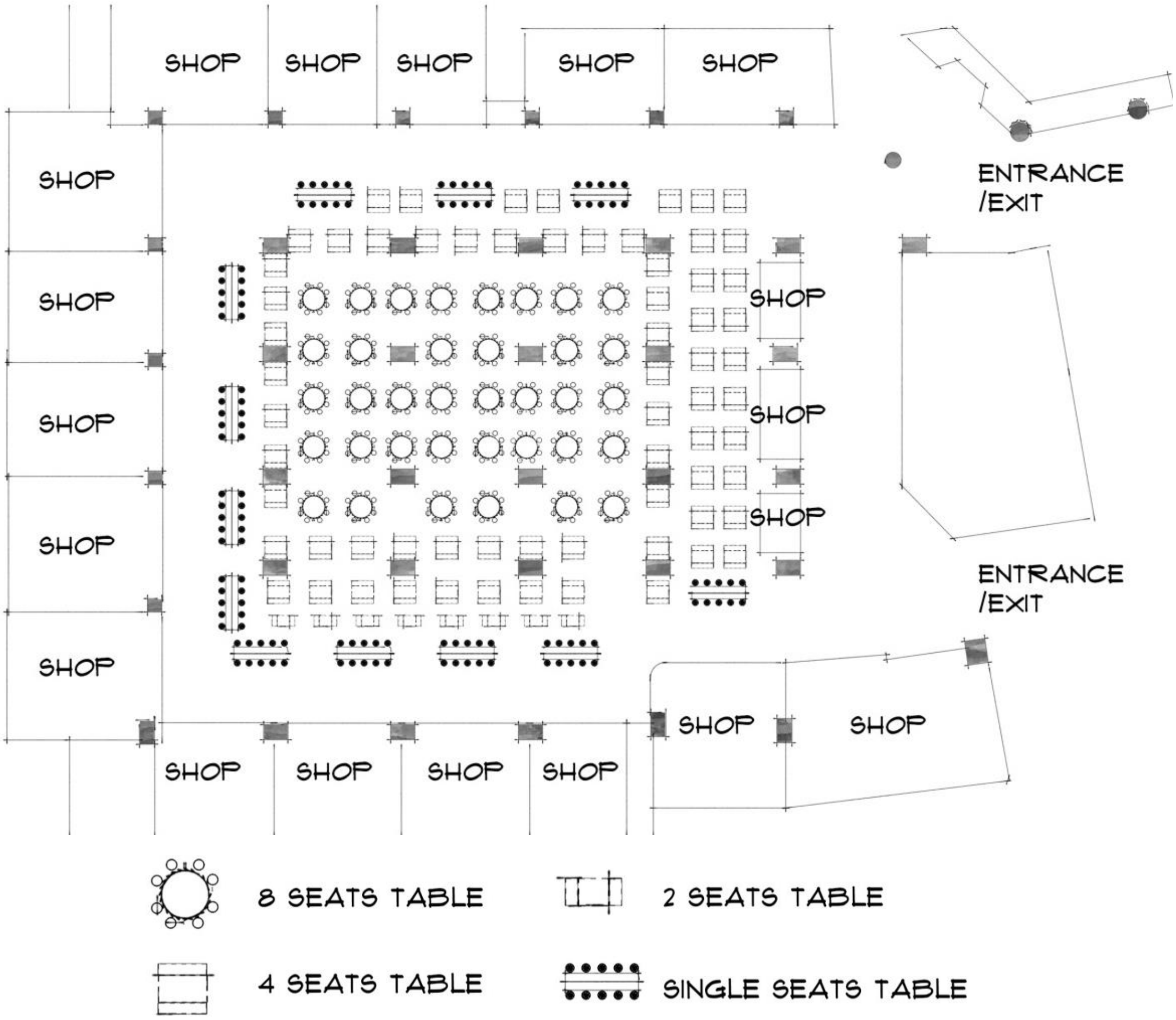

Fig. 2. The plan of the existing food court.

Figure 3 illustrates the proximity of tables to the existing architectural features (the columns and the backside of the central shops). The Most Preferred tables are the closest to any of the architectural features, the Intermediate ones are less close and the Least Preferred ones are the farthest from any of those architectural features. The classification of the tables is based on the relative proximity from the architectural features. The other classification of tables depends on their proximity to the shops as shown in Fig. 4.

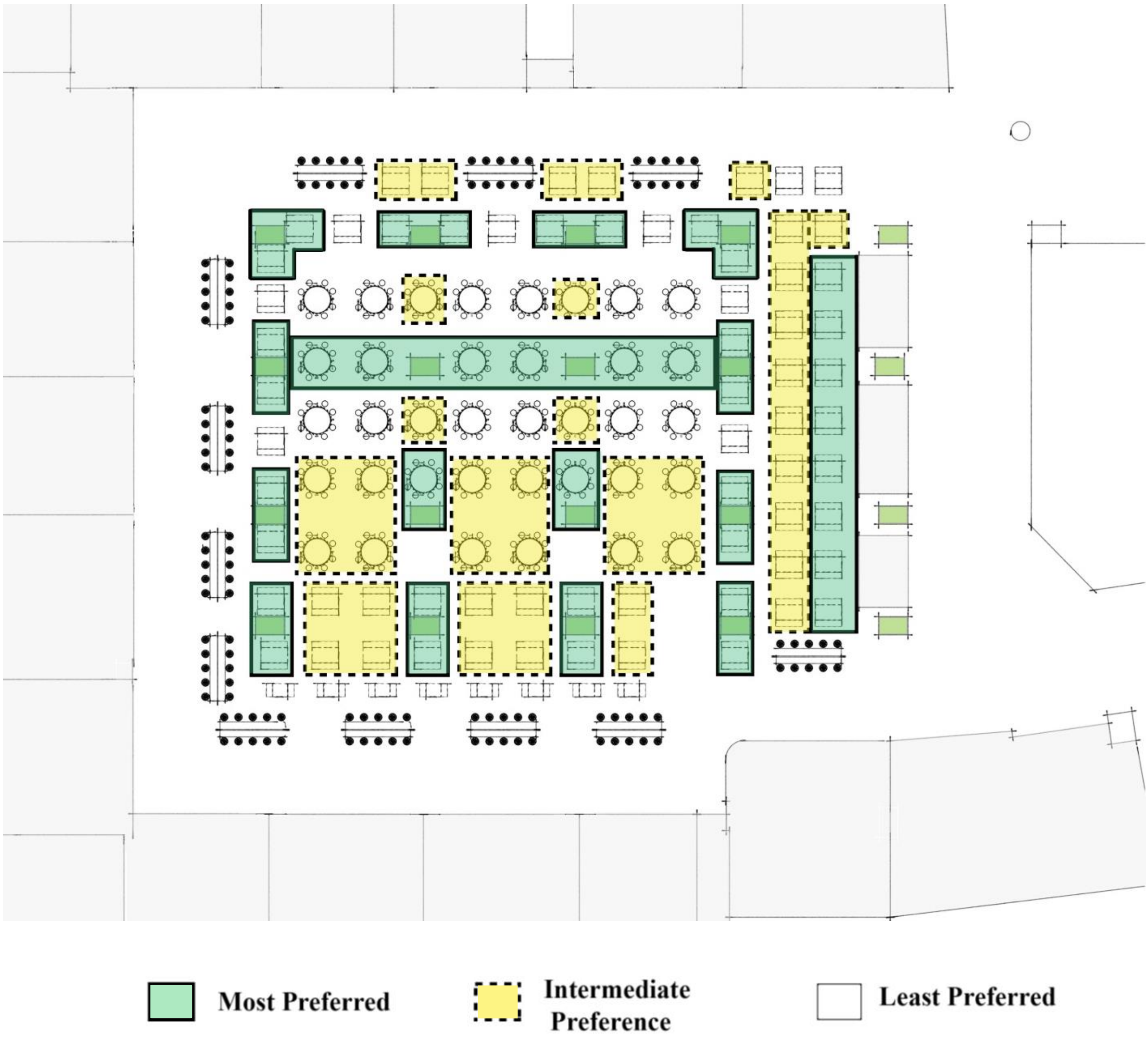

Fig. 3. The proximity of tables to architectural features.

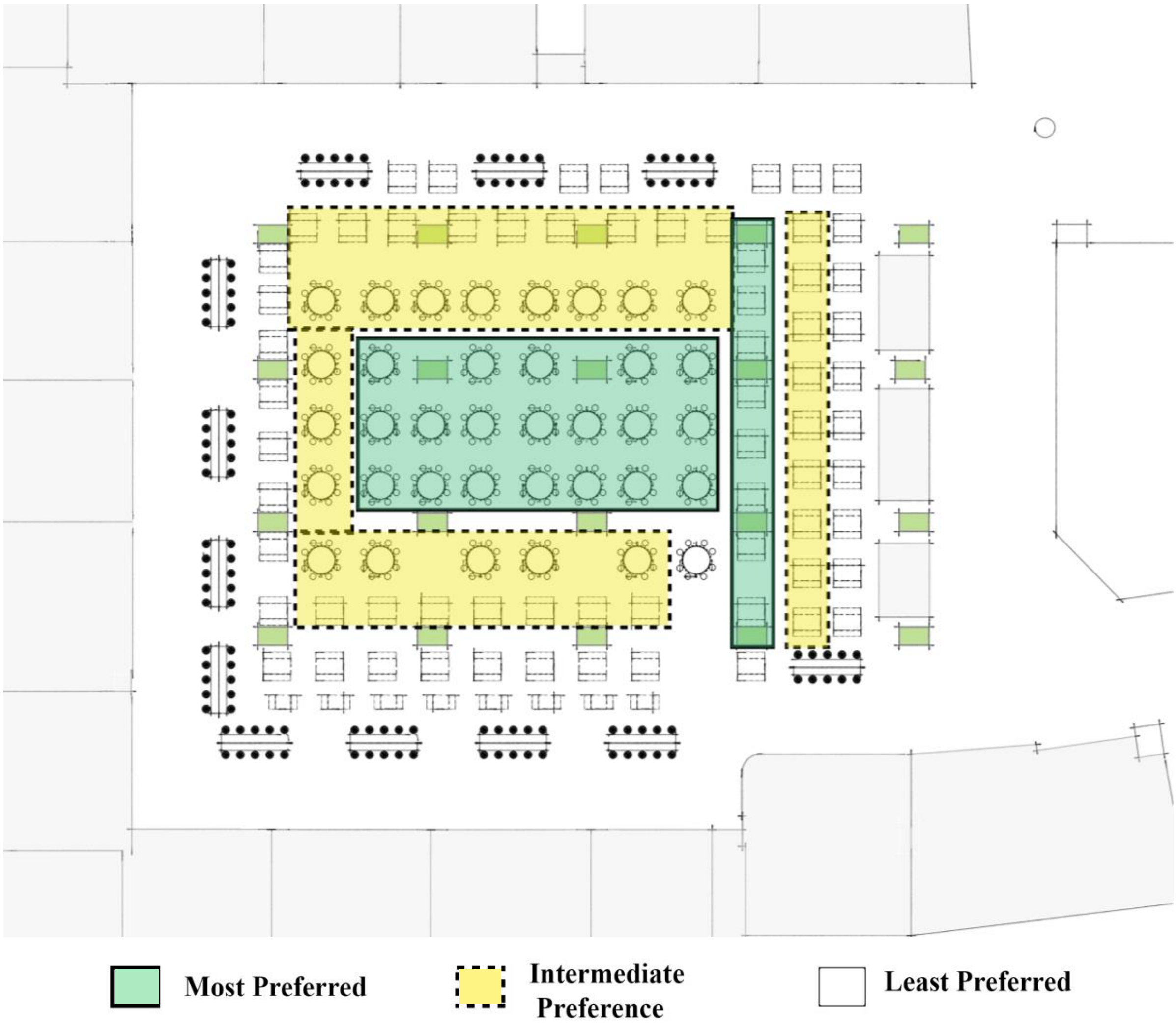

Fig. 4. The distance of tables to food outlets.

Figure 5 illustrates the overlaying of the proximity of tables to architectural features and food outlets. So as described in "The Agents" section, the agents check the Most Preferred tables at first. If there are no tables available, they check the next option and so on.

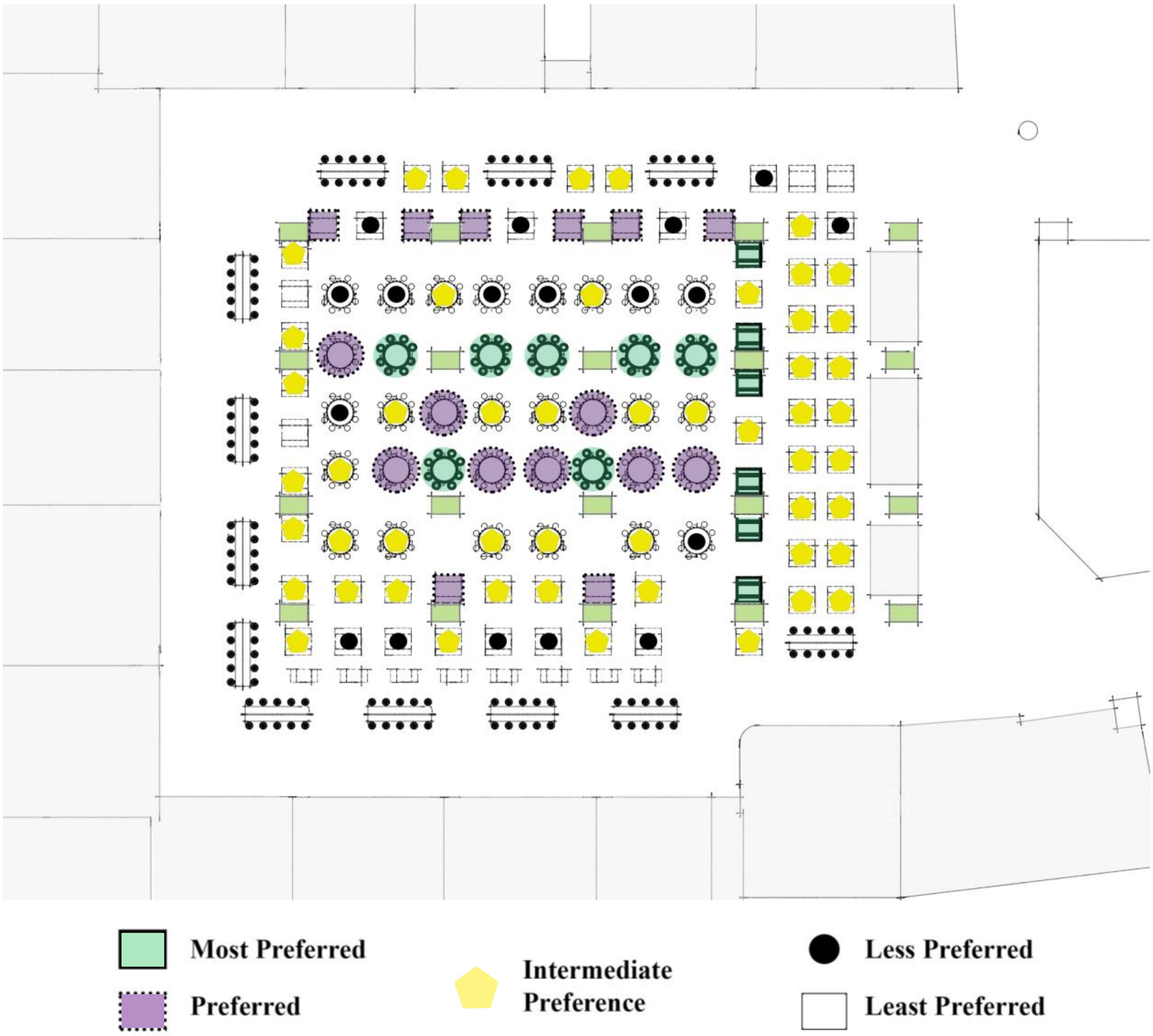

Fig. 5. The proximity of tables to both architectural features and food outlets.

3.3 The Design of the Simulation

The following design builds heavily on ABMS theoretical work [7]. The simulation is used to experiment with the possibility of using behavioral simulation in the assessment of seating arrangements in food courts. The ABMS approach was chosen because the problem is related to human behavior so feeding the virtual agents with those exact human behaviors allows designers to assess those arrangements virtually.

The agents in this experiment act like human beings who visit the food court to have a meal. The behavior of agents can be broadly described as entering the food court, choosing a food outlet, ordering food, picking a table, eating, then leaving. All of the attributes of agents are static; this means that no variable changes during runtime. The attributes include a special ID for each agent, a group state (how many agents are there in the group entering the space) and whether this agent buys food or just waits for another one to get it for him/her.

The seating area is surrounded from three sides by food outlets. The tables are anchored, come in four variations, and are distributed as shown in Fig. 2. 20 columns interrupt the sequence of tables and act as a permanent architecture features in the space. The only exit or entry is from the east side of the food court. Mobility of agents is the most important aspect of the simulation since each behavior assigned to the agents includes motion except for the time they wait at the table for eating or at the shops for getting food.

The agents behave differently according to their role. 1) The group leader chooses a table that has enough seats for the whole group and that is not occupied by another agent. The leader then gets to decide the location of the table. The most preferable location is the one closest to the architectural features and farthest from the outlets. If none of the tables with those specs is empty the agent gets to compromise on one of those qualities step by step till he reaches the worst location which is closest to the outlets and farthest from the architectural features. The leader then decides the duration of eating based on how good the location is (the better the location, the longer the duration would be). 2) The shopper chooses a random shop and stays there for a while then joins the rest of the group to eat. 3) The followers are simply the rest of the agents in the group that follow the leader in and out of the food court. Afterward, all the agents leave the table and exit the food court.

The agents avoid the seats that are being occupied by other agents while the interaction with the environment is apparent in behaviors such as: standing in front of an outlet for a reasonable time to order food, avoiding collision with physical elements, sitting only on chairs and determining the duration of the meal based on the table’s location.

The agents' behavior in relation to the environment is derived from the literature discussed above. However, the duration of staying at each table and the rate of accessing the space by agents is based on field observations of the actual space. This is elaborated thoroughly in the Data section.

3.4 The Data

As mentioned above, the agents' behavioral data is derived from literature and observations. The data derived from the literature (as discussed in the Background section) is that the agents' preference for choosing a table depends on its proximity to fixed architectural features and food outlets. The best table location would be the closest to the architectural feature and the farthest from the shops.

Another source of data is observations conducted at the actual food court. The methodology and findings of the observations cannot be fully detailed in this paper due to space limitations. The observations included the meal duration, frequency of people entering the food court and the average number of agents in a group. A total of 97 groups were observed. The average time spent per table turned out to be approximately 31 minutes while the frequency of groups entering the food court was approximately 38 seconds. Also, the groups comprising 4 to 5 persons represented the majority of the entering groups.

3.5 The Simulation

The simulation is developed in a game engine: Epic Games Unreal Engine 4.19.2. This engine affords full customization for both the agents' logic and the model. Due to optimization purposes, the simulation time is 1/8 of the standard time, this means that one minute in the simulation equals 8 minutes in real time. Consequently, the speed of the agents is eight times faster than the average human speed. Various fractions were tried but when the speed of the agents is multiplied by a number greater than eight, it becomes harder to track the agents.

The scoring system of the simulation counts the number of hits on each table during the two hours of the experiment. As explained above, agents spend more time on tables according to their location in relation to the fixed architectural features and the shops. Since the average time for meal duration is approximately 31 minutes according to observation, the better options are assumed to have ten extra minutes per option. This means that option 1 (as shown in Table 1) has 51 minutes meal duration, option 2 gets 41 minutes, option 3 gets 31 minutes, etc. The bigger the number of the score the higher is the turnover rate for the food court.

3.6 The Validation Design

After comparing the simulation against the existing seating arrangement in the actual food court, the simulation is used to evaluate alternate seating arrangements against the same behavior model for vlidation. An example of an improved design is shown in Fig. 6. The simulation for the existing model showed that groups of 5 and 6 needed more tables while there were extra tables for groups of 3 and 4. So in the new design fourteen 4 seats tables are removed and replaced by seven 8 seats tables. The tables have a different proximity setting compared to the existing one; most of the tables that had high proximity to architectural features are set further than their former location at the existing design.

This replacement of tables showed an improvement in the turnover rate by 12% compared to the original design. The scores for the alternative and existing designs were 250 and 224 respectively. Each score represents the number of occupied tables during the two hours of the simulation per each design.

4. DISCUSSION

Using ABMS to assess the seating arrangements in food courts showed to be of great assisstance. The existing food court was tested against a behavioral model of which its agents represented the expected users of the space; the simulation showed that groups of 3 and 4 had extra empty tables while groups of 5 and 6 at some point could not enter the food court because there were not enough empty tables. This outcome was the base upon which the food court was altered and retested against the same behavioral model. The simulations that lasted for two hours per design showed that the alternative design used for validation had a higher score for the turnover rate by 12%. The score for the original design was 224 while for the alternative one was 250. The process included some trials and errors but the presence of a system (simulation) that tests each proposal made it more convenient. The behavior used in this simulation could easily be altered to test different design purposes. In this paper the main testing criteria for the assessment was the turnover rate of the foodcourt. The use of this approach in design could be used for different functions and behaviors.

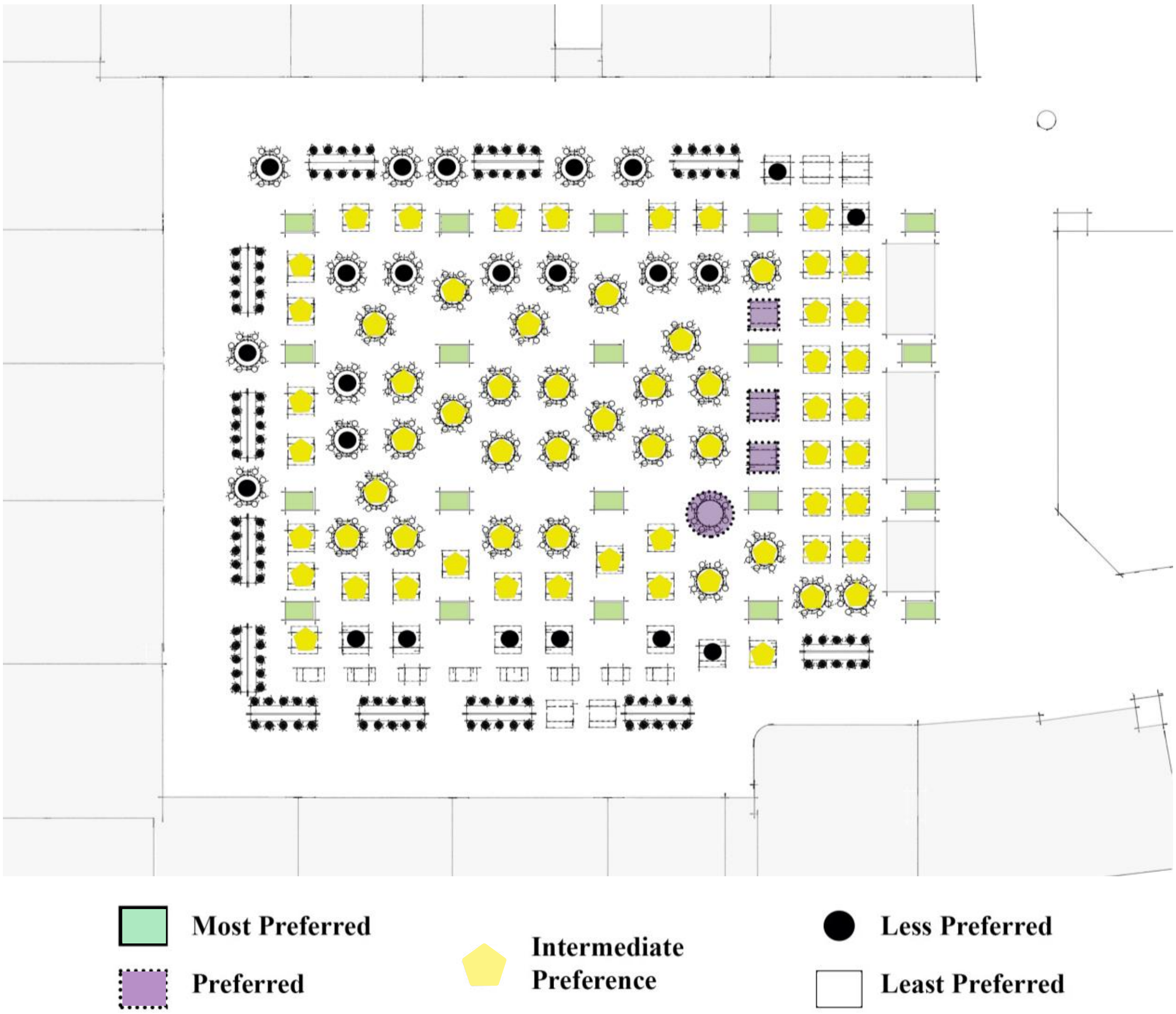

Fig. 6. The validation design for the food court.

5. CONCLUSION AND FUTURE WORK

The ABMS framework is widely used in different fields and it could be useful for architects. This paper experiments with the use of ABMS in the design of seating arrangements in a food court. The agents, who were programmed to enter the food court and pick tables based on preferences related to proximity to the shops and the architectural features, are the main judge for the assessment process. The main target of the experiment was to find the most suitable design with respect to the turnover rate of tables using ABMS.The use of ABMS in design assessment has many applications; this paper proposes one of them.

Further studies could focus more on the detailed accuracy of the behavioral system. The agents would have less generic features and would be totally based on actual observations for each behavior with the insertion of a factor of randomness. The simulation would focus more on mimicking the real behavior of people in the real world and that includes social factors. By then the simulation would produce more accurate results and would be more beneficial to the evaluation process of the design proposals. Moreover, the simulations also afford the tracing of the agents' motion paths, since they are programmed to find the shortest route to their destinations. This could possibly pave the road for studying the circulation design as well.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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النمذجة والمحاكاة المبنية على العميل الرقمى فى تصميم منطقة المقاعد والطاولات فى ساحات الطعام

يهدف البحث لإكتشاف إمكانية إستخدام المحاكاة لسلوك المستخدمين المتوقعين للفراغ فى التصميم وتقييم المقترحات التصميميه لهذا الفراغ ويتناول تجربة لإختبار إستخدام النمذجة والمحاكاة المبنية على الوسيط الرقمى فى تصميم منطقة المقاعد والطاولات فى ساحات الطعام حيث تم تطبيقه بأحد مراكز التسوق وفى أثناء المحاكاة تم حساب مجموع نقاط تمثل معدل التناوب للمستخدمين على المقاعد ثم تم إختبار نموذج اخر لترتيب المقاعد بإستخدام نفس المحاكاة وأظهرت نتيجة المحاكاة للنموذجين زيادة فى مجموع النقاط بنسبة ١٢% وأن إستخدام هذه الطريقة كان مفيداً فى تقييم المقترحات التصميميه ولكنه يحتاج إلى مزيد من التطوير التقنى للحصول على نتائج أكثر دقة.