Form Follow Mobility: A Method to Identify Potential Urbanization Area in the Over-Rail Plane under the Orientation of Station-city Integration and Pedestrian Priority

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Abstract
Under the people-centred approach, some areas have begun to abandon the network configuration that prioritises vehicles over walking, and create many pedestrian priority zones. In recent years, a new kind of pedestrian priority areas called over-rail plane has emerged with the concept of station-city integration. However, real examples show that not all developments with over-rail plane have been successful, and there is a need to make full use of pedestrian mobility and efficiently layout urban functions. This paper explores a methodology that can help to judge the functional potential within over-rail plane before formal design, and provides a reference for formal design: firstly, the wool algorithm is modified to generate paths with the shortest detours according to the requirements of over-rail plane; and then SDNA tool is applied to identify its flow potential and divide different potential zones for urban function. Taking Chongqing Shapingba Station as an example, this article evaluates the potential of implanting urban functional within over-rail plane and verifies the effectiveness of the method by comparing it with the real design; taking Shenzhen North Station as an example, the article identifies the high-potential areas in the current over-rail plane that can be embedded with additional functions.

Keywords: Over-rail Plane; Pedestrian-Priority Area; Identify Potential Urbanization Area; Wool Algorithm; SDNA tool

1 Introduction

1.1 Background

Under the people-centred approach, some areas have begun to abandon the network thought that prioritises vehicles over walking, and create many pedestrian priority zones when necessary. In recent years, a new kind of pedestrian priority areas has emerged in railway station areas with the introduction of the concept of station-city integration: Some railway stations add *covers above and around the railway yards which is called over-rail plane* (Fig. 1) and implant urban functions in this new substrate to fix the fragmentation between the railway station and the city. Shapingba Station has applied the strategy and achieved good development efficiency. However, not all railway stations with over-rail plane are successful. Some of them are oversize and lack of urban function to support people's staying and relaxing, therefore lack of vitality, such as Shenzhen North Railway Station and Guangzhou East Railway Station (Fig. 2). Therefore, for these railway stations which adopt the strategy of adding over-rail plane, *it is crucial to efficiently and rationally implant urban functions after determining the broad scope of over-rail plane*. On the other hand, over-rail plane development is an extremely complex design process. Therefore, *how to judge the potential of various areas for implanting urban* *functions within over-rail plane before the formal design, especially the high-potential area, becomes a problem worth exploring.*

Fig 1.Over-rail Plane of Shapingba Station
Source: Drawn by Author

Fig 2.Over-rail Plane of Guangzhou East Station
(Source: Drawn by Author)

1.2 Literature Review

Existing studies on mobility can be classified into three categories according to the transport modes involved: the first is to assess the ability of citizens to travel at large or medium scales based on rapid modes of transport such as cars, rail, buses and so on, the second is to assess the ability and priority of slow transport at small and medium scales based on walking, and the third is to assess the efficiency of the connectivity between different modes of transport. The second one is related to this research. Related studies mainly focus on the pedestrian network attached to carriageway roads (Jin R, 2023). Only a few studies focus on pedestrian mobility within pedestrian priority zones. Table 1 compiles a number of studies related to pedestrian priority: Allan Andrew (2010) proposes a number of benefits brought about by advocating pedestrian priority; GwangYa Han (2011) points out that pedestrian mobility and node organisation influences the outcome of the piazza as a pedestrian priority zone using the example of Roman squares, and he further proposes a system of urban design elements to improve the quality of pedestrian-oriented suqares in Rome; Bilgehan (2018) constructs an evaluation index system for urban squares based on pedestrian mobility. In addition to these studies, there is another kind of studies related to pedestrian priority zone in the table. They use the term “Pedestrian Priority” as well (Han Sangjin, 2013, 2021; Pahk So-Hyang, 2021; Jeon Woo Hoon, 2022). But these studies are looking for zones with higher pedestrian priority in the pedestrian network attached to the vehicular traffic, which is still essentially vehicular priority.

Overall, the above studies mainly focus on pedestrian priority zones such as at-grade pedestrian walkways and plazas, failing to pay attention to an emerging category of pedestrian priority zones in recent years – over-rail plane. This paper explores a methods for pedestrian network organisation and urban function arrangement in this area under the orientations of station-city integration and pedestrian priority, which is expected to fill the gap of existing studies on this area.

Table 1.Research Related to Pedestrian Priority

Time	Author	Title	Object

2010	Allan Andrew	Pedestrian Priority Addressing Car Dependency - Purposes and Benefits	/
2011	GwangYa Han; HeeWon Lee	Typological Design Language of Urban Public Space: An Analysis of Pedestrian-oriented Piazzas in Rome	Pedestrian-oriented Squares
2013	Han Sangjin	Selection of Primary Pedestrian Road Network in Pedestrian Priority Zone	Pedestrian-priority street
2018	Bilgehan Çakmak; Mehmet Topçu	An evaluation of urban open spaces in Historical City Center of Konya in the context of pedestrian mobility	Historical Squares
2021	Han Sangjin; Chang Justin S.	Identifying Priority Crosswalk Locations in Urban Road Networks	Pedestrian-priority Crosswalk
2021	Pahk So-Hyang; Gidong byun; Ha Mikyoung	A Study on the Observation Characteristics and Pedestrian Safety in Pedestrian Environment - Focusing on the Pedestrian-priority street and Shared street	Pedestrian-priority street
2022	Jeon Woo Hoon	Priority-Setting Methodology of Qualitative and Quantitative Analyses for Pedestrian Road Construction: Case Study of a National Highway in South Korea	Pedestrian-priority street

Source: Drawn by Author

2 Methodology

2.1 Research Object and its Character

The research object of this paper is over-rail plane, which can be classified into two kinds: with urban functions already implanted(Fig. 3), and to be implanted (Fig. 4).

For the first kind of research objects, the article applies the relevant methods to divide the functional potential areas in the over-rail plane, and compares the results with the actual design results to check the reasonableness of this method. This article selects the over-rail plane of Chongqing Shapingba Station as an example of this type of object (Fig. 3).

For the second kind, the paper applies the method to predict the high-potential areas in which urban functions can be implanted in the over-rail plane of the station. In this paper, the over-rail area of Shenzhen North Station is selected as an example of this type of object (Fig. 4).

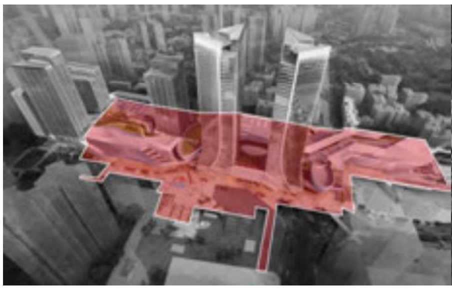

Fig 3. Aerial view of the Over-rail Plane of Congqing Shapingba Station
Source: Drawn by Author

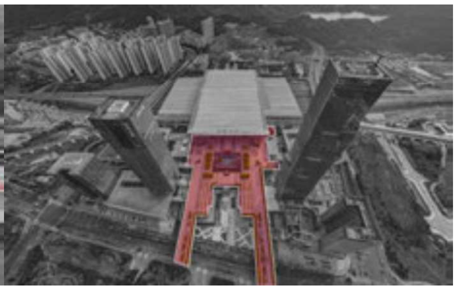

Fig 4. Aerial view of the Over-rail Plane of Shenzhen North Station
Source: Drawn by Author

There are several requirements in over-rail plane, in decreasing order of priority:

The first requirement is the priority of the railway yards and station buildings. Railway is development driver of the railway station area. The arrangement of the railway station building precedes other urban functions in the two selected cases and the arrangement of the railway station building is a constraint for subsequent decisions.

The second requirement is the priority of walking. Apart from little logistical transport, walking is the only mode of transport within the over-rail plane, and walking should be encouraged and prioritised in this area. What's more, railway station is a area for large pedestrian gather and leaving, which requires efficient pedestrian circulation as well.

The third requirement is station-city integration. Stations bring in a large number of people, and fully utilising the potential of pedestrian mobility in over-rail plane is conducive to improving functional performance and increasing functional output.

These requirements will be combined with specific method in following text.

2.2 Methods

The potential for implanting urban functions in the over-rail plane is mainly determined by the structure of the external connections. The location of the external pedestrain sources determines the possible walking paths within the over-rail plane as well as the flow potential of the corresponding paths, which will cut out several zones, and the potential of the paths adjoining these zones will determine the potential for implanting urban functions in this area, determining whether they are vibrant nodes suitable for commercial development, or or whether they will be used as logistical spaces, equipment spaces and other large-scale auxiliary spaces. According to the above understanding, two main methods should be selected and used in this paper: *method one is used to generate potential internal paths under external pedestrian flow conditions, and method two is mainly used to evaluate the pedestrian potential of these paths.*

2.2.1 Path Generation: Wool Algorithm

The methods and theories about path generation were first explored by Frei Otto in 1990s (Chenyuan Li,2021). He gave three different forms for pedestrian paths: 1. direct path network (Fig 5-a), 2. shortest path network (Fig. 5-b), and 3. shortest detour network (Fig. 5-c). The direct path network, where all destinations are directly connected, is the most direct and simplest path, however this network is not the shortest. Therefore he studied the second shortest path network. Soap bubbles will form a morphology with the smallest surface area in a stable environment, whereby Frey-Otto obtained the shortest path network with the total length of the paths being the only minimum fixed value, and the result of the morphology taking on a dendritic shape. However, the above two algorithms are more extreme and have their own advantages and disadvantages in terms of total path length and degree of detour, so he investigated a third shortest detour network. This network was obtained by the wool experiment(Fig 5-d): dry wool connecting various destination points adsorbed together after wetting because of water tension, and some of the paths aggregated into a new path. This method, called the wool algorithm, reduces the total length of the paths at each destination point while keeping the winding factor in a relatively low range. The wool algorithm is also used in the Kartal Pendik masterplan: the designer treats the roads on the periphery of the design area as emergent points of pedestrian flow, connects the emergent points to the opposite emergent points (Fig. 6-a), and performs morphology simulation operations through the wool algorithm

(Fig. 6-b) to get the initial road network of the urban design (Fig. 6-c); ultimately, a number of curves can be extracted from it to optimise the network (Fig. 6-d).

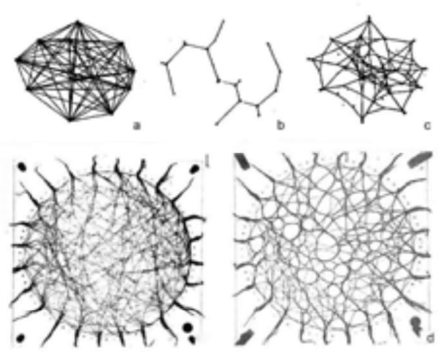

Fig 5. Frei Otto's Three Pedestrian Paths Source: Ninglin, liu and Peng Tang (2018) Research on the Path Generation Method of Composite Functional Spatial Paths of Cities and Buildings Based on Minimum Detour Networks (Conference paper), 2018 Chinese Academic Symposium on Teaching and Research on Architectural Digital Technology in Architectural Faculties.

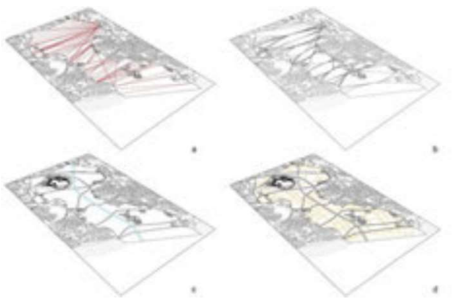

Fig 6. Use of wool algorithm in Kartal Pendik masterplanning (Source: Chengyuan, LI (2021) *Research on the application method of parametric shaping in architectural design*(Master thesis), Tianjin, Tianjin University.)

Ninglin Liu (2018) has compared the three path generation methods given by Frei Otto, pointing out that relative to the direct path network, the shortest path network makes the total length shrink by about 70%, and the third minimum detour network is 25%-35%; the minimum path network makes the number of paths between any two points drop to 1, and the minimum detour network controls its shrinkage by 30%-60%; the minimum path network makes the number of spaces is reduced by more than 70 per cent, and the minimum diversions network reduces it by about 25 per cent. Accordingly, she believes that the second network is suitable for the situation of obtaining the only shortest path, but the accessibility between any points in the site is poor, the reference value of spatial delineation is low, and the adjustment parameter is less flexible; whereas, the third network is more suitable for architects and urban designers to generate path prototypes on a daily basis. Considering the research object of this paper – over-rail plane, the construction of paths need to consider whether to meet the following needs: reasonable reduction of the total length of the path, to ensure convenient accessibility to any location within the site and the organic organisation of the path division space. On this basis, further combined with Liu 's research, the shortest detour network is suitable as the path generation method in this paper, and its specific generation algorithm is the wool algorithm.

However, the classical wool algorithm has several shortcomings in practical use that limit its application. The first one is that the classical wool algorithm cannot adapt to non-convex spatial contours (Fig. 7). Its generation results often go beyond that type of contour. The second one is that the generation results of the classical wool algorithm cannot avoid internal obstacle regions (Fig. 8). The two specific cases covered in this paper happen to involve these two conditions, so this paper will provide ideas for improved application of the classical wool algorithm, which is one innovation of this paper.

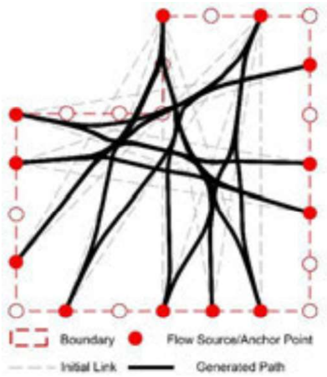

Fig 7. Result of Wool Algorithm Overflow the Non-convex Boundary
Source: Drawn by Author

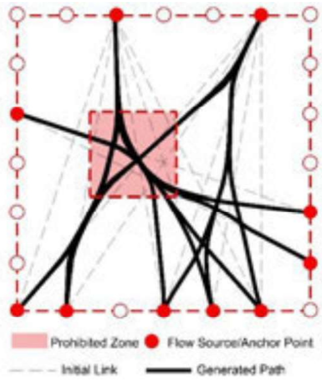

Fig 8. Result of Wool Algorithm Fail to Avoid Internal Obstacle
Source: Drawn by Author

2.2.2 Path Analysis and Zoning: Spatial Design Network Analysis Tool (SDNA)

Regarding the existing path analysis methods, there are Depthmap and SDNA (Spatial Design Network Analysis Tool) which is mature. Among them, Depthmap is mainly used for evaluating the planar network, which is not perfect in analysing the three-dimensional network, while SDNA is a tool developed specifically for three-dimensional network analysis. Since the relationship between the over-rail plane in this paper is three-dimensional, SDNA is chosen for the analysis. The specific tutorial on the use of SDNA can be found in its manual (https://sdna-plus.readthedocs.io/en/latest/). Regarding the selection of specific analysis indexes, this part is elaborated in conjunction with specific cases since different cases have different situations.

2.2.3 Integration of Methods

In this research, the modified wool algorithm is used to generate the initial pedestrian network, and the SDNA analysis tool is used to evaluate the potential of pedestrian flow and the path hierarchy. On this basis, the potential of different areas for implanting urban functions is judged. The specific steps are as follows:

(1) On-site research to determine the sources of pedestrian inside and outside the site;

(2) Establishing direct paths between sources of pedestrian;

(3) Simulate the process of the wool experiment to generate a pedestrian network pattern with minimal meandering;

(4) Converting the generated paths into segment according to analysis requirement and modelling the peripheral and underground pedestrian network;

(5) Evaluate the pedestrian potential of different paths using the SDNA analysis tool and classify the paths accordingly;

(6) Determining different potential areas of the over-rail plane that can be used for arranging urban functions according to the hierarchy of paths.

Among them, step 1, step 2, and step 3 are completed in GRASSHOPPER, and the full diagram of the program is as follows (Fig. 9); step 4 is completed in RHINO; and step 5 and step 6 are completed in ARCMAP.

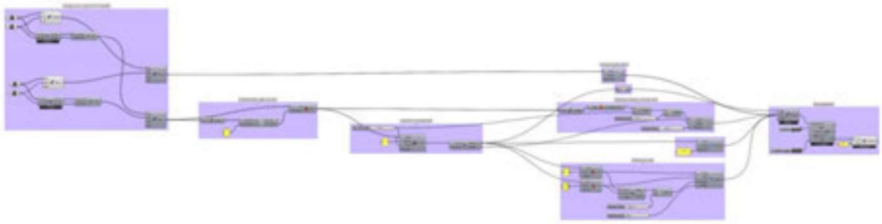

Fig 9. Wool Algorithm Programme Based on the Grasshopper Platform
Source: Drawn by Author

3 Application

3.1 The Over-rail Plane of Chongqing Shapingba Station

3.1.1 Determining Primary Source of People

Through on-site research, there are mainly three kinds of source of people in the over-rail plane area of Chongqing Shapingba Station:

(1) Entrance to the railway station building, as shown at point 1 in Figure 10, where a large number of train passengers enter or leave the covered area.

(2) Footbridge entrances and exits connecting to the neighbourhood, e.g. Points 2 - 12 in Figure 10, from which people from the neighbourhood enter or leave the over-rail plane.

(3) Major vertical transport facilities such as those leading to the metro station, e.g. Points 13 - 16 in Figure 10, from which citizens or travellers may enter or leave the covered area.

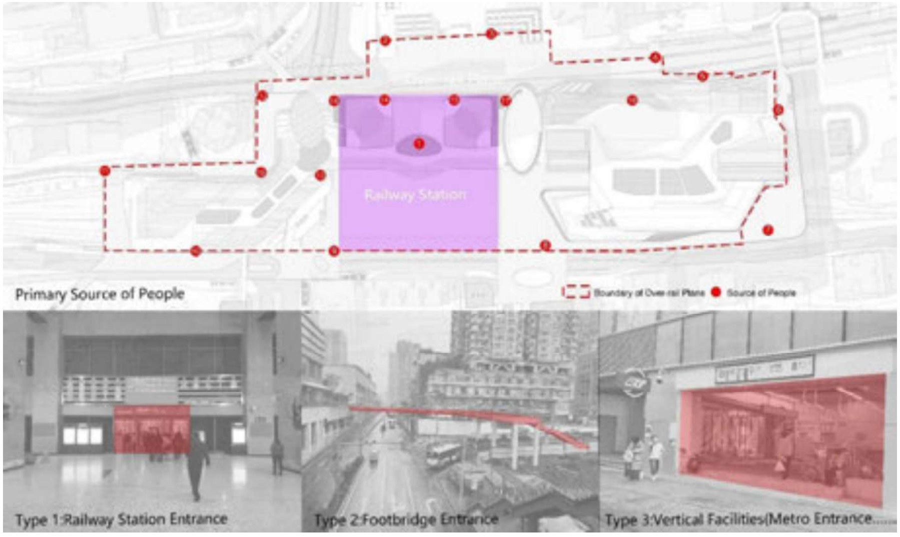

Fig 10. Primary Source of People and its Typical Types in the Over-rail Plane of Shapingba Station, Chongqing, China (Source: Drawn by Author)

It is also important to note that the railway station building has a higher priority than the pedestrian in the over-rail plane, and the generation result of the point placement as described above will show a result that pedestrian flows go through the railway station building. However, this area requires ticket checking and has security requirements in reality, and does not allow the public to freely enter and exit without a ticket. In order to avoid this situation, the wool algorithm needs to be improved. Since the railway station building is not free to pass through, citizens who originally planned to pass through this area will instead go around the outer contour of the railway station building, making the corner space of the railway station building a meeting point for pedestrian flow (Fig. 11). Therefore, this research set two pedestrian intersections at the corners of the railway station house (point 17 and point 18 in Fig. 10) when the wool algorithm was used to generate the walking network, and this modification could avoid the generation of paths that cross the railway station house as an obstacle area. Similarly, the irregular shape of the upper cover plate leads to a similar phenomenon (Fig. 12), and the intersection points of foot traffic are set at the corners of the contours (point 19 of Fig. 10).

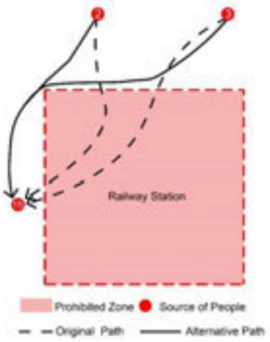

Fig 11. Changes in Path Affected by Railway Station
Source: Drawn by Author

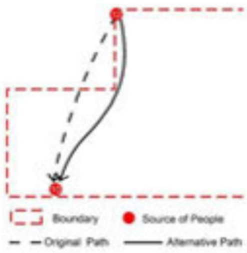

Fig 12. Changes in Path Affected by Concave Corners
Source: Drawn by Author

3.1.2 Generation and Evaluation

After completing the selection of pedestrian sources, the link between them is added according to reality and the wool algorithm is initiated aggregate the paths to obtain the shortest meandering walking path (Fig. 13). The resulting network is simplified to a segment model according to the analysis requirements of SDNA tool, and the peripheral and underground pedestrian network is built to obtain a complete pedestrian network model (Fig. 14). In Figure 14, red is the ground pedestrian network along the carriageway, grey is the next level of red one, blue is the over-rail pedestrian network to be assessed for its potential, and the other colours such as green and brown are the underground pedestrian network that supports the over-rail network. The above networks are imported into Arcmap and the analysis is carried out following the steps of the SDNA tool.

In this case, BtH (Hybrid Betweenness) is selected as the index for path evaluation. It is a measure of intermediation/penetration is an indicator of pedestrian potential, equivalent to Choice index in spatial syntax. The larger the value means the higher the potential for pedestrian flow. BthX indicates that the flow potential is calculated considering X meters as the distance, and Bth500/Bthn is generally chosen according to the needs. In the evaluation results of this case, there is some correlation among the three indicators of Bth500, Bth750, and Bthn, and Bth750 has the most outstanding effect for visualisation, so Bth750 is chosen to visualise the analysis result. Figure 15 shows the global visualisation results. Since this is a three-dimensional model, resulting in a serious superposition of above and below ground in the plan view which seriously affect the judgement. So the visualisation results related to the over-rail plane are extracted separately (Fig.16).

On the basis of Fig.16, we can determine the level of each path: the green and blue paths in Fig. 16 are classified as ordinary paths, these paths have low potential for pedestrian flow and are indicated by thin lines in Fig.17, which can be adjusted according to the needs of the subsequent design; the paths in other colours in Fig. 16 are classified as high-potential paths for pedestrian flow, these paths have high potential for pedestrian flow and are indicated by bold lines in Fig.17. With the help of the high-potential paths and little low-potential paths, we divided a number of zones (Fig.17): the zones adjacent to two high-potential paths are judged to be areas with high potential for implanting urban functions and are shown in red; the zones adjacent to one high-potential paths are judged to have medium potential for implanting urban functions and are indicated in yellow; and the zones away from the high-potential paths are judged to have low potential for the implantation of urban functions and are showed in blue. The red zone is suitable for implanting functions that require high pedestrian flow, such as commerce. And the blue areas are prioritised for layout of equipment space, logistic space, large anchor shops, etc.

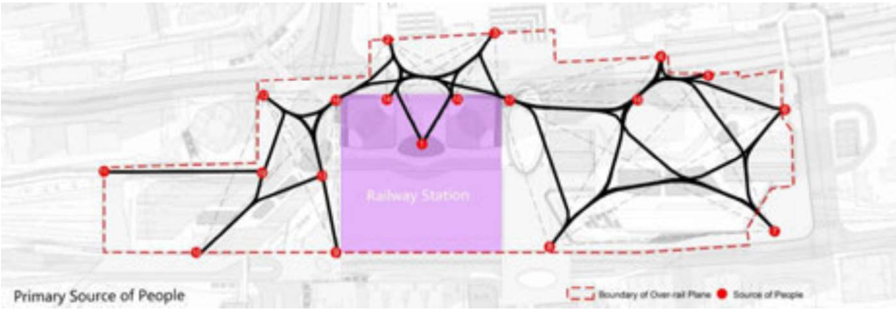

Fig 13. Network Morphology Generated by Wool Algorithm
Source: Drawn by Author

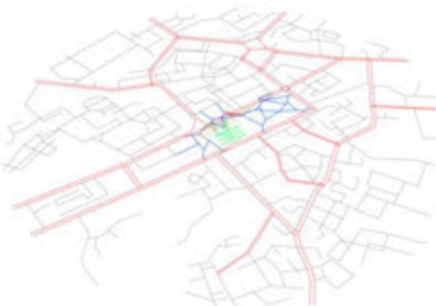

Fig 14. Pedestrian network in station area
Source: Drawn by Author

Fig 15. SDNA Calculation (all)
Source: Drawn by Author

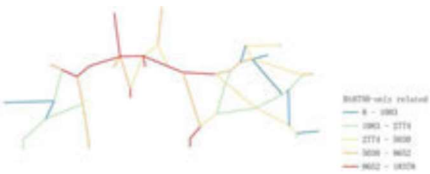

Fig 16. SDNA Calculation (part)
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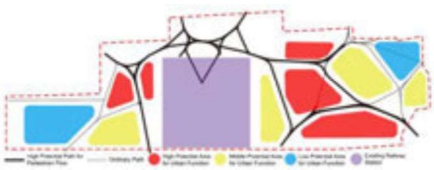


Fig 17. Identification of the Potential of Path and Regions (Source: Drawn by Author)

3.1.3 Overlay Comparison with Existing Design Results

In order to verify whether the above results are sufficiently effective in guiding subsequent design practice, the article compares the results with the design outcomes. Considering that the Chongqing Shapingba Railway Station Complex has produced some modifications during the implementation process due to management and other factors, the author chooses the first version of the complete text of the programme, which has a text marking time of June 2018, to compare with this case. The analysis was carried out by means of a stacked comparison, in which Figure 17 and the layout plan for the over-rail plane were superimposed to obtain Figure 18.

The following phenomena can be observed from Figure 18:

1. the shapes of the functional areas are regularised considering the efficiency of plane utilisation, indicating that the path generated by the wool algorithm is still flawed. It only considers the performance and potential of the paths and ignores the regularity of the regions formed by the path cuts, which is a direction that can be further optimised in the future.

2. The types of functions and the potential of the area show some consistency: in the red area, there are a large number of small and medium-sized shops that bring vitality, with only a small amount of back-office space; in the yellow area, the number of medium-sized shops is beginning to increase, with a certain amount of back-office space and traffic space; in the blue area, there are mainly large warehousing spaces (the supermarket) and vertical traffic space.

This demonstrates the effectiveness of the methodology to a certain extent, but there is potential for further optimisation.

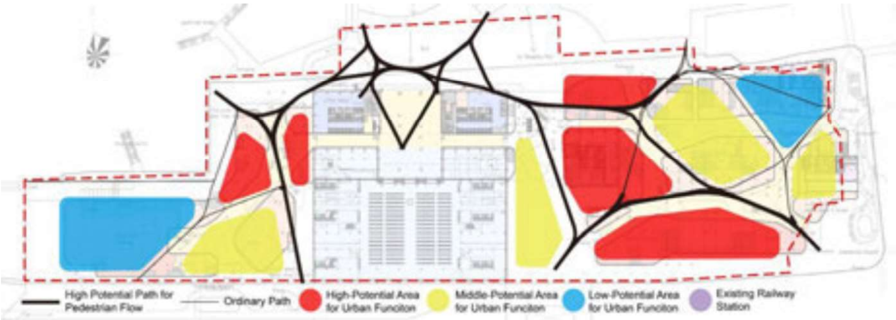


Fig 18. Overlay of Analyses and Actual Design Results
Source: Drawn by Author

3.2 The Over-rail Plane of Shenzhen North Station

3.2.1 Determining Primary Source of People

In the over-rail plane of Shenzhen North Railway Station, the following types of entrances and exits become the source of pedestrian (Fig. 19):

(1) Entrance to the railway station building, as shown at Point 1-3 in Figure 19, where a large number of train passengers enter or leave the covered area.

(2) Footbridge entrances and exits connecting to the neighbourhood, e.g. Points 4-5 in Figure 19, from which people from the neighbourhood enter or leave the over-rail plane.

(3) Major vertical traffic such as escalators to the MTR station, e.g. Point 12-15 in Figure 19, citizens or travellers are likely to enter or leave the covered area from this portion.

(4) Office buildings, commercial buildings, and transport facilities located at the edge of the over-rail plane, such as Points 6 - 11 in Figure 19, where points 6 and 9 are entrances and exits of commercial buildings, points 8 and 11 are entrances of office buildings, point 7 goes to the taxi stand, and point 10 goes to the bus stop.

In addition, since some of the points are too close to each other, it is considered to combine these neighbouring points to reduce the amount of computation, e.g. Point 3 is actually a collection of railway station entrances and two adjacent vertical facilities leading to the metro.

What's more, the current situation in the over-rail plane needs to be considered. Since the existing sunken courtyard is not freely accessible, people who had planned to pass through this area will instead follow the outer contour in a roundabout way, making it a pedestrian intersection. Therefore the research sets four pedestrian intersections at the corners (point 16-point 19 of Fig. 19) in order to avoid generating paths through the courtyard. This is similar to the way dealt with previously (Fig. 10).

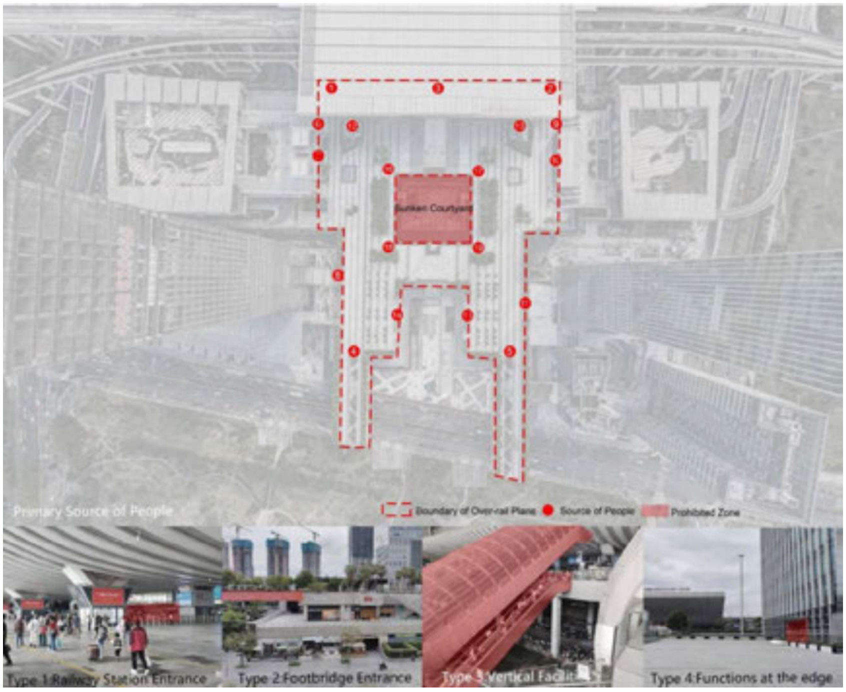


Fig 19. Primary Source of People and its Typical Types in the Over-rail Plane of Shenzhen North Station, Guangdong, China (Source: Drawn by Author)

3.2.2 Generation and Evaluation

The analytical application process for this case is essentially the same as the previous case, where differences are highlighted in italics:

In this case, the wool algorithm is also used to obtain the shortest meandering walking paths (Fig. 20), and the resulting network is simplified to a segment model in accordance with SDNA analysis requirements. After supplementing with the peripheral and subterranean walking network, the SDNA tool is used to analyse as well.

In this case, Bth (Hybrid Betweenness) is also selected as the indicator for path evaluation. *During the path evaluation process of this case, three indicators, Bth500, Bth750 and Bthn, are used to be visualised, but the effect was not outstanding, indicating that the* over-rail plane *of Shenzhen North Station is not closely connected with the surrounding area, and its centrality of the station area is not strong. Therefore Bth300, which reflects centrality in smaller scale, is used for the visualisation.* Figure 21 shows the global visualisation results. Similarly, the visualisation results related to the over-rail plane are extracted separately (Fig. 22).

On the basis of Figure 22, the article determines the hierarchy of paths (Fig. 23, with exactly the same criteria and methodology as in the previous case). With the help of high potential path for pedestrain flow, *we selected a number of high potential areas (Fig. 23) according to two criteria: firstly, they are adjacent to three or more high potential paths, and secondly, they have a regular shape, which will facilitate a more efficient use of the planes in the case of smaller planes.*

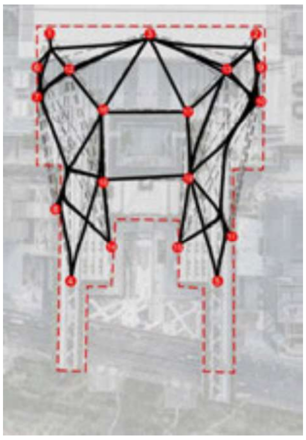
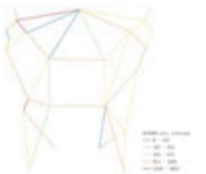


Fig 21. SDNA Calculation (all)



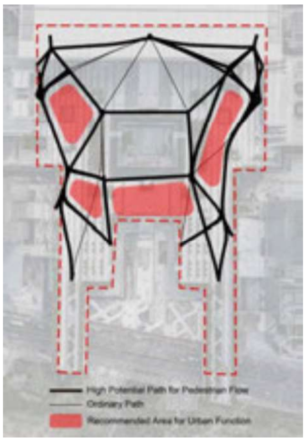


Fig 20. Network Morphology Generated by Wool Algorithm Source: Drawn by Author

Fig 22. SDNA Calculation (part) Source: Drawn by Author

Fig 23. Identification of the Potential of Path and Regions (Source: Drawn by Author)

4 Discussion and Summary

This paper combines the wool algorithm and the SDNA analysis tool to explore a method to generate paths and divide potential functional zones in the over-rail area, and its innovations are mainly as follows:

(1) This paper improves the classical wool algorithm: firstly, it can be adapted to the existence of non-convex space after improvement; secondly, its generation results can avoid the internal obstacle zones, which expands the application possibilities of this classical algorithm.

(2) Focusing on an emerging kind of pedestrian priority areas – over-rail plane, we summarise the points inside and outside this class of areas that may become sources of pedestrian flow, and provide a method to organise its pedestrian system based on the sources of pedestrian flow and delineate the functional potential areas.

At the same time, we also found that the method has some shortcoming that deserve further enhancement:

(1) The wool algorithm can not be directly used to generate pedestrian networks, but only provides reference for path generation. Because it only considers the performance of paths and ignores whether the sites generated by path cutting are suitable for the embedding of urban functions. In the future, the regularity of the shape generated by cutting can be further taken into consideration to make it closer to the final design ;

(2) The research on the effectiveness of the current method is a qualitative comparison of the stacked maps, and more quantitative studies are to be conducted by introducing elements such as poi (point of interest).

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