Architecture and Planning Journal (APJ)

Volume 28 Issue 3 *ASCAAD 2022 - Architecture in the Age of the Metaverse – Opportunities and Potentials*
ISSN: 2789-8547

Article 11

March 2023

COMPUTATIONAL DESIGN FOR ARCHITECTURAL SPACE PLANNING OF COMMERCIAL EXHIBITIONS - A FRAMEWORK FOR VISITORS INTERACTION USING PARAMETRIC DESIGN AND AGENT-BASED MODELING

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Recommended Citation

MORSI, NIHAL; KAMEL, SHAIMAA; SABRY, HANAN; and ASSEM, AYMAN (2023) "COMPUTATIONAL DESIGN FOR ARCHITECTURAL SPACE PLANNING OF COMMERCIAL EXHIBITIONS - A FRAMEWORK FOR VISITORS INTERACTION USING PARAMETRIC DESIGN AND AGENT-BASED MODELING," *Architecture and Planning Journal (APJ)*: Vol. 28: Iss. 3, Article 11.
DOI: https://doi.org/10.54729/2789-8547.1206

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Abstract

Using computational tools for evaluating spatial layouts of commercial exhibitions provides an opportunity for assessment of performance before execution. However, most evaluation techniques take into consideration only the physical qualities of the built environment, excluding important factors such as crowds. Crowds are essentially dynamic obstacles that hinder visibility and can induce flight response, but they are also a sign of good exposure when in reasonable amounts. This is mostly due to the challenge of quantifying spatial qualities such as users' interaction and movement for computational representations. This paper proposes a framework using agent-based modeling for simulating user interaction in commercial exhibition spaces combined with a parametric representation of the built environment. The framework is then evaluated by applying it to a case-study of three layout scenarios in a generic exhibition hall. The simulation results show that layouts with vertical aisles, and less horizontal aisles have better footfall distribution.

Keywords

Space Planning – Commercial Exhibitions – Agent Based Simulation- Parametric Design.

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ABSTRACT
Using computational tools for evaluating spatial layouts of commercial exhibitions provides an opportunity for assessment of performance before execution. However, most evaluation techniques take into consideration only the physical qualities of the built environment, excluding important factors such as crowds. Crowds are essentially dynamic obstacles that hinder visibility and can induce flight response, but they are also a sign of good exposure when in reasonable amounts. This is mostly due to the challenge of quantifying spatial qualities such as users' interaction and movement for computational representations. This paper proposes a framework using agent-based modeling for simulating user interaction in commercial exhibition spaces combined with a parametric representation of the built environment. The framework is then evaluated by applying it to a case-study of three layout scenarios in a generic exhibition hall. The simulation results show that layouts with vertical aisles, and less horizontal aisles have better footfall distribution.

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ملخص
إن استخدام أدوات الحاسوب لتقييم التخطيط الفراغي للمعارض التجارية يتيح الفرصة لتقييم الأداء للمبني قبل تنفيذه في الواقع. لكن معظم طرق التقييم تأخذ في الاعتبار الخصائص المادية للبيئة المبنية، وتستثني بعض العوامل الأخري مثل تزاحم الزائرين داخل فراغات العرض بالمعارض التجارية. يعتبر تزاحم الزائرين عقبة تعيق تحركهم وفي نفس الوقت تعطي احساس بالرغبة في الهروب من تلك الفراغات، على الرغم من ذلك، فإن هذا التزاحم في بعض الأحيان يعتبر علامة جيدة لنجاح ورواج المعروضات داخل تلك المعارض. تهدف هذه الورقة البحثية إلى اقتراح إطار عمل لاستخدام النمذجة القائمة على الوكيل وذلك لمحاكاة تكامل تفاعل الزائرين في المعارض التجارية مع التمثيل البارامتري للبيئة المبنية. تم تقييم إطار العمل المقترح من خلال تطبيقه علي دراسة حالة لثلاثة مقترحات تصميمية لقاعات لمعرض تجاري ودراسة حركة الزائرين بها. اظهرت نتائج المحاكاة أن التخطيط الفراغي الذي يتكون من الممرات الرأسية يؤدي الي توزيع أفضل للزائرين علي أجنحة العرض.

الكلمات المفتاحية: تخطيط الفراغات، المعارض التجارية، النمذجة القائمة على الوكيل، التصميم البارامتري.

1. INTRODUCTION

Commercial Exhibitions play a vital role for businesses to sell their products, gain exposure and interact directly with consumers (Patel, 2017). Due to the importance of the opportunity produced by these events business owners pay a great deal for getting maximum exposure, by reserving the best spots for their attractive booths. Studies have shown that the layout configuration of commercial facilities affects traffic patterns, visitors' emotional responses, and behavior (Bohl, 2012). Also, it is found that users are influenced by environmental cues produced by surrounding users (Dalton, Hölscher and Montello, 2019).

Recently there has been an increase in computational power, extending the capabilities of architects. One of these opportunities lies in advances in computational simulations to evaluate buildings before execution. Computational simulations provide insight and analysis of designs beyond human designers' capabilities (Helbing, 2012). Space is defined as a result of the dynamic activities of designers and occupants, it extends beyond physical static boundaries (Andia and Spiegelhalter, 2015). However, most traditional computational simulation techniques deal with quantifiable metrics and represent the built environment as a static entity.

Agent-based models have proved successful in simulating human behavior and producing realistic results (Bonabeau, 2002). Although Agent-based simulation has been studied in many architectural applications such as museum exhibitions (Batty, 2008,Pluchino et al., 2014), shopping malls (Sousa, Caetano and Leitao, 2017, Feng, Yeung and Mayne, 2016), , hospitals (Lu, 2011; Lee and Lee, 2019, 2020) no studies were found applying it to commercial exhibitions layout design. (Nagy et al., 2017) had discussed the commercial exhibition layout planning problem from the generative design process approach and how to evaluate the resulting design space, however, their process needs very high expertise, and the resulted oblique layouts may cause navigation difficulties.

This paper aims to propose a framework using parametric modeling and Agent-based simulation to help architects evaluate visitors' interaction in commercial exhibition layout design.

2. OVERVIEW OF COMMERCIAL EXHIBITIONS AND USER EXPERIENCE

In this section, an outline of the planning process of commercial exhibitions is discussed with a highlight on the effect of crowding on user experience in commercial buildings and how Agent-based modeling can help in layout design.

2.1. The Planning Process for Commercial Exhibitions

The usual process of commercial exhibition layout planning starts with choosing an appropriate premise, then organizers start by dividing the exhibition hall layout into aisles and corridors and dividing the remaining spaces for booth allocations. Premium booth spots are sold to clients willing to pay more. High-traffic zones are characterized by high visibility, these are spaces near entrances and exits, main aisles, within the visible triangle zone from the entrance, and at the center of the exhibition. Since booths of popular brands usually gain a lot of traffic, organizers try to spread those out for equal traffic distribution (Adams, 2022).

For creating a positive experience, visitors need to find their way easily. A successful layout should help in reducing bottlenecks, waiting times, the number of dead spots, and provide wide enough circulation space for walking, stopping, bending to view exhibited products, talking, and exchanging information (Patel, 2017). Also providing equal exposure to both large and small businesses is important for exhibition success.

2.2. The Effect of Crowds on User Experience in Commercial Buildings

Commercial exhibitions usually attract many visitors and crowding is an important parameter in this case. In retail environments, perceived crowding is found to have an inverted U-shaped effect on visitor experience, crowded spots to a certain level can act as a pointer to popular destinations, however, after that point, it can lead people away due to feelings of stress (Mehta, Sharma and Swami, 2013). Perceived crowding can be due to the number of people in space or its geometrical configuration(Machleit, Kellaris and Eroglu, 1994). (Penn, 2005) shows that crowding causes people to keep moving instead of viewing exhibited products and engaging with them. Crowding also acts as a dynamic obstacle to visibility. Research using Agent-Based Modelling and experimental studies have shown that visibility is one of the prime factors that affect navigation and wayfinding, and one of the environmental factors affecting navigation is the environmental topology that allows for more gaze range (Barton, Valtchanov and Ellard, 2014).

3. AGENT-BASED MODELING FOR ARCHITECTURE SIMULATION

Agent-based modeling is a computational model that simulates dynamic interactions between autonomous agents and the environment. The agents act in different situations according to pre-defined rules (Bonabeau, 2002). A lot of commercial agent-based simulation tools are available and used by architects, although they usually need some special expertise, like Pathfinder, PedSim, Repast Simphony, NetLogo, AnyLogic, and many others (Bamaqa et al., 2022, Abar et al., 2017). Agent-based simulations are used in social experiments, industrial design, and architectural design-related applications such as pedestrian movement, evacuation studies, form finding, and circulation evaluation (Puusepp, 2011). Many studies used Agent-based modeling for evaluating building safety. (Pluchino et al., 2014) used Agent-based modeling to evaluate the carrying capacity of the Castello Ursino museum in Catania (Italy), the main aim was to find the number of visitors to the building to perform well without any safety issues, the authors evaluated factors such as waiting time at artifacts and time taken for evacuation in different exit scenarios and different amount of visitors.(Sousa, Caetano and Leitao, 2017) proposed a framework of Agent-based simulation and generative design to test evacuation time in a shopping mall. (Schaumann et al., 2016) used Agent-based modeling coupled with a detailed activity sequence to simulate nurses' movement trajectories to increase layout efficiency by reducing nurses' walking distance. Agent-based modeling can also act as a driver for form generation, (Ghaffarian, Fallah and Jacob, 2018) developed a tool to generate architectural space through an organic form-finding process by using agent-based behavior systems.(Puusepp, 2014) used Agent-based modeling to generate circulation systems both on the urban and the dwelling scale.

4. METHOD

This section presents an outline of the design framework utilizing parametric modeling and Agent-based simulation, then an application using a generic case study for framework evaluation and the simulation method applied.

4.1. Proposed Framework

The presented framework as shown in Figure (1), consists of two main parts. The first part is the parametric representation of the exhibition layout, this is to introduce change to the proposed layout configuration in a fast and flexible manner. The second part is to simulate visitors' movement using Agent-based simulation. Both processes are done in Grasshopper (an add-on to Rhino 3D modeling software).

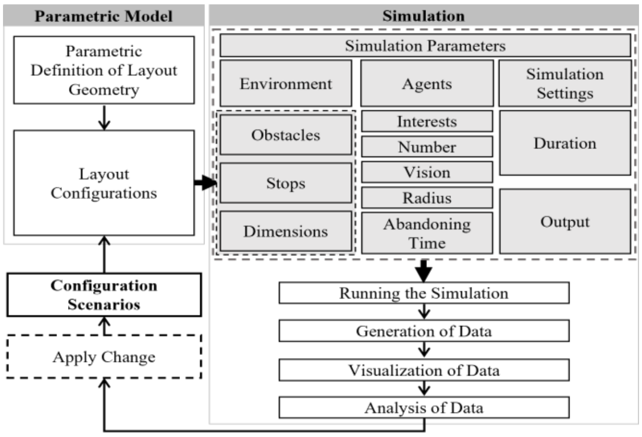

Fig.1: Framework outline

4.1.1. Parametric representation of commercial exhibition layout

The model consists of three main parts, border booths adjacent to three sides of the hall with spacing between them to allow for secondary exits (for evacuation and services). Then a central area, with different booth configurations. The third part is the area adjacent to the entrance and exit. The main division method is using control points to divide the central area, whether it is used as a whole or divided by main aisles. The model has three outputs designed specifically for simulation purposes, an outline of booth groupings for obstacle representation, booths divisions, and central access points to be used as interest stops. The model was built to be adaptable to any orthogonal space for layout plan modeling, all output is in 2D. A diagram of the geometry definition is shown in Figure (2).

The model parameters are:

- Width and length of exhibition space.
- Location of booths at border walls.
- Width of booths adjacent to exterior walls (a constant value of 3 meters).
- Central area booths width (these vary according to vertical aisle width).
- The number of vertical aisles.
- Number and width of horizontal aisles of central area (these are split according to the resulting subsets from horizontal main aisles).
- Main vertical aisle width.
- Main horizontal aisle width.
- The number of booths.
- Entrance area length (the width is the width of the exhibition hall).

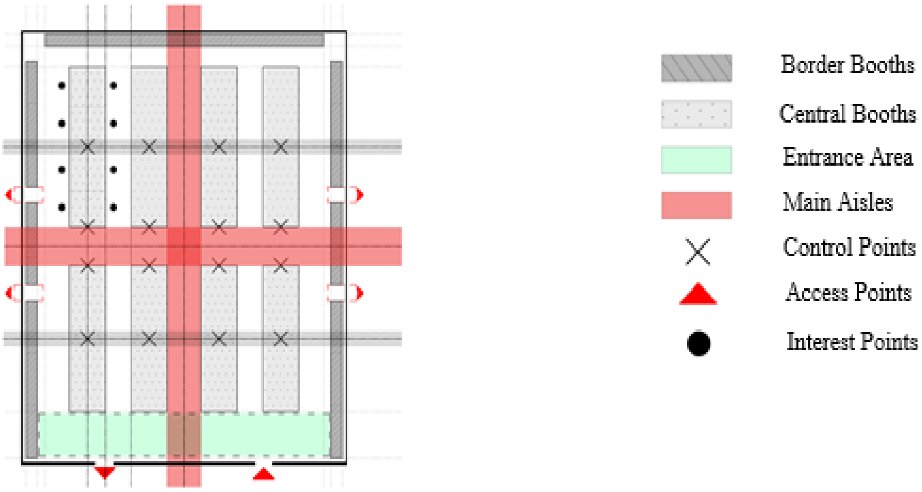

Fig.2: Parametric representation of commercial exhibition layout

4.1.2. Agent-based simulation

The software used for simulation is PedSim (commercial version), an add-on to Grasshopper, this tool is based on the social-force model (Helbing and Molnár, 1995). Agents are driven by multiple forces, target forces, person and obstacles repulsion forces, and a random noise force to reduce bottlenecks (Wang, 2022). PedSim is chosen for this study due to its ease of use, and ability to connect to other parametric and simulation tools. Also, social-force models are shown to be an accurate method for predicting pedestrian behavior (Bauer, 2011).

PedSim had been applied in many applications regarding agent interaction. (Chen et al., 2022) used PedSim for producing a dataset of people's movement in an underground shopping space to be later used for predicting COVID-19 transmission. (Lee, Lee and McCuskey Shepley, 2020) used it to simulate the pedestrian movement of nurses in hospital nursing units. (Abu Ghazala et al., 2021) designed a simulation environment that combines agent-based social simulation with IoT ecosystems to test the interaction between agents and the systems. (Lee and Lee, 2020) proposed an approach integrating space syntax and agent-based analysis for an evaluation framework to measure spatial and social attributes to study how layouts can encourage inflows to common gathering spaces, which would lead to an increase in social participation of the residents in older adult care facilities. (Yeung Cho et al., 2021) proposed an approach using PedSim to help model different scenarios with various intervention strategies like layout changing, social distancing, and population limitations for safe accessibility of office spaces.

The simulation model consists of the physical environment, the agents, and the engine. The physical environment is an output of the parametric model and input as obstacles for walls, transparent obstacles for booths (they are assumed to be open enough to be see-through), stops for entrances, exits, and a point of interest at each booth. The agents here represent exhibition visitors, the agents' parameters are defined in "person templates". Finally, the engine calculates possible agents' trajectories and runs the simulation.

4.2. Application

For testing the proposed framework, a case study of a generic exhibition hall is used as the premise of simulation. The hall is of an area of 10,000-meter square and 90 m in width and 110 m in length. Each hall has 6 openings, 2 main entrances, two side entrances, and two service entrances. All common features of commercial exhibition spaces.

The proposed simulation scenarios as shown in Figure (3), are meant to test different movement aisle configurations. Scenario 1 "A" starts with a basic case of only 4 vertical aisles, then horizontal aisles are added in "B" and "C" with the same width as vertical aisles. For Scenario 2 "A", a main vertical aisle is introduced and same as Scenario 1, horizontal aisles are added. In the last Scenario 3, both vertical and horizontal main aisles are added, this divided the central area into four quarters, each has horizontal aisles added to it in "B" and "C". The number of booths is constant in all scenarios (100 booths), with a minimum dimension of 3 meters. The border booths width is 3 meters, and the central booth width is set to 5 meters.

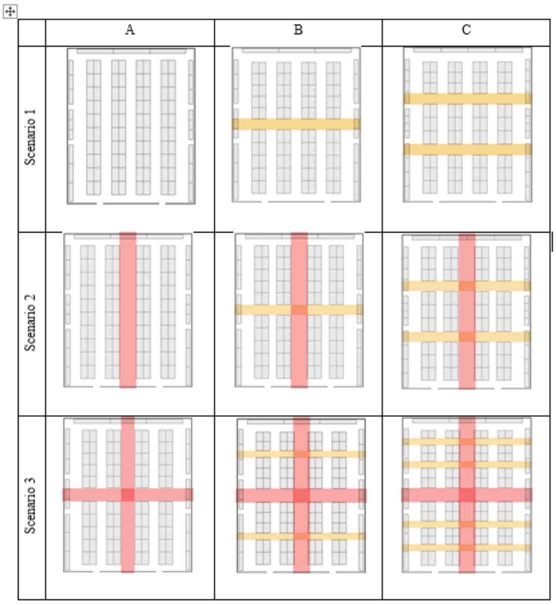

Fig.3: Configuration scenarios

For all scenarios, there is only one main entrance and exit. Other stops represent interest points, these are central points at accessible sides of each booth. The layout is divided into three zones as shown in Figure (4). Each represents three different interests. Agents are divided equally into three groups; each is interested in one interest .The number of agents' visits per interest is 10 visits, 30% of booths per zone (Expo Exhibtion Stands, 2022), with a visiting time of 30 seconds, within the range of time spent per exhibit by visitor according to (Sandifer, 2003). The capacity of each interest stop is 5 agents (fitting 50% of booth space). Number of visits per booth and booth capacity vary greatly according to exhibited product, these data can be collected by exhibition managers from past events for more accurate simulations, however for the purpose of framework application, recurring numbers in the literature are assumed.

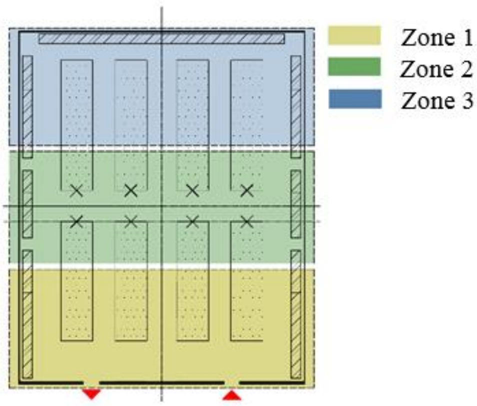

Fig.4: Interest zones division

4.3. Simulation

Agents' stops and obstacles are collected from the baked output of the parametric model. Agent properties set are vision as panoramic 360-degree vision, an abandoning time of 60 seconds, which means a person will abandon the current target of interest if this time has passed and moves on to the next visible target (this measures the effect of crowds making certain booths not accessible), and body radius of 0.3 m.

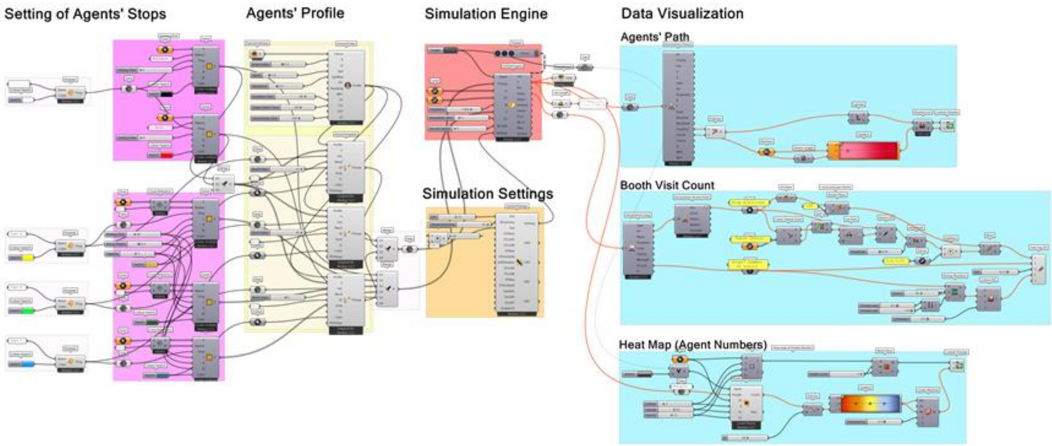

Fig.5: Grasshopper Definition

Simulation settings are a duration of 20 minutes and a population of 1000 agents (this number is an average number collected from past similar events in a similar-sized venue).

Data output and visualization: PedSim records agents' trajectories, number of agents per cell, and visit counts per stop. The cumulative density of agent path trajectory is used to measure visitors' movement at the start of the exhibition, these are recorded 10 minutes from start. Visitors number per cell heatmap to define bottlenecks and dead zone areas, the cell size is 2*2 meters for easier computation. The number of visitors per booth is calculated to investigate both booth and zone exposure. Also, several screenshots were recorded showing agents' interactions.

5. RESULTS AND ANALYSIS

5.1. Cumulative Trajectory

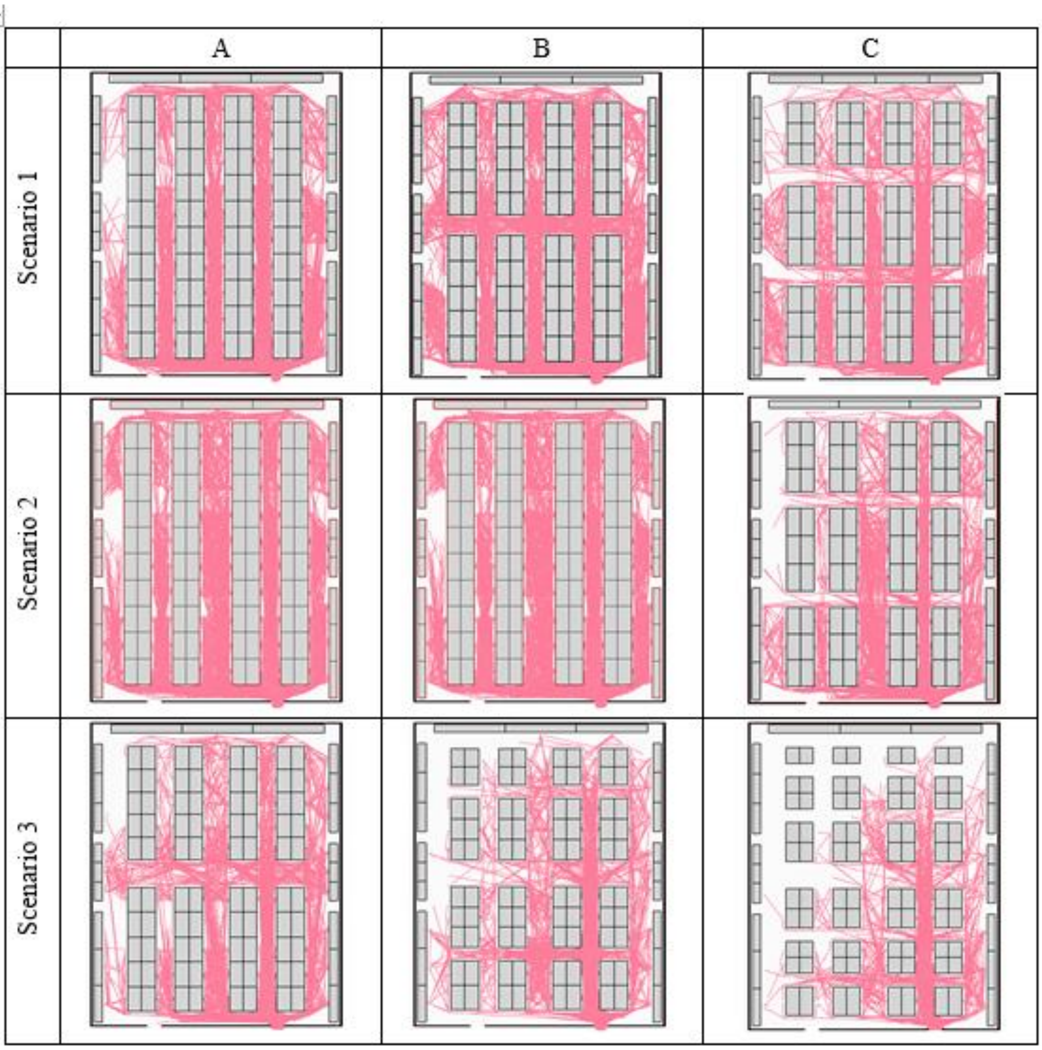

Fig.6: Cumulative trajectories at the start of simulation

During simulation, it is observed as shown in Figure (6) that aisles facing the entrance are first to get filled with visitors, even if this aisle is not the main aisle. Increasing aisle width helps in lessening bottleneck zones too and reducing loitering areas forces visitors to move on to their next target directly with less traveled distance which creates more even distribution of foot traffic.

5.2. Number of Agents Per Cell Heatmap

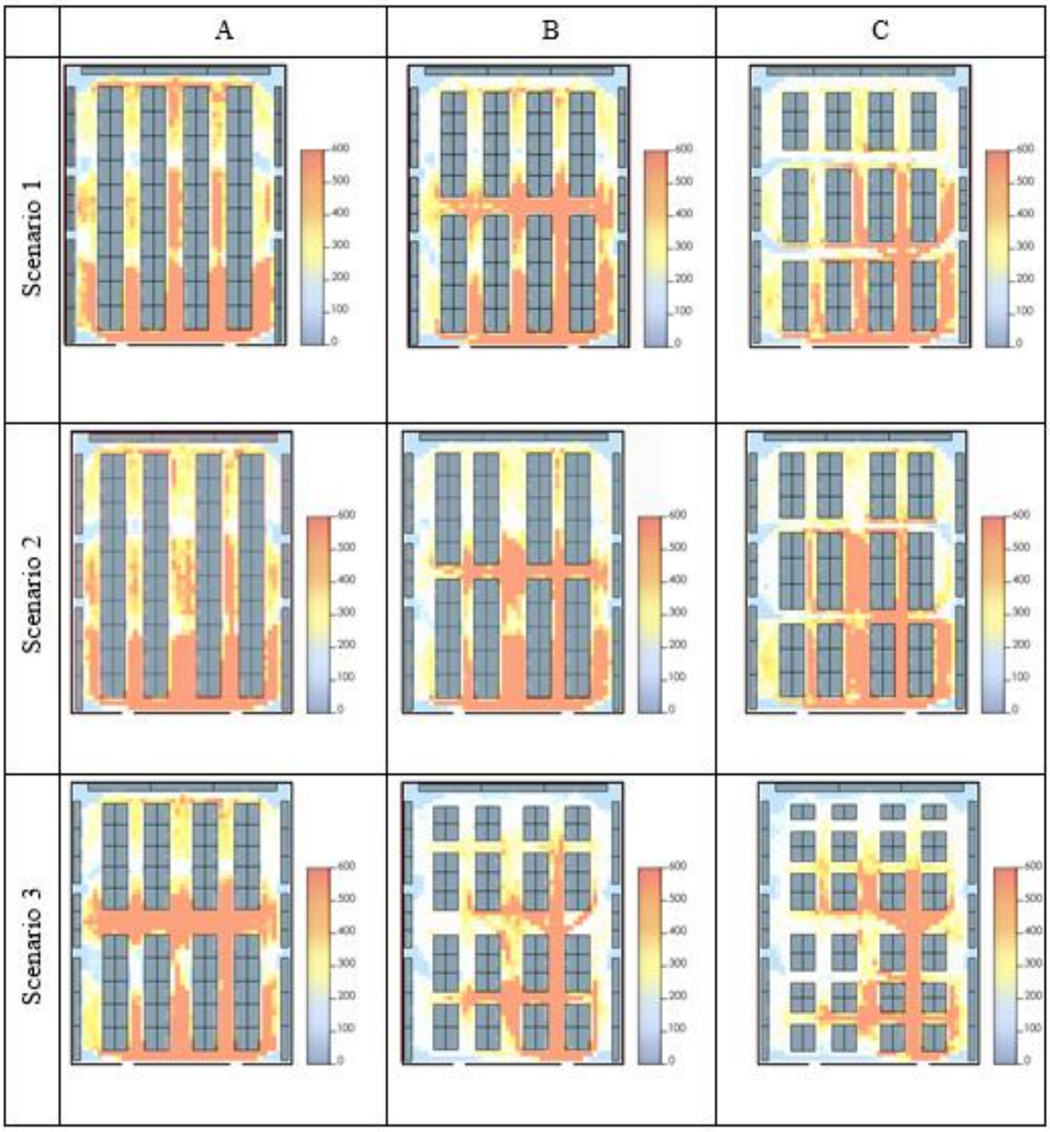

Fig.7: Agents Number Per Cell Heatmap

As shown in Figure (7), in scenario 01, bottlenecks exist in zones near the entrance, for “A” high traffic exits especially in aisles closest to the entrance. Adding horizontal aisles concentrates high traffic and reduces traffic in vertical aisles but increases dead zones at the furthest quarter from the entrance. In scenario 02, adding the main aisle distributes traffic better near the entrance, however, dead zones are increased in the furthest half. In scenario 03, adding both main vertical and horizontal aisles create bottlenecks at their intersection, this could prevent agents from reaching further zones. Overall scenarios with vertical aisles have better foot traffic distribution.

5.3. Agents Visit Count Per Booth

Figure (8) shows the distribution of zones with highest visitor counts and lowest visitor counts, it is observed that there is a quarter-like distribution, with the quarter closest to the entrance with the highest count and a quarter further away with the least visitor count.

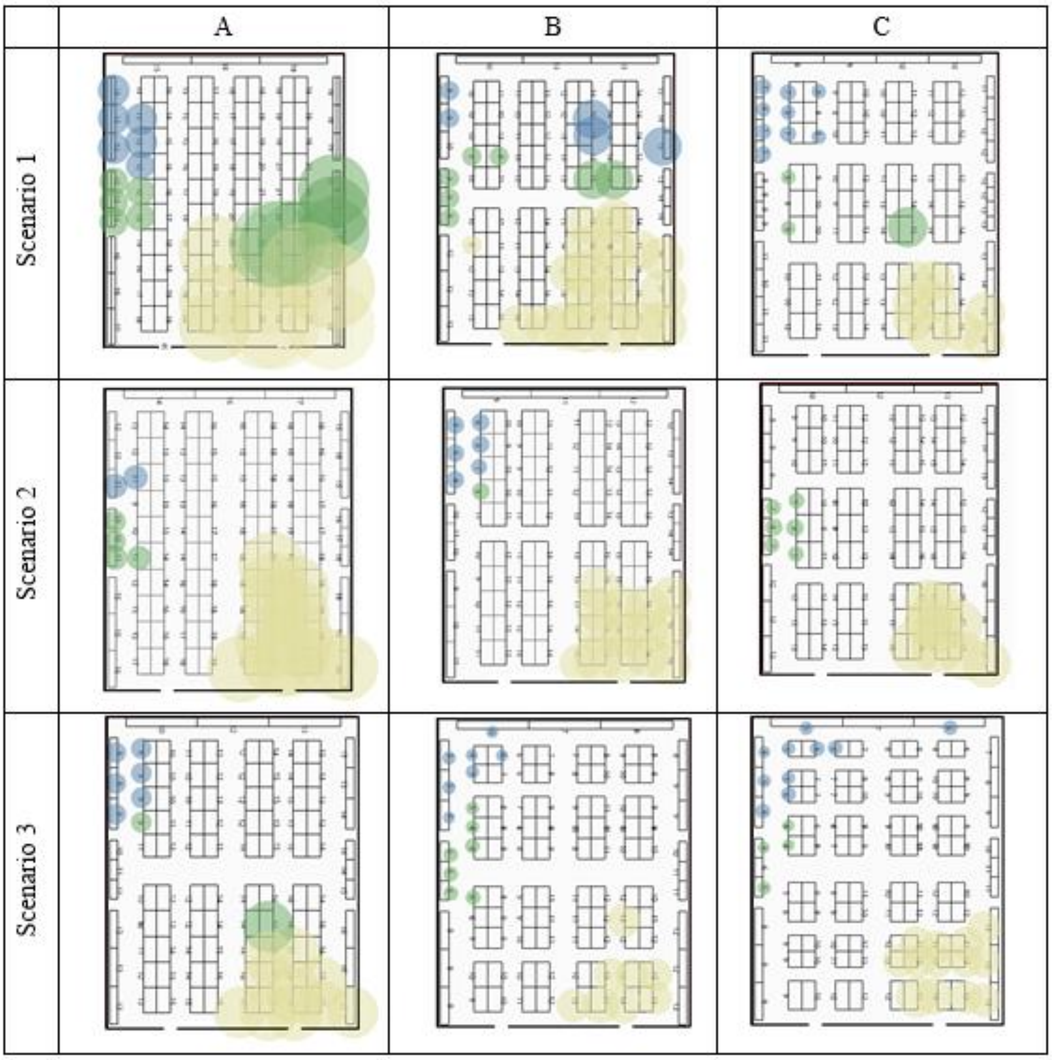

Fig.8: Map of Highest and Lowest visitors count per booth

In Figure (9) Scenarios with vertical aisles only seem to have the highest visitors count as seen in scenarios 01 and 02 case “A”. Scenario 02 “B” however has the best visit count distribution although the visit count isn’t as high as vertical aisles only scenarios. In most scenarios, zone 3 being furthest from the entrance always has the least visitor count, except in cases “B” in scenarios 01 and 02, these cases have better visit count distribution.

According to (Shaw, 2018), The crowd density ranges from loose crowds needing about 1 meter square per person to extremely dense crowds of 0.3 meter square per person, according to the maximum number of visit counts, a single grid cell would hold about 5 to 10 users which is quite dense.

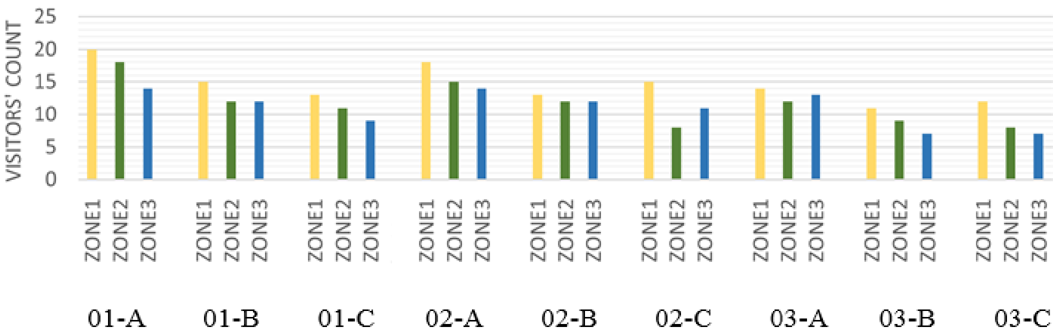

Fig.9: Visitors’ Count per Interest Zone

DOI: 10.54729/2789-8547.1206

5.4. Booths Type Zoning

Zoning of booths according to possible visitor interest influences visitor accessibility to points of interest, this is observed during the simulation in Figure (10), visitors of zone 1 create bottlenecks that hinder other visitors from reaching their points of interest. In some scenarios, bottlenecks at horizontal aisles create that same effect creating bottleneck areas twice, although no stops are present in this area.

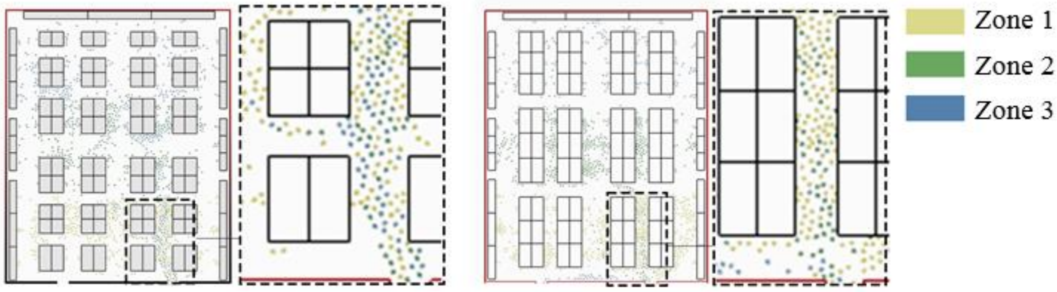

Fig.10: Map of Highest and Lowest visitors count per booth

6. DISCUSSION AND CONCLUSION

Users' interaction in spaces of public buildings has a great impact on user experience and proper building functionality. In the case of commercial exhibitions, layouts undergo a lot of change in very little time due to their temporary nature. Proposing a framework using agent-based modeling for simulating user interaction and the effect of the crowd on booth accessibility can provide important insight for proper decision-making in the layout design process. Agent-Based Modeling has many advantages that make it suitable in this regard, as stated by (Helbing, 2012), it provides us with the opportunity to visualize the interaction between different individuals and entities, it is modular, flexible, and has a wide range of applications. Also, it can be smoothly combined with other kinds of models allowing expansion of simulated scenarios and parameters. This is tested by adding a parametric representation of the commercial exhibition layout to the proposed planning framework, which increases the flexibility of making alterations to the layout design. Also, both the parametric and simulation models are run on the same platform (Grasshopper), reducing time and complications caused by the transfer of data from drawing platforms to simulation platforms since simulation platforms require precise drawings with no geometry overlap.

However, there exists a couple of limitations to the Agent-based modeling approach. First there is the difficulty in verification and validation of such models, due to the lack of data (Heppenstall and Crooks, 2012). Second, the abstraction level of the model itself has to be suitable to the application goals, as too much abstraction can miss vital parameters and too high level of detail can make the model too complex to run and understand (Couclelis, 2002). Agent-based models are also computationally expensive. Finally, there is the issue of the complexity of modelling human behavior, as the motivations of these behaviors can be due to a number of reasons, both rational and emotional (Kennedy, 2012). (Batty and Torrens, 2005) argues that such models should be used in the capacity of learning rather than forecasting, and that the stochastic nature of these models is an important parameter that enables Agent-based models to simulate complex processes even though that means the results may vary with each run.

The proposed framework has proven successful in pointing out possible bottleneck areas and dead zones. The simulation results coincide with the previously mentioned booth spots that attract visitors the most. Also, the simulation points out that features such as aisle width and configuration, and booth grouping have an influence on foot traffic distribution, and the most successful layouts being those with no or a small number of horizontal aisles. For future work, many other scenarios can be furtherly tested, such as adding several entrances, dividing booths groups irregularly, changing interest zones division and experimenting with multiple populations.

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