EXPLORING SPATIAL ARRANGEMENT OF LOCKER AREA IN SKI RESORT HALL FOR ENHANCING INTERPERSONAL DISTANCING USING UNITY ENGINE

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Abstract. With the success of the recent Winter Olympics, there has been a rising demand for winter sports in the Asian region, particularly in China. During peak seasons, the surge in ski tourists often leads to overcrowding at ski resorts, resulting in circulation congestion. This paper investigates how the locker room spatial layout in a ski resort hall influences skier behaviour and perception using agent-based modelling (ABM) via Unity3D. First, this paper examines how unique skier behaviours, such as transitioning into heavy ski suits, affect crowd circulation and density. Second, this research explores the influence of psychological distance on tourist satisfaction by employing a logarithmic algorithm based on Proxemics, a widely applied social distancing theory. Third, we harness machine learning approach (Unity's ML-Agent) to optimize locker layouts by balancing overall perceived crowd density and utility efficiency, generating more informative results compared to traditional empirical methods. These findings could inform architects, planners and managers with quantitative evidence in future Ice sport renovation and development projects. The methodology outlined in this work also offers valuable insights for evaluating and optimizing spatial layouts to enhance the ski experience in regions experiencing a surge in winter sports popularity.

Keywords. Ski resort, Locker placement, Agent-based Modelling, Proxemics, Machine learning.

1. Introduction

The ski industry is rapidly developing in China. Due to the hosting of the Beijing Winter Olympics in 2022, the number of ski tourists in China increased from 170 million in 2017 to 344 million in 2022 and is expected to reach 520 million in 2025. According to the 'National Ice and Snow Site Facilities Construction Plan (2016-2022),' over 200 new ski resorts have been constructed, and additional resorts are planned for the future. China has emerged as the only rapidly growing emerging ski market globally and is currently experiencing a peak period of construction. Drawing

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on the experiences of regions with well-established ski industries, such as Scandinavia and North America, it becomes evident that a robust ski infrastructure not only fosters the growth of winter sports but also enhances the local economy, ecological sustainability, culture, tourism, and other associated industries. Consequently, optimizing the development of ski resorts holds significant importance.

Crowding is a widespread issue in ski resorts worldwide, especially during peak periods like weekends and holidays. Industry reports indicate that overcrowding can have a profound impact on tourists' physical safety, psychological well-being, and the economics of ski resorts. From a safety perspective, overcrowding can lead to a decline in overall safety within the ski resort. In extreme cases, 'crowd turbulence' may occur, potentially causing safety incidents like stampedes. Concerning psychological well-being, arousal theory suggests a curvilinear relationship between crowd density and satisfaction, with both high and low levels of arousal leading to negative experiences (Filingeri et al., 2017). Economically, crowding is a significant factor considered by tourists when choosing ski destinations. It diminishes visitor satisfaction and loyalty while posing challenges to the appeal of ski resorts.

Factors influencing congestion in non-emergency situations include improper building layout and human individual and social behaviour (Sun & Turkan, 2020). In ski resorts, social behaviour involves a complex mix of activities, such as ticket purchasing, equipment rental, and adapting attire to changing body sizes, resulting in intricate behavioural patterns. Traditional design methods often rely on qualitative analysis by architects, making it challenging to align the layout with these complex behaviours.

Agent-Based Modelling (ABM) has emerged as a powerful approach for modelling complex processes and phenomena. ABM's core properties of autonomy and sociality make it highly suitable for addressing issues involving complex interactions, heterogeneous populations, and topological complexity. In previous studies, ABM has found applications in architectural and urban research.

ABM is considered a powerful tool for understanding cities through spatial modelling (Batty, 2007) and is suitable for simulating pedestrian flow in large-scale traffic buildings (BALMER et al., 2004). Crooks suggested the use of ABM to analyse space evacuation efficiency in emergency situations (Crooks et al., 2008), while Klein proposed the utilization of sensors and data on factors such as energy consumption to simulate the relationship between building environments and residents (Klein et al., 2012). Additionally, Pantazis advocated for the use of architectural elements as agents to optimize architectural design (Groenewolt et al., 2018), and Raoufi proposed applying ABM to simulate the construction efficiency of construction site workers (Raoufi & Fayek, 2020). These examples demonstrate the progressive extension of ABM's advantages to encompass various elements of the architectural design process.

This paper's ABM model introduces several innovations. Firstly, it incorporates the use of appropriate body colliders for agents at different stages, leveraging the flexibility of Unity to enhance the realism of pedestrian simulations within the ski resort. Secondly, the model evaluates the impact of social distancing among agents, drawing on Proxemics theory, rather than focusing solely on agent traffic efficiency. Thirdly, it employs Unity's machine learning program, ML-Agents, to optimize ski resort layouts using simulation-generated data, thereby providing architects with data-driven insights for informed decision-making.

2. Method

2.1. RESEARCH FRAMEWORK

Figure 1 provides an overview of the research framework. This paper examines the challenges encountered by skiers wearing bulky snowsuits, specifically focusing on reducing the dissatisfaction they experience due to congestion in the ski resort hall during peak hours. We employ Agent-Based Modelling to simulate the relationship between skier circulation and obstacles within the ski resort hall, quantify skiers' satisfaction with social distance based on Proxemics theory, and utilize machine learning technology to optimize the arrangement of lockers in ski resorts. Finally, we provide potential outcomes for architects to consider when optimizing the spatial arrangement of locker placements.

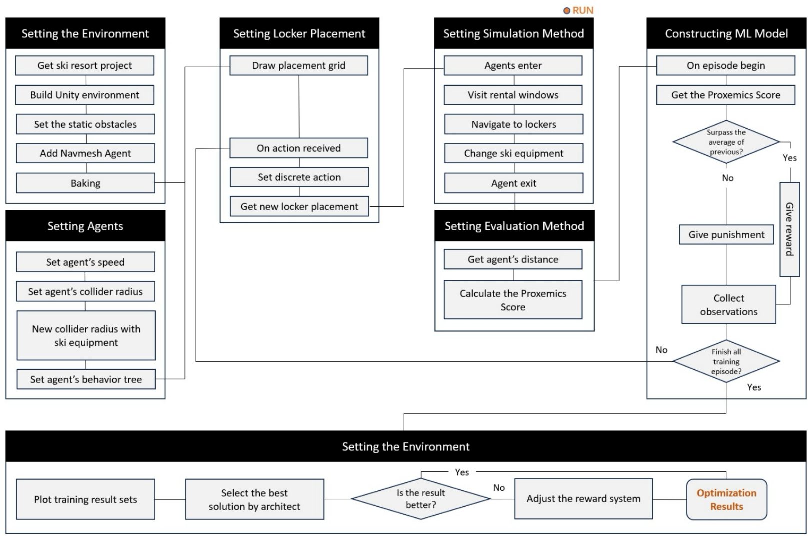


Figure 1. Research Framework

2.2. PROXEMICS: MEASURING INTERPERSONAL DISTANCING

Human perception of crowding is subjective and depends on individuals' assessments of density, determined by the number and spatial relationships of spatial elements, as well as the number of humans and the degree of social interaction (Zehrer & Raich, 2016). Sociological research, such as Proxemics, explains how distance, posture, and visual behaviour affect social distancing. In Proxemics, Edward T. Hall describes interpersonal distances as distinct zones that humans maintain between themselves and others, developing it as the discipline for measuring the spatial distance of individuals in social and interpersonal relationships (Hall et al., 1968). Proxemics divides interpersonal distance between people into four zones (Figure 2):

- Public distance $\leq$ 7.2m

- Social distance ≤ 3.6m
- Personal distance ≤ 1.2m
- Intimate distance ≤ 0.45m

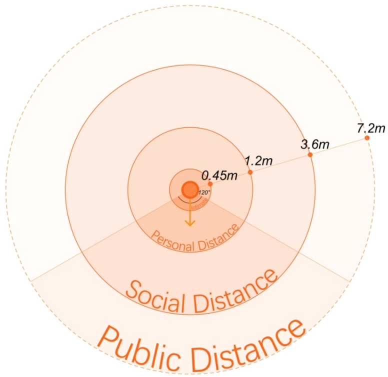


Figure 2. Proxemics Zones

This paper introduces a method for measuring human crowding based on Proxemics. Drawing from the Weber-Fechner law of perception in psychology, which establishes a logarithmic relationship between the perception of a stimulus and its size, and considering studies that have indicated the suitability of the logarithmic function in spatial relational science (Henkel et al., 2014), we have chosen the logarithmic function to represent how crowding perception changes with distance. The logarithmic function is expressed as follows: $y = \ln(x + a) + b$, where y represents the scalar value of crowding, x represents the distance between agents, and the variables a and b are calculated through curve fitting to achieve the desired curve. The scalar value y for crowding scoring ranges from 0 to 1, while the scalar value x for the distance between agents ranges from 0 to 3.6. Consequently, the function can be expressed as follows:

$$y = \sum_{i=1}^{n} \sum_{j=1}^{n} (-\ln(-x_{ij} + 5.79) + 1.758)$$

2.3. ML-AGENTS TOOLKIT: SPATIAL OPTIMIZATION

The Unity Machine Learning Agents Toolkit (ML-Agents) is an open-source Unity plugin built on the powerful PyTorch algorithm. It offers a versatile, interactive, and easily configurable training environment. In the traditional architectural design iteration process, ABM primarily simulates the plans provided by designers. Designers often offer a limited number of alternative schemes, resulting in an inefficient and empirical iterative process. This issue can naturally be addressed using machine learning technology.

In the ski resort, the placement of lockers plays a pivotal role in determining the flow of skiers. In this paper, lockers are treated as a distinct agent type, and ML-Agents are employed to train an optimization solution set for locker placement. This is achieved through the following steps:

- Setting locker pair: Organizing locker pairs, each consisting of m columns of $2m$ lockers facing opposite directions (the value of m depending on the ski resort's size), forms the basic unit.
- Defining training boundaries and a grid: Establishing the maximum boundary within which lockers can be placed and dividing it into an orthogonal grid. Each grid unit corresponds to a single locker pair, allowing locker pairs to be repositioned within the grid.
- Specifying locker placement rules: Implement appropriate locker placement rules to adhere to building codes. These rules can significantly reduce training iterations and enhance training performance. For instance, lockers can be placed adjacently on the non-opening side, but a specific aisle space must be reserved on the opening side to prevent adjacency.
- Determine the reward mechanism: Calculating the cumulative Proxemics score based on a designated function in each training episode. Rewards will be given if a new training result surpasses the average score of all previous training episodes; otherwise, punishments will be assigned.
- Training and results: Depending on the ski resort's size and skier traffic volume, after a sufficient amount of training, an optimized locker layout set is derived.

2.4. TRAINING ENVIRONMENT SETTINGS

2.4.1. Case Description

This paper focuses on the Jiangjun Mountain Ski Resort located in Altay, Xinjiang, China (Figure 3(c)). Following its renovation and subsequent reopening in 2020, the resort experienced a notable increase in visitor numbers, leading to challenges associated with overcrowding. The resort spans approximately 4,000 square meters and includes a tourist area of 1,400 square meters, accommodating 150-200 individuals at one time. The internal space consists by a 500 square meter lobby, an equally sized locker area housing 178 lockers, and a 400 square meter ski equipment rental section featuring 6 rental windows. The hall follows a conventional rectangular floor plan, resulting in a triangular flow pattern that encompasses the entrance, exit, ski equipment rental, and changing areas.

2.4.2. Environment Settings

This study utilizes Unity's NavMesh Agent Tool for streamlined navigation management. Closed static polygons in Unity represent structural elements, delineating impassable zones for skiers, such as walls and obstacles. These polygons, offset inward by the agent's collider radius, create an impassable buffer zone. The navigable environment for the agent comprises 3D closed polygon areas within this buffer zone.

The computational demands of calculating the cumulative Proxemics score for all agents globally in each Unity frame necessitate selective computation. Consequently, the Proxemics score is computed only in specific areas, such as the locker area, at defined intervals (e.g., every 0.1 seconds). The total Proxemics score for a machine learning episode is the summation of scores from all agents.

2.4.3. Agent Settings

According to ergonomics, the walking speed of the skier agent is set at 4 km/h, and it has a 120-degree field of view to avoid collisions. Moreover, adjusting the agent's collision radius dynamically is vital for this study. Initially, the radius is set at 0.3 meters when the agent is in regular clothing, increasing to 0.35 meters when wearing a snowsuit (Figure3 (a)).

The Unity plug-in Behaviour Designer is used as the control tool for the agents' behavioural logic (Figure3 (b)). The sequence of actions for each agent entering and exiting the ski resort is as follows:

- Entering through the lobby entrance, the agent randomly visits a window in the ski equipment rental area, briefly waits, picks up the ski equipment, and receives a key for an unoccupied locker.
- The agent then navigates to the assigned locker to change into a ski suit.
- Upon donning the ski suit, the agent's collision radius changes, and it proceeds towards the exit.
- Finally, the agent leaves the ski resort hall.

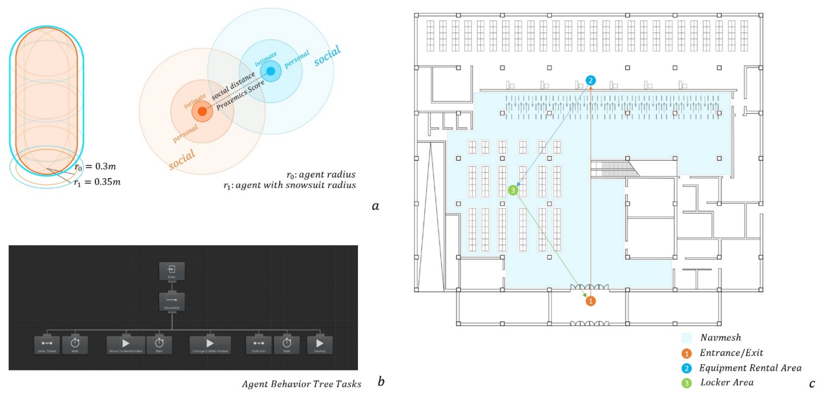


Figure 3. Training Environment Settings

3. Results

3.1. MACHINE LEARNING RESULTS

3.1.1. Training Results

In this paper, we simulated the ski resort hall during peak hours and used the resulting data, including locker layout and Proxemics scores, for machine learning training. To enhance training efficiency, we set the duration of the training episode to 10 minutes and accelerated the simulation to 10 times normal speed. All spawned skiers left the ski resort before the end of the episode, totalling 170 skiers.

After 500 hours of training, which involved approximately 30,000 episodes and 50,000,000 steps, we obtained an ONNX (Open Neural Network Exchange) file containing parameters such as TensorFlow checkpoints, PyTorch models, and Unity Brain. We deployed this ML-Agents neural network brain to a new Unity environment to generate optimized results. Figure 4(a) presents some of the results selected by architects.

3.1.2. Results Observation and Optimization

Based on our analysis of the training results, we have identified a distinctive '<' shaped pattern (Figure 4(c)) rather than the past 'I' shaped pattern (Figure 4(b)) in the arrangement of lockers. This discovery is intriguing and represents a departure from conventional locker layouts. The '<' shaped spatial arrangement is primarily attributed to the triangular spatial topological relationship among the entrance/exit, the equipment rental area, and the locker area. This arrangement is expected to enhance the smoothness of traffic flow. Furthermore, the diagonal placement of lockers is situated farther compared to the aligned placement. This arrangement enhances Proxemics scores by increasing the social distance between skiers while keeping the total number of lockers constant.

In summary, drawing inspiration from a machine learning algorithm, we selected the Figure 4(d) solution for further manually calibration by architects, resulting in the solution illustrated in Figure 4(e). In the upcoming chapter, we will conduct a thorough comparative analysis with the original plan. To enhance the reliability of our simulations and mitigate the potential variability in a single simulation, we calculated the average value from 10 runs to determine the final parameter for each analysis.

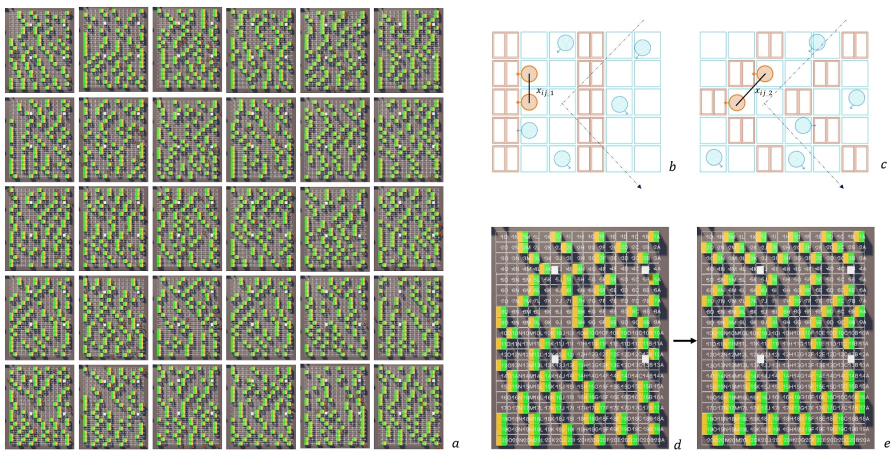
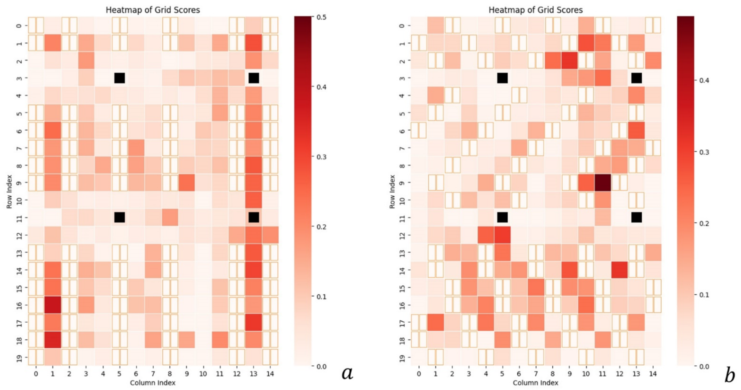


Figure 4. Training Results

3.2. PROXEMICS SCORE ANALYSIS

3.2.1. Grid Average Proxemics Score

To evaluate the quality of Proxemics scores within each grid area of the ski resort changing area, we utilize the ratio of the cumulative Proxemics score for each grid to the total duration that skiers spend in that specific grid as our evaluation metric. As depicted in Figure 5, when contrasting the results obtained from the original scheme (Figure 5(a)) with those from the optimized scheme (Figure 5(b)), it becomes evident that the optimized scheme demonstrates a more even distribution of Proxemics scores



across the spatial units, resulting in fewer disparities in spatial quality. Consequently, this implies that a greater number of skiers positioned in proximity to the lockers can enjoy an enhanced and more comfortable changing environment.

Figure 5. Grid Average Proxemics Score

3.2.2. Proxemics Score Per Second

The cumulative Proxemics scores of all skiers within the Locker area were assessed at one-second intervals, serving as the comprehensive evaluation metric for gauging changes in the crowd experience (Figure 6). When comparing the previous and revised plans, it is evident that the new plan achieves a higher total score with reduced fluctuations. This indicates that skiers' perceptions of social distancing not only reach a higher level but also exhibit increased stability over the entire process.

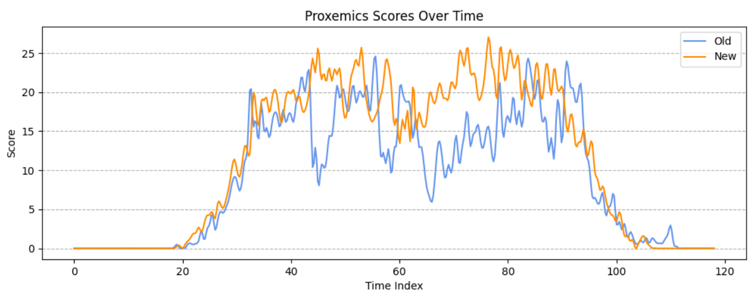


Figure 6. Proxemics Score Per Second

3.2.3. Agent Proxemics Score

By calculating the cumulative Proxemics score for each skier from entry to exit at the ski resort, we can assess their overall Proxemics experience. Figure 7 shows that more skiers achieve higher scores in the new ski resort, and Table 1 reveals significantly higher minimum, maximum, and average scores in the new solution. These results indicate an overall improvement in skiers' gear-changing experience. However, there is also an increased variance in skier scores under the new scheme, signifying persistent disparities among individual skiers, despite the general improvement in overall stability.

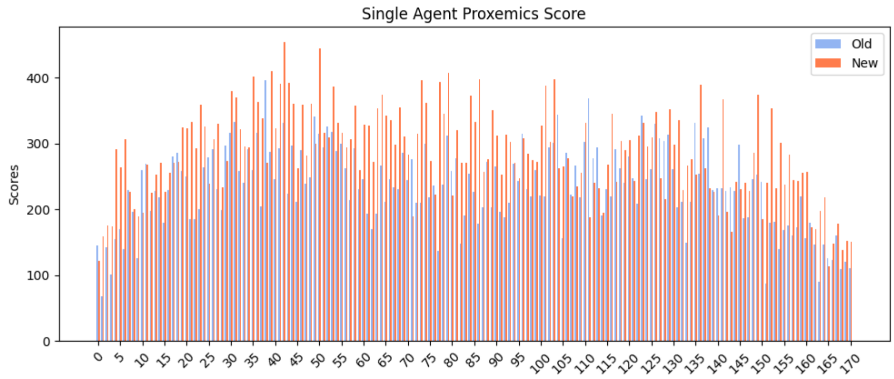


Figure 7. Agent Proxemics Score

	Number	Minimum	Maximum	Mean	Std. Deviation	Variance
Old	170	67.96	396.41	234.45	61.32	3759.82
New	170	113.61	454.64	284.58	67.56	4564.87

Table 1. Descriptive Statistics for agent Proxemics Score

4. Discussion

Our analysis of both traditional and innovative locker arrangements reveals that the unconventional '<' shaped layout offers significant benefits over the standard 'I'-shaped design. We believe this diagonal arrangement enhances dressing privacy, provides more cover, and improves the overall dressing experience.

However, this paper has limitations. Our skier behaviour model might not fully capture the complexity and unpredictability of real-world scenarios. We omitted inter-floor connections from our analysis. Also, the varying sizes and layouts of ski resorts mean not all configurations could be addressed in this study. Furthermore, we did not consider discrepancies between the Agent's global vision and actual conditions. We plan to explore these limitations in future research.

5. Conclusions

Since the hosting of the Winter Olympics in China, skiing has experienced a surge in popularity within the country. This trend presents a unique challenge for architects:

efficiently managing the spatial constraints imposed by bulky snow equipment and clothing. To address this challenge, this paper utilized Proxemics theory in conjunction with Agent-Based Modelling simulations and machine learning techniques. This innovative approach enabled us to generate a series of optimized layouts for ski resort locker areas.

The effectiveness of our method was substantiated through a quantitative analysis by comparing the performance of traditional designs with our newly proposed solutions. The results demonstrated that our method provides architects with a wider range of spatial arrangement options, optimizing the utilization of available space within existing constraints.

This research delved into the intriguing and complex issue of spatial layout simulation in ski resorts. While our primary emphasis has been on enhancing skiers' perception of social distancing, we have also recognized its potential impact on traffic efficiency. This trade-off between comfort and efficiency is an aspect that we intend to investigate further in future research.

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