Research on Traffic Organisation Design Strategies for Commercial Buildings Based on Depthmap and MassMotion

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Abstract. In order to quickly predict people distribution and traffic behavior in commercial buildings and further provide the quantitative basis for traffic organization design, this paper presents the analysis of Pedestrian Clustering and Pedestrian Density under selected circulation spaces of a shopping mall in Wuhan (China) by applying the software: Depthmap and MassMotion. To compare the correlation and difference between the visualization graphs of the above two software, results show that using Depthmap and MassMotion alone or in combination can meet the different needs of each design phase.

Keywords: Pedestrian Clustering; Pedestrian Density; pedestrian simulation modelling; circulation space; commercial buildings

1 Introduction

As computers deepen their application in various fields, they are also used more and more in building technology, particularly in performance analysis and personnel simulations. In the traditional design method, it is often necessary to simulate the building only after the end of the design, and then based on the feedback after the analysis of the design scheme to make adjustments, and continually refine the program until it is completed. As a result of this iterative process, a lot of time and energy is expended by the designers, which adversely affects the quality and efficiency of the final product. Consequently, a method that can quickly determine the traffic behavior of people in a space at the beginning of the design, improve the accuracy of the design scale, and enhance scheme generation efficiency is required.

The research on people simulation in commercial buildings in recent years has focused primarily on consumers' perspectives. For instance, Wang De [1] and others analyzed and evaluated the spatial behavioral characteristics and patterns of commercial complexes from a consumer behavior perspective. Wang Can [2-3] and others obtain the spatial optimization of commercial complexes by simulating consumer

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behavior and explore the intrinsic law of the functional compound effect from their perspective. Xia Zhengwei [4-5] and others analysed space and function as a function of flow distribution within high-rise commercial complexes, and developed a comprehensive analytical model for flow distribution within the complex. Guo Haoxu [6] and others conducted simulation studies on pedestrian flow distribution in shopping centres under different spatial organization modes. The current study follows a fairly traditional methodological approach, which is to simulate and analyse the distribution of people in the completed building. However, it is difficult to have a prospective impact on the optimization of the spatial scale of the program since the study of predicting people distributions from the perspective of the design stage is inadequate.

To evaluate a building space's performance, such as line-of-sight integration degree and spatial Pedestrian Clustering, as well as to quickly evaluate space use efficiency through sketching, spatial syntax Depthmap software is often used in domestic and international evaluations. As an example, Yasmine Sabry Hegazi [7] and others assess vulnerable spaces around heritage buildings concerning their socio-spatial properties. Zhang Daizong [8,9], based on spatial syntax, assesses and optimizes the commercial value of underground commercial spaces in rail transit. When optimizing the spatial scale, MassMotion is often used to determine the instantaneous density of pedestrians and the maximum density of pedestrians in the finished space, in order to determine whether the space meets the expectations at the beginning of the design, which ultimately leads to space optimization. Using MassMotion and PyroSim, Quan Jingli [10] and others analysed Pedestrian Density in urban complex spaces; Asmaa Eldiasty [11] and others simulated and analyzed urban heritage sites. Despite a large amount of research on pedestrian simulation and modelling, most of them focus on Depthmap Pedestrian Clustering or MassMotion Pedestrian Density without taking into account their complementarity, correlation, and commonality. In order to make the study's results have general significance and reflect real life as closely as possible, a commercial building in Wuhan (China) has been used as a case-study.

2 Materials and Methods

2.1 Primary Research Object

Depthmap Pedestrian Clustering: Based on Depthmap software's spatial syntax, Pedestrian Clustering can help designers better understand traffic organization within a space, and people's behaviors within it. Pedestrian Clustering images can analyse the density and distribution of people, as well as information such as the degree of aggregation and dispersion of people. A number of fields can benefit from using this method, including urban planning, traffic planning, and architectural design. In architectural design, Pedestrian Clustering can help designers better understand people's activities and behaviors inside the building, thus enabling them to design it better. Designers can use crowd analysis in shopping malls, museums and other public places to better understand how people move and interact, so that display areas and rest areas can be designed accordingly. Nevertheless, the Pedestrian Clustering may differ from the actual situation in some cases due to the simplicity of the software and its limited number of parameters.

MassMotion Pedestrian Density: Pedestrian Density analysis uses MassMotion software to calculate the maximum density of pedestrians in a given area. The capacity of a space can then be better understood by planners and designers and utilised more efficiently. A railway station or airport planner can use this analysis to determine how many people can safely occupy an area at once. Additionally, this analysis can help designers identify ways to optimize the layout of a space so that it can accommodate a maximum number of people while remaining safe and comfortable. Pedestrian Density is calculated using MassMotion software by simulating people's flows. The software uses advanced simulation techniques to model pedestrian flows and generates detailed reports and graphs based on the simulation results. Planning and designing are aided by these reports and graphs by providing recommendations for optimizing space capacity and usage. In MassMotion, Pedestrian Density analysis often reflects the real situation of pedestrian flow because it has a high degree of simulation for space and pedestrians. Due to factors such as a large number of setup parameters and a slow simulation speed, this method cannot be used in a convenient manner to push the spatial scale as a pre-design approach.

Both Depthmap's Pedestrian Clustering analysis and MassMotion's Pedestrian Density analysis can be used to quantify pedestrian traffic in a building. These two approaches have their own advantages and disadvantages, but they complement each other, and the convenience of Pedestrian Clustering analysis coupled with the authenticity of Pedestrian Density analysis constitutes an indispensable tool for this study.

2.2 Research on The Current Situation

To build a model and integrate the data, we use pedestrian counting method and video footage to record selected building’s circulation spatial shape and pedestrian flow at each entrance at different time periods. Following that, the model and data are loaded into Depthmap and MassMotion to obtain two sets of image data, Pedestrian Density and Pedestrian Clustering. For concluding, slice sampling is used to analyze the images. A flowchart showing the research and simulation process can be found in Figure 1.

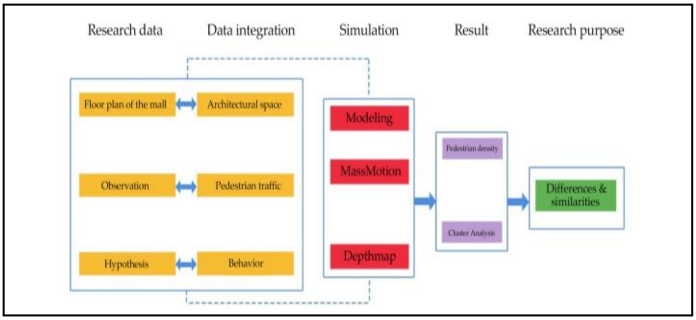


Fig. 1. Technical framework diagram

2.2.1 Research program

The building selected for the study is 23.5m tall, 3 story shopping mall (named Aeon Mall), located in Wuhan which was opened in 2015. The area of the site is 129,900 square meters. The building has a total floor area of 274,600 square meters and 4,500 parking spaces underground, with approximately 190,000 passengers passing through the facility every week. (Figure 2).

Fig. 2. Aeon Mall

Four public transport stations are near the 5 entrances of the site, with walking distances less than 300 meters to the building and pedestrians usually enter other floors through the first floor circulation space. To make the simulation area more representative, this paper uses the first floor of Aeon Mall. Moreover, the model is simplified to some extent, retaining the main entrances and the main use, and excluding the staff entrances and low traffic spaces. Figure 3 shows the first floor plan.

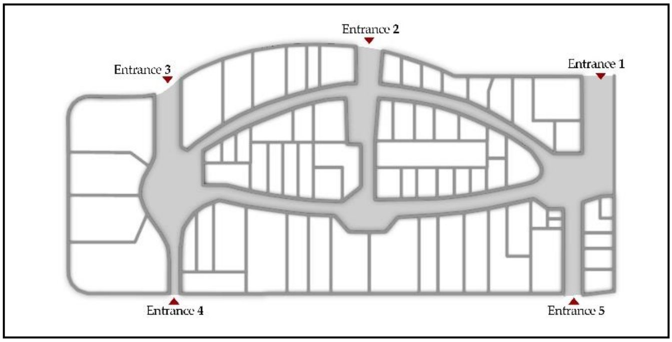


Fig. 3. Floor plan of Aeon Mall

For the purpose of gathering adequate research data, Sunday, 11th June 2023 was chosen for the research. The researchers recorded the data at the entrance to the first floor of the building. Depending on the mall's opening hours, the research time was divided into six periods: 10:00-12:00, 12:00-1400, 1400-16:00, 16:00-18:00, 18:00 - 20:00, 20:00 - 22:00. For each time period, researchers collected samples at fixed entrance/exit observation points for 10 minutes and counted pedestrians entering and leaving the building.

Aeon Mall has a rectangle-shaped plan with an elliptical circular traffic space connecting each floor's various areas and entrances.

2.2.2 Research findings

In the table below (Table 1), the specifics of the number of people who entered the building on the 14th of August and distributed over the traffic space are presented as a result of the field research:

Table 1. Headcount

Entrance	Time period	time	Access	Out	Total
1	10:00-12:00	10 m	35	14	49
	12:00-14:00		30	35	75
	14:00-16:00		45	22	67
	16:00-18:00		51	44	95
	18:00-20:00		40	37	77
	20:00-22:00		27	55	82
2	10:00-12:00	10 m	158	32	190
	12:00-14:00		160	51	211
	14:00-16:00		177	85	262
	16:00-18:00		210	125	335
	18:00-20:00		166	88	254
	20:00-22:00		90	131	221
3	10:00-12:00	10 m	90	33	123
	12:00-14:00		85	66	151
	14:00-16:00		92	73	165
	16:00-18:00		65	66	131
	18:00-20:00		54	75	129
	20:00-22:00		32	86	118
4	10:00-12:00	10 m	65	30	95
	12:00-14:00		71	54	125
	14:00-16:00		78	64	142
	16:00-18:00		80	52	132
	18:00-20:00		58	41	99
	20:00-22:00		33	67	100
5	10:00-12:00	10 m	110	99	209
	12:00-14:00		117	132	249
	14:00-16:00		166	140	306
	16:00-18:00		161	183	344
	18:00-20:00		166	195	361
	20:00-22:00		120	155	275

3 Results

3.1 Depthmap Simulation - Pedestrian Clustering

In Figure 4, we show the results of an analysis of Pedestrian Clustering in the mall plane using the Depthmap. The spatial Pedestrian Clustering map uses different colors to differentiate cumulative pedestrian passes, divided into 10 levels. The more times an individual pedestrian passes through the grid, the closer the color is to red, and vice versa, the closer the color is to blue, and the worst is black. (Table 2).

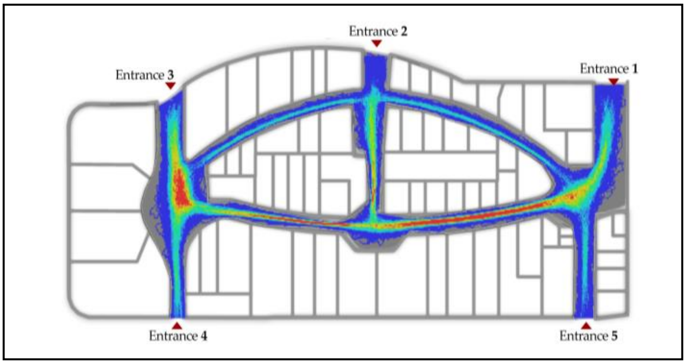


Fig. 4. Pedestrian Clustering image

Table 2. Pedestrian Clustering levels

Rank	Pedestrian Clustering index	Level
A	X=0	
B	0<X≤15	
C	15<X≤30	
D	30<X≤45	
E	45<X≤60	
F	60<X≤75	
G	75<X≤90	
H	105<X≤120	
I	120＜X≤135	
J	135 < X	

3.2 MassMotion Simulation Modelling - Pedestrian Density

3.2.1 Parameter setting

Considering the research on the integration of research data, this paper mainly sets the following parameters in the simulation:

Timetable (number of people entering the building in different time periods): In a day, the number of people entering the mall changes in a different time period, so this paper divides the source of the crowd according to the six time periods in the mall's business hours, and the number of people entering the mall in different time periods is determined based on the research data.

The weight of the starting point (and destination): In order to represent the real situation to the greatest extent possible, this paper is based on the proportion of the number of people entering and exiting different entrances and exits within a day in order to control the weight of the starting point (and destination).

3.2.2 Simulation results

In MassMotion, the mall planar model is constructed by analyzing and integrating the research data. Parameters and pedestrian flow are set, and simulation is carried out. Figure 5 shows the 12-hour Pedestrian Density map. In the maximum Pedestrian Density map, different colors are used to distinguish the cumulative number of pedestrian passes, which is divided into 10 levels. The more pedestrians pass through the grid, the closer the grid is to red, and vice versa, the closer it is to blue, and the worst is black. (Table 3).

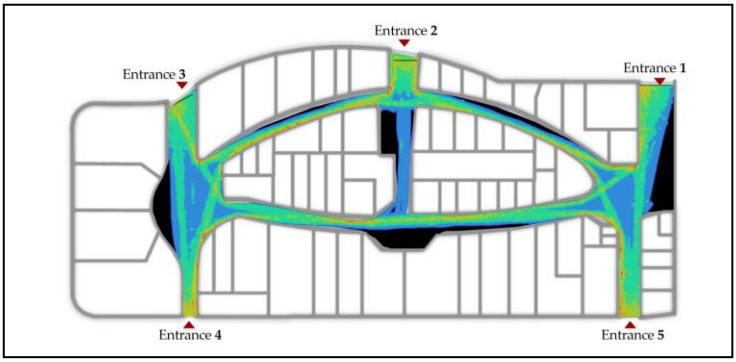


Fig. 5. 12-hour Pedestrian Density map of Aeon Mall

Table 3. Pedestrian Density levels

Rank	Pedestrian Clustering index	Level
A	0<X≤0.2	(black)
B	0.2<X≤0.4	(dark blue)
C	0.4<X≤0.6	(blue)
D	0.6<X≤0.8	(light blue)
E	0.8<X≤1.0	(cyan)
F	1.0<X≤1.2	(green)
G	1.2<X≤1.4	(yellow-green)
H	1.4<X≤1.6	(yellow)
I	1.6<X≤1.8	(orange)
J	1.8 < X	(red)

3.3 Image Comparison and Analysis

This paper selects three plan forms that are more common in this building based on the simulation images presented in the previous section: the atrium area ("X-shaped area"), the corridor area ("—-shaped area"), and the connecting area ("H-shaped area") (Figure 6). Our study examined the consistency of the upward and downward trends in Pedestrian Density and Pedestrian Clustering images by using the slice sampling method, and expressed the results in the form of a line graph.

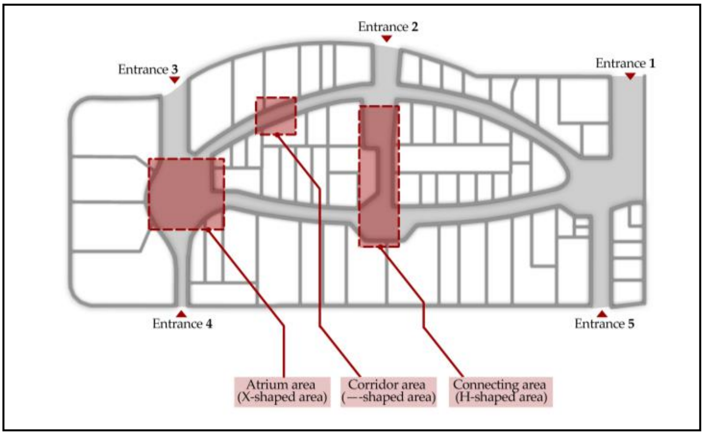
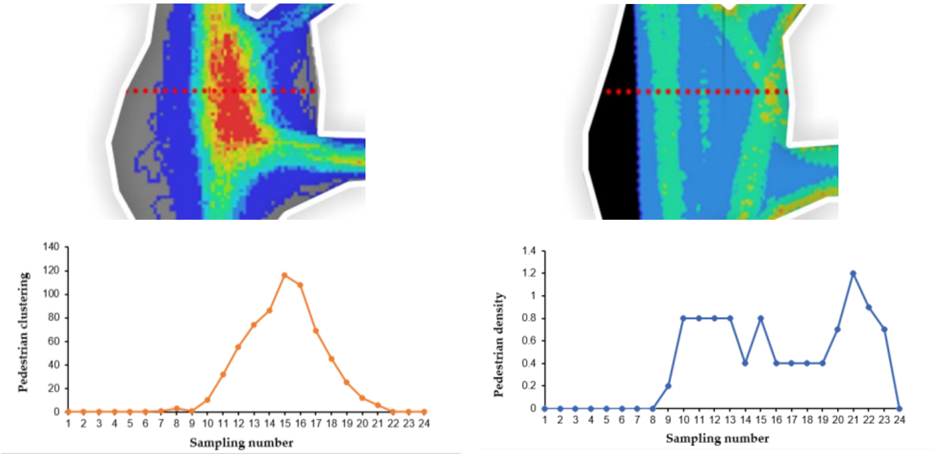


Fig. 6. Selected areas

3.3.1 X-shaped region image analogy



Pedestrian Clustering **Pedestrian Density**

Fig. 7. X-Shaped area Pedestrian Clustering vs. Pedestrian Density

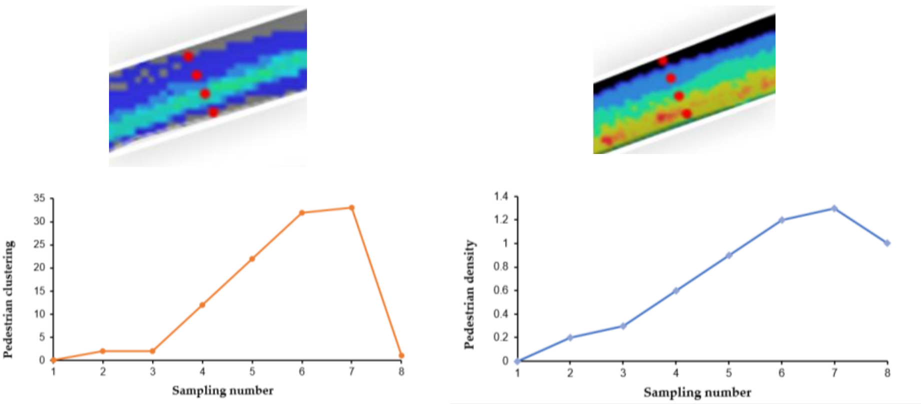
Table 4. Sample data of X-Shaped area

Sample	Pedestrian Clustering	Pedestrian Density
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0

7	1	0
8	3	0
9	1	0.2
10	10	0.8
11	32	0.8
12	55	0.8
13	74	0.8
14	86	0.4
15	116	0.8
16	108	0.4
17	69	0.4
18	45	0.4
19	25	0.4
20	12	0.7
21	6	1.2
22	0	0.9
23	0	0.7
24	0	0

The X-shaped area is an aisle connecting the two entrance corridors and the two interior corridors, so there are four directional sources of pedestrian flow in this area. As shown in Figure 7, the center of the area has better Pedestrian Clustering; however, in the Pedestrian Density image, footfall tends to be concentrated on the shortest path connecting the two corridors, which is more in line with the real situation. (Refer to Table 4 for specific values.)

3.3.2 — -shaped region image analogy



Pedestrian Clustering **Pedestrian Density**

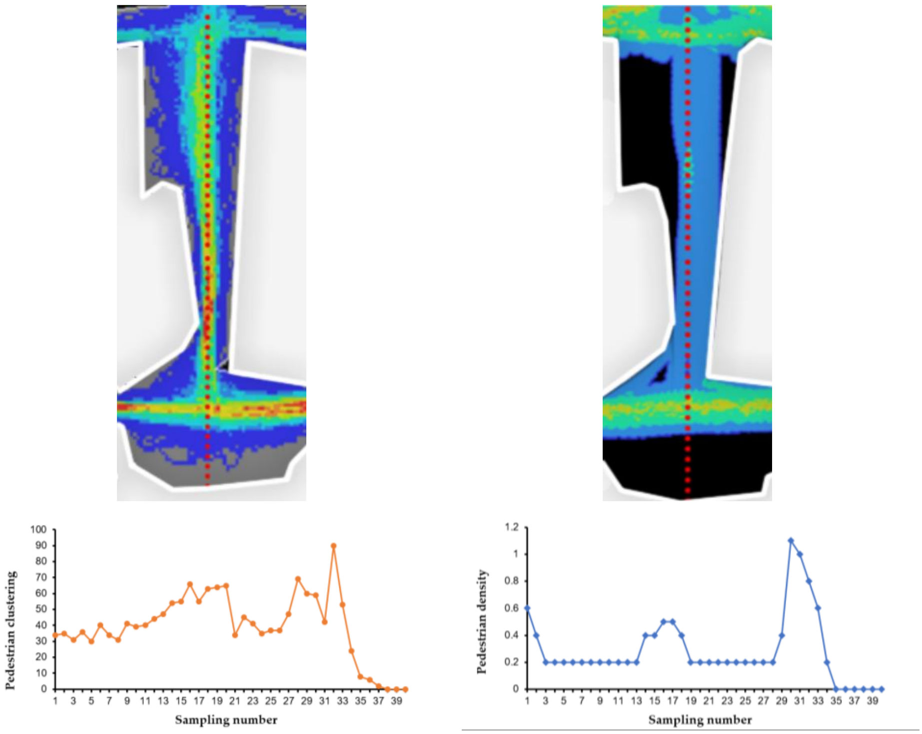
Fig. 8. — -Shaped area Pedestrian Clustering vs. Pedestrian Density

Table 5. Sample data of — -Shaped area

Sample	Pedestrian Clustering	Pedestrian Density
1	0	0
2	2	0.2
3	2	0.3
4	12	0.6
5	22	0.9
6	32	1.2
7	33	1.3
8	1	1

— -Shaped areas are traffic spaces that connect different areas. Based on Figure 8, Pedestrian Clustering and Pedestrian Density change in roughly the same pattern along the corridor's truncated surface: Pedestrian Clustering and Pedestrian Density are higher in the central area. (Refer to Table 5 for specific values.)

3.3.3 H-shaped region image analogy



Pedestrian Clustering **Pedestrian Density**

Fig. 9. H-Shaped area Pedestrian Clustering vs. Pedestrian Density

Table 6. Sample data of H-Shaped area

Sample	Pedestrian Clustering	Pedestrian Density
1	34	0.6
2	35	0.4
3	31	0.2
4	36	0.2
5	30	0.2
6	40	0.2
7	34	0.2
8	31	0.2
9	41	0.2
10	39	0.2
11	40	0.2
12	44	0.2
13	47	0.2
14	54	0.4
15	55	0.4
16	66	0.5
17	55	0.5
18	63	0.4
19	64	0.2
20	65	0.2
21	34	0.2
22	45	0.2
23	41	0.2
24	35	0.2
25	37	0.2
26	37	0.2
27	47	0.2
28	69	0.2
29	60	0.4
30	59	1.1
31	42	1
32	90	0.8
33	53	0.6
34	24	0.2
35	8	0
36	6	0
37	2	0
38	0	0
39	0	0
40	0	0

The H-shaped area contains the atrium and the corridor. As shown in Figure 9, the Pedestrian Clustering and Pedestrian Density in the H-shape area as a whole show the same pattern of change: overall, the Pedestrian Clustering and Pedestrian Density in the H-shape area is higher than that in the corridor area. However, in the part of the H-shape area away from the corridor, Pedestrian Clustering and Pedestrian Density fall off a cliff and are lower than in the — -shape area. (Refer to Table 6 for specific values.)

Based on the Pedestrian Clustering image generated by Depthmap software and the Pedestrian Density image generated by MassMotion software in this paper, the similarity between the two images under multiple spaces was verified using slice sampling. Accordingly, the following conclusions are drawn:

- In the X-shaped area, the Pedestrian Clustering image and the Pedestrian Density image are more compatible and analogous from the data trend.
- In the -shaped area, the Pedestrian Clustering image and the Pedestrian Density im-age are more compatible and analogous from the data trend.
- In the H-shaped area, the Pedestrian Clustering image and the Pedestrian Density image are quite different from each other in terms of data trends and are not very analogous.

By comparing the results of Depthmap and MassMotion, it is found that there is a certain gap between Pedestrian Clustering and Pedestrian Density, except for the X-shaped area: the image shows that the center of the area is better for Pedestrian Clustering; and in the Pedestrian Density image, the pedestrians are concentrated on the shortest path connecting the two corridors. The reason for this gap may be that pedestrian roaming simulated in Depthmap does not have a purpose. It is only related to the spatial form of the building. In contrast, pedestrians simulated in MassMotion have purposeful activities based on parameter settings. This is more in line with the real situation. The other areas are basically the same.

The simulation results based on Depthmap software and MassMotion software produced basically similar images of Pedestrian Clustering and Pedestrian Density. However, in some complex spatial environments, the Depthmap software and MassMotion software have a slight deviation in the analysis of the pedestrian flow situation. However, they still have great reference value.

4 Conclusions

Depthmap software and MassMotion software can be used to simulate crowds in commercial complexes, observe the interaction between pedestrians and architectural spaces, identify problems in the design of commercial spaces and optimize them in multiple dimensions. With today's increasing focus on design efficiency, a simulation analysis makes possible a more holistic and quantitative approach to optimizing the design process. Through the research and analysis of Aeon Mall, the optimisation of the existing design methodology can be carried out in the following ways.

In the sketch phase of the design, Depthmap Pedestrian Clustering analysis can be used to pre-determine the trend of Pedestrian Density at the existing spatial scale, and scale optimisation can be made on this basis.

At the completion stage of design, MassMotion can be used to analyse the Pedestrian Density of the optimised spatial scale, to verify whether the spatial efficiency meets expectations, and to provide a quantitative reference for architects and owners to quickly predict the distribution of people and traffic behaviour in commercial buildings, and to optimise the design.

With the combination of Depthmap and MassMotion software, it is possible to get plan layout suggestions. In order to maximize the utilisation rate of commercial space and increase its commercial value, main shops can be positioned in areas with high Pedestrian Density, and other general shops can be arranged and distributed according to Pedestrian Density.

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