

Develop the Design Principles for Demand-Responsive Railway Station Areas

Abstract

Some station areas suffer from overcrowding and emptiness **issues** due to the fluctuation caused by events. This paper aims to develop design principles that help create demand-responsive station areas and establish a methodology for discovering similar principles. It develops a multi-step **methodological** framework that includes establishing design objectives and spatial dimensions, collecting data from literature and cases, processing data through systematic examination and research-by-design, evaluating initial findings, and reflecting the final findings through expert interviews. Applying this framework, using 12 papers and multiple cases (including Beijing West Railway Station, Shanghai Railway Station, Rotterdam Central Station, Utrecht Central Station, Bijlmer Arena Station, and so on) as the sources of heuristics for research-by-design, **resulted** in the discovery of 26 design principles, which can be viewed from various perspectives.

Keywords: Overcrowding, Emptiness, Urban design, Pattern language

1 Introduction

In some railway stations, overcrowding and emptiness (Fig. 1), which are two extremes of passenger fluctuation (Section 1.1), are tricky issues causing economic and experiential losses. Overcrowding is unpleasant for users and, more importantly, is a safety concern of stampedes ([ChinaDaily, 2008](#); [de Almeida and von Schreeb, 2019](#)). Emptiness is a waste of space as resources for society, especially in high-density urban areas or cities; It is a waste of maintenance for railway companies; It causes economic loss, as stores or real estate property owners get less commercial revenue due to lack of customer patronage; It decreases users' experience, as spaces being empty makes people feel dangerous, especially at night. All these negative effects necessitate solutions to address overcrowding and emptiness in railway stations.

Addressing overcrowding and emptiness is relevant for many stations as they are challenged by various types of events. Such as spring festivals in China, Vietnam, and South Korea; and beer festivals, carnivals, and sports events in European cities ([CityR](#)). As events are ever-growing in cities ([Tallieu](#)) enriching the city dynamics, it is necessary to build stations that are capable of facilitating this. Also, addressing the after-event emptiness of space and making full use of space as a resource is helpful in promoting sustainability, especially in high-density cities where space is scarce.



Figure 1: Overcrowding and emptiness in railway station areas. (Image source: [a] - [163.com](#); [b] - [Sohu.com](#))

1.1 The nature of overcrowding and emptiness

1.1.1 Viewing stations from the pedestrian flow perspective

A basic unit of pedestrian movement can be seen as pedestrians transfer from their origins to their destinations through some spaces/passages/connections, and possibly **bottlenecks** (i.e., station components that have a limited capacity to handle the passenger flow, due to various reasons such as security/ticket checks, level changes, narrow passages, a limited number of trains, and disruptions on the railway lines) (Fig. 2 a). This basic unit can be repeatedly seen in various forms (Fig. 2 a-1, a-2) in the station area (Fig. 3). Station components that are working well during normal times can still become bottlenecks during big events (e.g., national holidays and football matches) when there are surging passengers. To accommodate the detained passengers, ‘redundant’ spaces are needed. These redundant spaces can be overcrowded during peak times while empty during non-peak times. Therefore, overcrowding and emptiness, which may seem two opposite phenomena, actually result from the same reason - fluctuated passenger flow due to events.

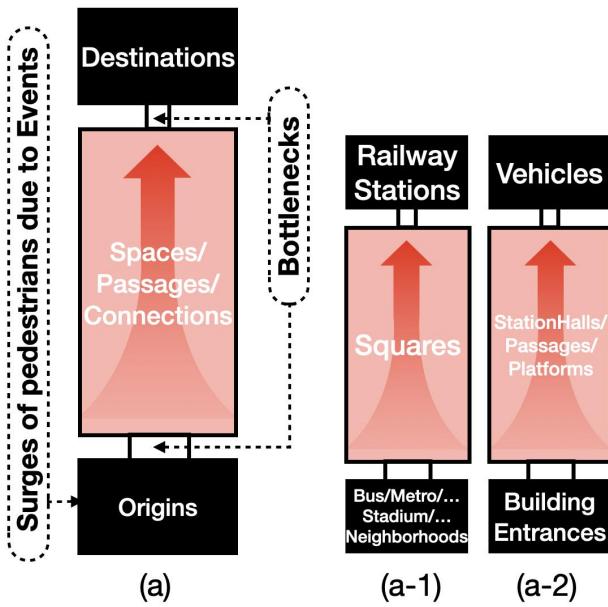


Figure 2: A conceptual basic unit of passenger flow (a) and its variations (a-1, a-2). (Image source: by authors. Inspired by (Fruin, 1971))

1.1.2 Spatial relevance of the problems

With professional backgrounds in architecture and urban design, we saw the spatial relevance of overcrowding and emptiness to spatial configurations. The spatial considerations in these two fields usually include the form of space, layout of elements, accessibility, visibility, and so on, on building and district levels. In cases like Beijing West Railway Station (Fig. 4 a, b), overcrowding and emptiness are associated with the poor connection with the neighborhood, the gigantic non-human size of buildings, messy facilities on the square blocking view, and deteriorating space qualities, a lack of visibility from eye level to see the sunken plaza and atriums, traffic separate the use of walkable spaces, and so on. The station is relatively isolated from the neighboring city areas, and spaces within the station areas are separated by bottlenecks, which decrease the peak time capacity and make the station less attractive for non-transport use during non-peak times.

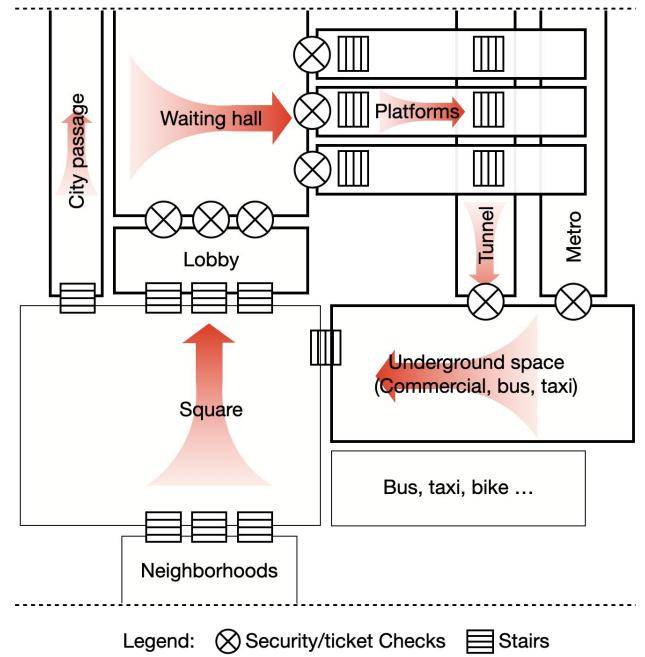


Figure 3: The mechanism of overcrowding and emptiness in Beijing West Railway Station area. (Image source: by authors)



Figure 4: Spatial relevance shown by an example case of Beijing West Railway Station. (Image source: [a] - [Meipian.cn](#); [b] - [Wikimedia.org](#). Redrawn by the authors)

1.1.3 Temporal and spatial scales of the problem-causing events

Various events on different temporal scales ([Carmona et al., 2010](#)) can influence stations (Fig. 5), such as daily and weekly commuting, multi-weekly sports events, yearly holidays, and multi-decennially Olympics. However, daily and weekly commuting is more of a topic for metro stations than railway stations and is commonly investigated in research on ‘TOD (Transit Oriented Development)’ ([Ibraeva et al., 2020](#)). Low-frequency events such as the Olympics are too rare to find patterns ([Alexander, 1977](#)). In contrast, multi-weekly to yearly events are peculiar because they result in relatively drastic pedestrian fluctuation, and it is feasible to find patterns. They are of particular concern to railway stations and have barely been studied.

Events on different spatial scales can all impact stations, whether they happen within station buildings, within station areas, or outside station areas. For example, markets are held in the station hall of Zurich Main Station, and concerts are organized in the station hall of Antwerp Central Station. In station areas, there are concerts/sports events in the multiple stadiums near Bijlmer Arena station and conference events in the Jaarbeurs convention center near Utrecht Central Station, which bring surging passengers during event times. Some other events, not necessarily in the station areas, cause peak flow for stations, such as the Chinese national holidays, the Munich beer festival, and the Zandvoort F1 match.

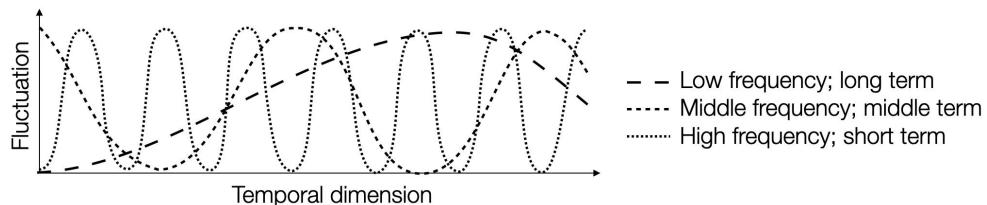


Figure 5: Temporal scales. (Image source: drawn by the authors, inspired by fig. 130, on p. 38 of ([de Jonge and van der Voordt, 2002](#)))

1.2 Demand-responsive as an objective

The overcrowding and emptiness issues urge relevant station areas to be ‘demand-responsive.’ Since this paper studies the particular issues - overcrowding and emptiness- which are barely addressed by existing spatial design research, there are no corresponding termed solution packages. Therefore, this paper needs to name a term for possible solutions and enrich the meaning of the term. One ideal term this paper found is ‘demand-responsive’ inspired by the word ‘demand-responsive transport,’ which is a practice ideal ([Enoch et al., 2006](#)) used in the transport service field, describing a flexible mode of transportation that adapts to the demands of its user groups ([Hunkin and Krell, 2018](#)). This paper transfers the meaning of ‘demand-responsive’ to the station context regarding **spatial design** perspective, defining it as **a quality of station areas that can address the use fluctuation caused by events, reduce potential overcrowding and emptiness, make spaces sufficiently be used during non-peak and peak time, and satisfy users’ needs.** (See also Section [2.5.2 Literature](#), and [Supplementary materials](#))

1.3 Spatial solutions as a research objective

This research hypothesizes that spatial solutions (on district and building levels) can contribute to demand-responsive solutions. Firstly, overcrowding and emptiness sometimes result from poor spatial configuration (Section 1.1.2), spatial relevance of the problems). Therefore, good spatial solutions will make a change, and in cases like the Rotterdam Central Station (CS) and Utrecht CS areas, through proper spatial design, great improvement has been achieved during the latest redevelopments. Secondly, it is common for spatial solutions to resolve non-spatial issues or to enhance non-spatial solutions. Indeed, “a pattern of events cannot be separated from the space where it occurs” (Alexander, 1979, p. 73). Overcrowding and emptiness in stations are often a mixture of spatial and non-spatial issues, and possible solutions can come from spatial design, among other fields such as transportation engineering, management, and planning. For example, a (spatially) well-designed plaza can serve as a basis for (managerially) organizing leisure events, hence reducing emptiness.

1.3.1 Address both overcrowding and emptiness

Spatial solutions should be able to address both overcrowding and emptiness and should not ignore one of them. If only overcrowding or emptiness were considered, there could easily be a paradox of ‘larger’ or ‘smaller’ spaces for railway station areas. For example, to reduce overcrowding, stations can be designed with ‘larger’ redundant spaces, but then the emptiness issue during non-peak time will be exacerbated; to reduce emptiness, stations can be designed with ‘smaller’ redundant spaces, but they will be more overcrowded during peak time. To avoid the paradox, design solutions should be able to reduce both overcrowding and emptiness. That is to say, solutions should 1) increase transport (i.e., transfer/waiting) capacity without significantly enlarging spaces that are prone to be empty or 2) increase the leisure use of space without significantly reducing transport capacity.

1.3.2 Spatial scales of concern: the district and building levels (within 250m radius)

For issues related to railway stations, typically, there are potential solutions across different spatial scales, and spatial solutions at the district level are less studied (Fig. 6). On regional or city levels, many studies have investigated planning interventions to improve stations’ performance (Yin et al., 2015; van den Berg et al., 1998; Borghetti et al., 2021). In these studies, stations are simplified as nodes within networks. These nodes (station areas) are usually defined with a range **around 500-1000m** (Zhang et al., 2019; Borghetti et al., 2021). At these levels, overcrowding can potentially be solved by the shared capacity from other stations (Bešinović, 2020; Lu et al., 2022) or other mobilities (Martins et al., 2019), and emptiness can potentially be solved by better accessibility (Borghetti et al., 2021; Jehle et al., 2022) that promotes more use.

However, interventions at these higher levels are usually non-spatial, missing the complexity of overcrowding and emptiness relating to 3D and configurations (Section 1.1.2). In contrast, district-level interventions can take district structures and 3D urban forms into consideration. And yet, little is known about district-level interventions.

In this research, we investigate station areas with a range within approximately 250-300m, smaller than the typical 500m range in planning-oriented research. This is because we take user perception into consideration. As noted by Peek and van Hagen (2002), in practice, a 300m radius for the so-called “station environment” is used. This smaller range serves this study’s explorative nature to investigate spatial configurations that lie in urban design (and architecture, as explained in the following paragraph) domains. During field visits of selected cases, we found that the stations are usually visually perceivable around the maximum 250m range (see [Supplementary Materials](#), figs. 48, 49, and 50, depicting areas of different stations).

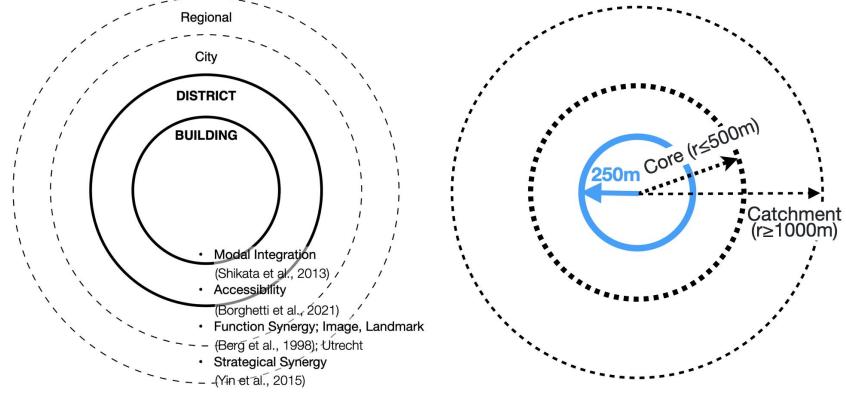


Figure 6: Spatial scales of station areas. (Image source: ([Chen et al., 2024](#)))

Besides the district level, the building level (at which we analyze the station building) should also be considered. In railway development, urban design schemes at the district level are commonly determined by the layouts of station buildings at the building level. For example, in Utrecht Central Station and Rotterdam Central Station, the large structures - city axes, are much determined by the qualities of city passages embedded in the station buildings.

Building-level and district-level interventions can be mixed. For example, a book that is highly referenced by railway station studies in China, titled ‘Holistic Design on Urban Architecture’ ([Han, 1999](#)), conveys many ideas that mix the boundaries of urban and architectural design, including ‘the socialization and giantization of architecture,’ ‘the three-dimensionalization and interiorization of urban design.’

Yet Building-level and district-level interventions also have their own strengths and limitations. District-level concepts can be expensive to realize within buildings or lead to non-human scale mega buildings. For example, in Fig. 7, to improve the fragmented Amsterdam Sloterdijk station areas, the architectural proposals featured mega-building roofs that span several hundred meters, while the urban design proposals are more realistic, sorting out the clear human-scale district street structures, with normal-sized buildings. Therefore, in this research, we investigate the station areas with a range of within 250m at the district and building levels.

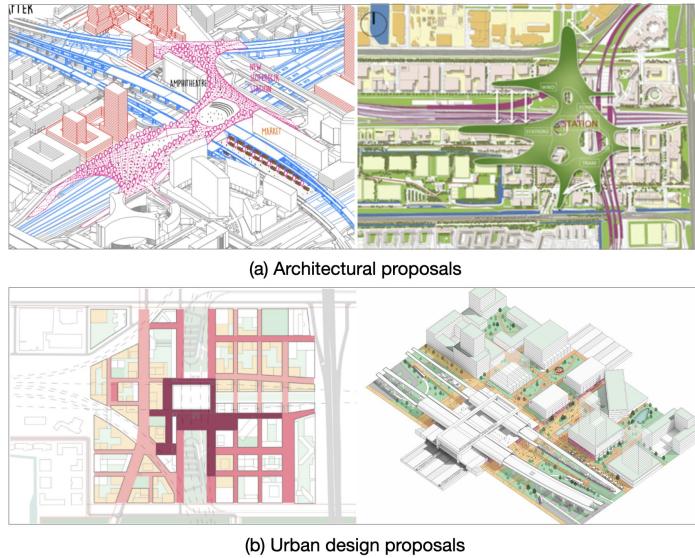


Figure 7: Architectural and urban design proposals for Amsterdam Sloterdijk station (Image source: [a] ([Triggianese et al., 2019](#)); [b] ([Andrianos, 2023](#)))

1.4 Relevance with station-city integration

Demand-responsive is interconnected with the research topic of ‘**station-city integration (SCI)**,’ as they can interchangeably be the context or solutions for each other. SCI is a research topic that aims to get various possible benefits by integrating stations and cities. It has a relatively long history of rich academic conversations across multiple fields ([Cheng](#)

et al., 2021; Yin et al., 2015), including spatial design (Calthorpe and Poticha, 1993; De Wilde, 2006; Shikata et al., 2013; Zemp et al., 2011; Du et al., 2021; da Conceição, 2015). Spatial interpretations for integration typically include mode integration, mixed use of land, high-density development, the stack of building floors, and so on.

SCI brings potential as well as risks for demand-responsive solutions. When stations and cities are ‘integrated,’ it is possible for stations to benefit from an enlarged accommodation capacity and increased user numbers, therefore relieving the overcrowding and emptiness issues. The opposite side effect is also possible, though; stations may be more overcrowded in peak time due to the increased number of passengers or more empty if the city areas are mostly empty by themselves. The city users may even cause flow conflicts for transport passengers. The city areas can benefit from stations’ massive passengers, a vibrant environment, and increased commercial revenue; it is also possible to have side effects such as being rendered into chaotic areas due to traffic elements. Developing city areas beyond pure stations may require a heavy initial investment, resulting in high maintenance costs after development. The dual possibilities of benefits and side effects make SCI a fruitful and challenging topic for demand-responsive solutions. To reduce overcrowding and emptiness, stations should be integrated with cities carefully, possibly with the help of a systematic assessment of design interventions.

1.5 Knowledge Gap and Research Question

The above introduction explains the nature of overcrowding and emptiness (O&E) as related to events, and reveals the research objective: spatial solutions for demand-responsive (DR) station areas, which bring potential and avoid risks to station-city integration (SCI).

Aimed at the research objectives, an ongoing Ph.D project is being conducted, which 1) articulates the overcrowding & emptiness problems from the spatial design perspective, 2) establishes an assessment framework for design evaluation, and 3) develops **design principles** (fig. 8). This paper is part of the project and specifically addresses the design principles.

The main research question of this paper is: **What are the design principles for demand-responsive railway station areas?** A subsequent question is: **What is a practical way to develop design principles?**

The remainder of this paper is structured as follows: Chapter 2 describes the methodology, Chapter 3 reports the results, Chapter 4 discusses the whole research and results, and Chapter 5 draws conclusions.

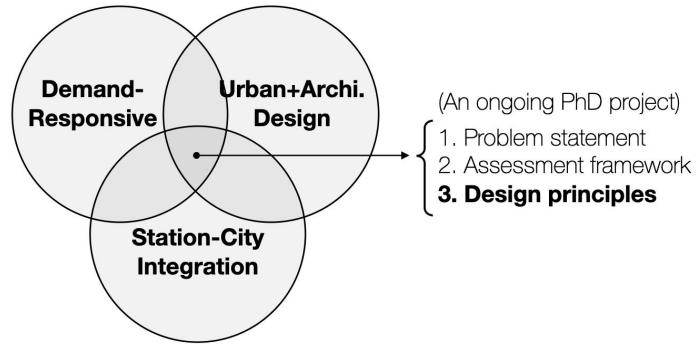


Figure 8: This paper is part of a PhD project at the intersection of three topics. (Image source: by authors)

2 Methodology

In this section, we first define what ‘design principles’ are, and then describe the methodology for developing them.

2.1 What is a design principle?

Design principles/guidelines are commonly used in the design field. Their meanings vary in different research or design projects, from vague to more specific (Liu, 2020; van der Hoeven and Juchnevich, 2016). We adopt the well-defined concept called ‘patterns’ from Alexander (1979, 1977) as what we mean by ‘design principles.’ In the following two paragraphs, we briefly describe the related concept of ‘patterns’ and how we make use of them.

“*Each pattern is a three-part rule, which expresses a relation between a certain context, a problem, and a solution. Each pattern depends both on the smaller patterns it contains, and on the larger patterns within which it is contained*” (Alexander, 1979, pp. 247, 312). Following these ideas, in this research, we treat the design principles as ‘solutions’ for

'problems' within 'contexts' (Section 3.3). In chapter 1 **Introduction**, we already describe the general context and problems. In chapter 3 **Results**, Section 3.3 **Design principles**, some design principles aimed at their own and more specific problems within certain contexts; we describe these problems and contexts whenever necessary in the description of each principle.

Alexander organizes different patterns in a scalar hierarchical **network**, in which the relationships between patterns are illustrated (and the network is indeed the structure of the **pattern language**) (Alexander, 1979, p. 314). Similarly, we organize all our design principles in a network (fig. 15).

2.2 A seven-step methodology framework for developing design principles

To systematically discover and evaluate design principles, we propose a methodology seven-step framework (Fig. 9), which includes (S1) developing design objectives and design dimensions, (S2) collecting data from cases and literature, (S3) data processing, (S4) proposing hypotheses, (S5) evaluation of hypotheses, and (S6) presenting final results. Iteration, as a typical procedure in design-related research (Nijhuis and Bobbink, 2012), is also embedded as Step 7 (S7) and as a sub-step within Step 3. The following sections describe some key components of the framework.

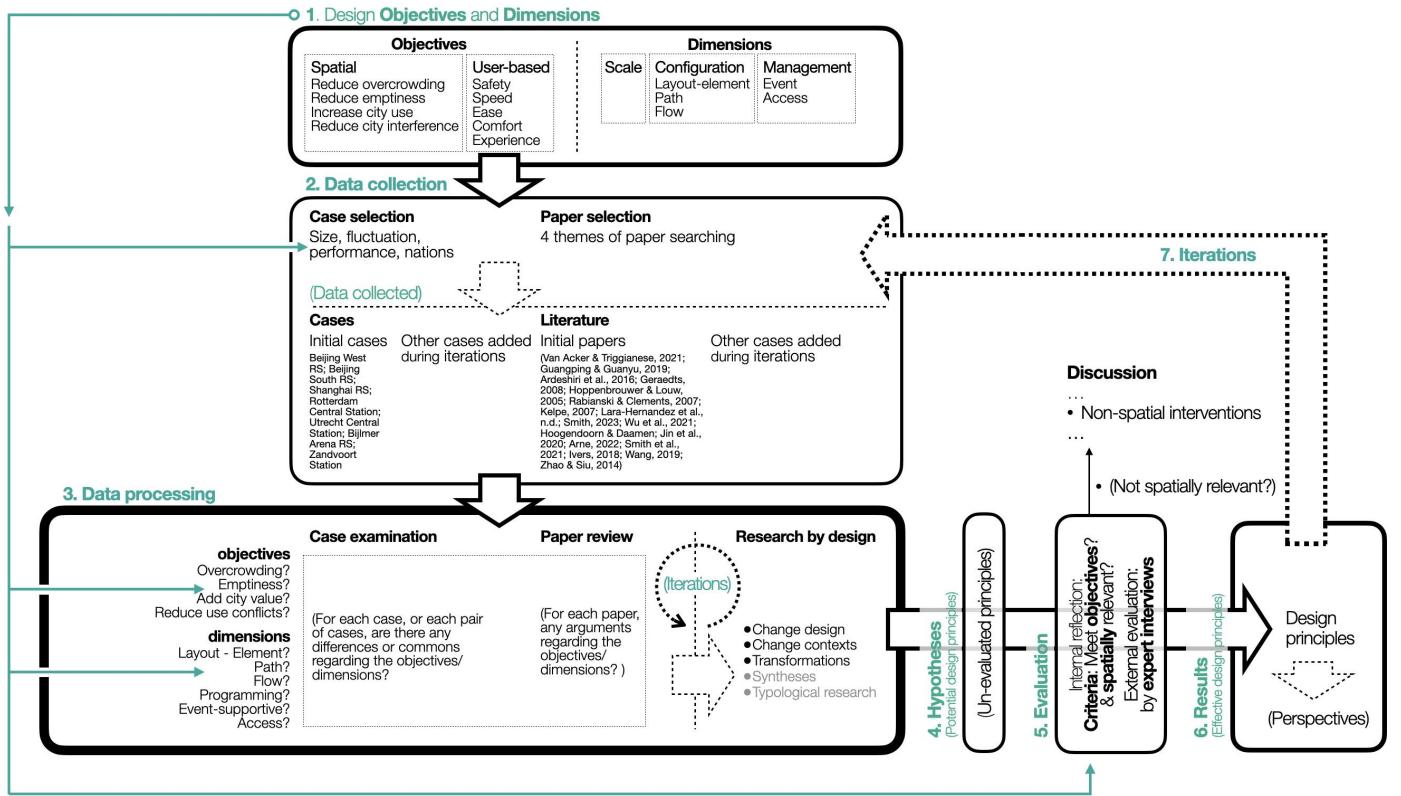


Figure 9: The process of developing design principles. (Image source: by authors)

2.3 Design objectives

Multiple design objectives are established in this paper, which are categorized into a) problem-solving and value-creating and b) user-based. The objectives in the first category are more relevant to stakeholders' interests, and the objectives in the second are more relevant to users' experiences.

2.3.1 Problem-solving and value-creating objectives

Four design objectives are defined in this category. The initial problems this paper investigates are overcrowding and emptiness, so 1) reducing overcrowding and 2) reducing emptiness naturally becomes the two primary objectives. Since this research is also embedded in the station-city integration topic, it considers beyond the station, setting two extra objectives for the city: 3) adding value to the city and 4) reducing interference to the city. Objectives 1) and 2) are the added values to stations, and 3) and 4) are the added values to cities. In this sense, these objectives contribute to station-city integration. These design objectives serve as guidance for collecting relevant data (in Step 2. Data collection), guide

the examination of input data (in Step 3. Data processing), and function as criteria to evaluate the initial results (in Step 5. Evaluation, fig. 9).

2.3.2 User-based objectives

Various user-based design objectives are set. As transport infrastructure, stations have their primary users as transport passengers; While stations are also promoted as places in the city (Bertolini and Spit, 1998), they should also consider the non-passengers (e.g., neighborhood residents) as users. For passengers, according to van Hagen (2011), there are five types of needs: safety, speed, ease, comfort, and experience. A further study by Chen et al. (2024) translated these needs into quantifiable spatial and behavioral/perceptual features. For non-passengers, since they are diverse in nature, it is hard to define their universal needs; One attempt by Carr et al. (1992) specifies the general public space users' needs as comfort, relaxation, passive engagement with the environment, active engagement with the environment, and discovery. This paper therefore set corresponding design objectives as: 5) enhancing the five types of passengers' needs, and 6) enhancing the multiple general public space needs.

2.4 Dimensions of spatial and managerial interventions

This paper examines spatial interventions relevant to design and management. Railway station development is a complex topic addressed by different practice fields, including planning, design, management, and so on. These fields typically have interventions taken on certain temporal scales. Planning strategies may be implemented once a few decades, design and engineering renewals may happen every few years, while management interventions can be taken on a daily basis (Carmona et al., 2010). As design research, this paper primarily investigates spatial design solutions; while it also investigates solutions relevant to management (and have spatial implications) because events (both as problems and solutions) are closely related to management. Planning is a spatially much broader and temporally long-term field, which is less relevant to the issues this paper addresses and is left out here.

2.4.1 Spatial scales of station areas

This paper investigates the station areas at the building and district levels (Fig. 10; Fig. 11 a). Spatial scale is a critical issue in both railway station research and urban design research (Du et al., 2021; Lloyd-Jones, 2001). at the district level, various ranges have been proposed to define railway station areas (Calthorpe and Poticha, 1993; Bertolini, 2008)), typically around 500-700m. This paper, however, chooses a more humble range, 250-300m, what Peek and van Hagen (2002) call "station environment." This smaller range is more appropriate as it relates more to user experiential perception (Chen et al., 2024), and is more relevant to the urban design interventions in station development (e.g., see the Rotterdam Central Station redevelopment site range in <https://www.archdaily.com>).

2.4.2 The configuration of station areas

This paper views the configuration of station areas from four perspectives to encompass a comprehensive understanding of this complex system. Firstly, in the introduction part (Section 1.1), this paper already explained the station configuration as it facilitates pedestrian flow transfer from origins to destinations (Fig. 2, 3). Secondly, similar to the general flow analysis, designers in design practice often examine specific paths of users to gain experiential/perceptual understandings of space (Fig. 11 c) (Arne, 2022). Thirdly, design is also commonly treated as the study of elements and layout (de Jonge and van der Voordt, 2002; Liu, 2020). For station areas at the district level, elements include the station building, squares, city passage, urban furniture, and so on; and the layout is about the composition/constellation/organization/network of these elements. at the building level, the layout is about the organization of various mobility sites (railway, metro, bus, tram, bike, taxi/car) and building components (gates, indoor public spaces, hall, escalators, and so on) (Fig. 11 b; Fig. 10 b). Fourthly, the station areas can also be seen as things that belong to either the station or the neighboring city (Fig. 11 a). The configuration analyses from these four perspectives can be conducted at the district and the building levels.

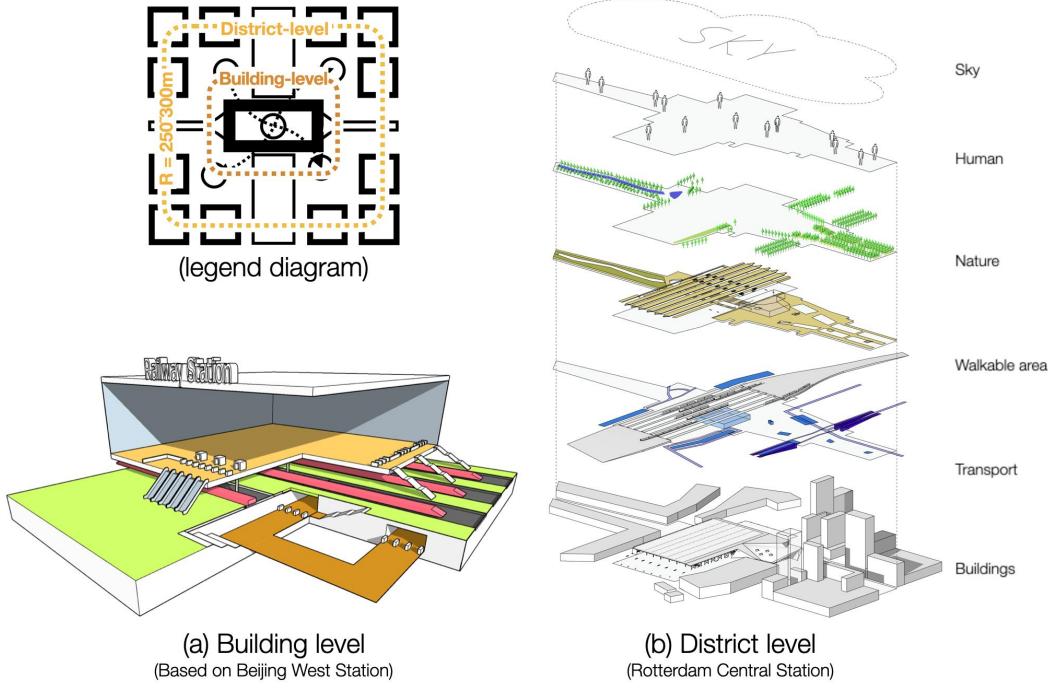


Figure 10: The station at the district and building levels. (Image source: by authors)

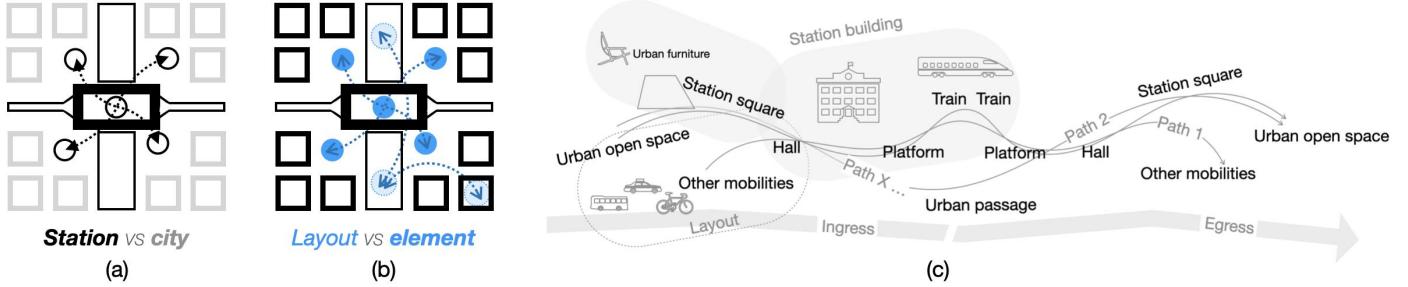


Figure 11: The configuration of the station. (Image source: by authors)

2.4.3 Managerial interventions

This paper considers two types of managerial interventions: organizing events and regulating access. According to Carr et al. (1992), there are several types of rights in public space, including access, claim, change, ownership and disposition, and so on. Management interventions can regulate these rights. Inspired by this, the paper realizes at least two types of managerial interventions - organizing events and regulating access (or routes and paths), can help to address overcrowding and emptiness. Firstly, although some (problem-causing) events affecting transport are the sources of the overcrowding and emptiness issues (Section 1.1), some other leisure events can be part of the solutions; When the redundant spaces in station areas are empty during normal times, (solution-oriented) leisure events can be organized to reduce emptiness, such as exhibitions in station buildings, and markets or crowd dancing on station plazas (van Nieuwenhuize, 2023). Secondly, regulating access/route/path is commonly seen in crowd management practices to (re-)distribute the pedestrians and avoid overcrowding.

2.5 Data sources

This paper uses real-world cases and literature as data sources to discover initial relevant solutions (that already exist in practice). It uses ‘research by design (RbD) (13)’ to further develop new solutions (that do not exist in practice (Nijhuis and Bobbink, 2012)). Combining literature and cases with RbD enables us to find solutions from the past and for the future and to leverage both theoretical and practical knowledge (Fig. 12).

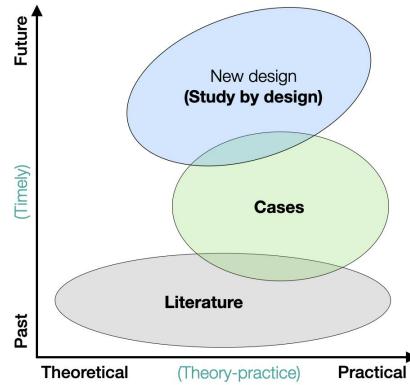


Figure 12: Data sources. (Image source: by authors)

2.5.1 Cases

The cases used in this paper include seven initial station cases, multiple extended station cases, and non-station cases. Seven initial station cases are selected, including Beijing West Railway Station (RS), Beijing South RS, Shanghai RS, Rotterdam Central Station (CS), Utrecht CS, Bijlmer Arena RS, and Zandvoort RS. They differ in 1) fluctuation contexts and/or 2) performance addressing fluctuation. Some of them - 'poor' examples (Beijing West RS and Beijing South RS) - have overcrowding and emptiness phenomena yet not solved, while others - 'good' examples - potentially solved these phenomena. Most of them are major stations of the cities (see [Supplementary Materials](#), Table 1; Section 4.3 Station typology implied by the cases).

These initial cases are also chosen due to our physical vicinity to the cases, which enables us to do site visits and get experiential/perceptual heuristics.

Extended station cases and non-station cases are also added in several situations: 1) When initial station cases are not enough to illustrate the discovered solutions, 2) When extra cases extend the generalizability of the design principles. The non-station cases are primarily selected from airports, shopping malls, and stadiums because they, like stations, are also large infrastructures that deal with massive users.

2.5.2 Literature

Literature is searched through four themes. 12 papers are finally selected and used for providing heuristics for research-by-design (see [Supplementary Materials](#), fig. 47). The first theme of searching is demand-responsive related concepts (Section 1.2), including 'resilience,' 'flexible,' 'dynamic,' 'adaptive,' 'robust,' 'movable,' 'reconfigurable,' 'multi-functional,' 'temporary,' and so on (see Section 6.1.1 in [Supplementary Materials](#) for more explanations). The second theme is specifically for searching heuristics that deal with overcrowding: pedestrian simulations of railway stations. The third theme is specifically for searching heuristics that deal with emptiness: events (or activities) in public spaces (or urban/open spaces,' 'places,' and 'landscapes'). The fourth theme includes the station-city consideration: station-city integration from the urban design perspective. Google Scholar was used as the database for searching, considering its diverse range of literature types, making it suitable for design-related content beyond typical scientific knowledge.

2.6 Data processing

2.6.1 Examine relevance

We examine each case and literature paper regarding its relevance to design objectives and dimensions (See [Supplementary Materials](#), fig. 51, and Sections 2.3, 2.4).

2.6.2 Comparing cases

We also compare various pairs of cases to see evident commons or differences.

2.6.3 Research by design

Research by design (RbD) is a research method that uses design to develop knowledge. We adopt the definition of RbD proposed by [de Jonge and van der Voordt \(2002\)](#), in which RbD is defined as **changing the design itself or its**

context and studying the effects of the transformations (Fig. 9).

More specifically, in this research, the changes/transformations we made include transferring strategies between different types of buildings/spaces; transferring strategies between different scales; testing with different shapes, sizes, positions, directions, and so on (DADFT, 1991); making novel combinations/syntheses of different objectives and measures.

Fig. 13 is an example of using RbD to study the relationship between event typology and the positioning of city passages. (See also Supplementary Materials explaining the validity of research by design.)

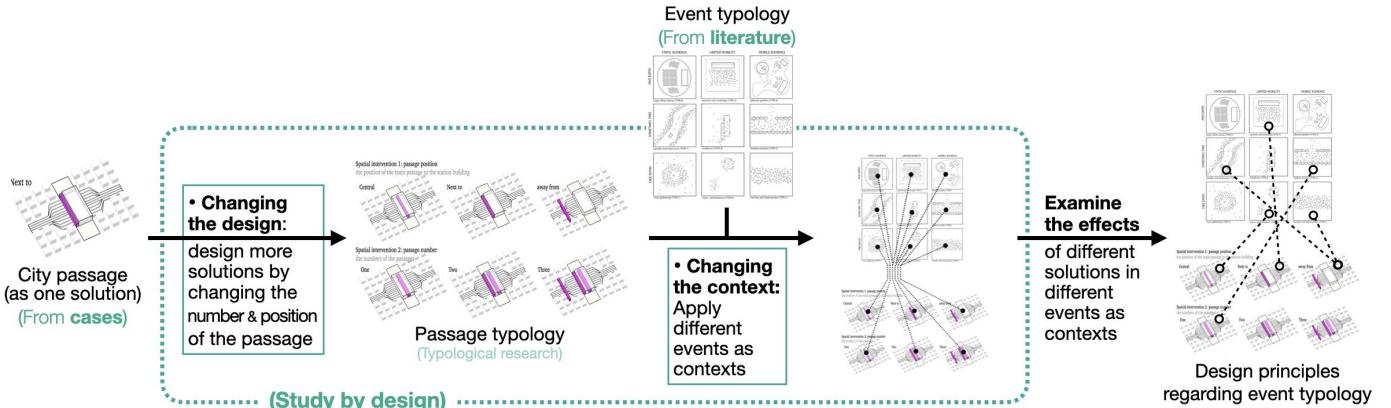


Figure 13: An example of research by design. (Image source: by authors)

RbD facilitates new knowledge production. New knowledge is urgently needed to extend the usefulness of existing knowledge in various situations in this research: when meaningful heuristics are found while no real-world solutions exist; when there is an existing solution and it has the potential to be extended; when some heuristics from literature is purely about activity and not related to spatial features, so spatial translation is needed.

RbD facilitates our investigation of the effects of design interventions. It is common that the context and design solutions are not clear during the design process. ‘Research by design’ helps designers to make both context and design interventions more explicit, hence making the effects of design interventions more evident to judge.

2.7 Criteria for evaluation

We evaluate the design principles with two criteria: 1) whether the findings meet design objectives (Section 2.3); 2) how practical they can be used in practice (Nijhuis and Bobbink, 2012). Firstly, we check the design solutions by ourselves using a table where design objectives are listed against principles (See Supplementary Materials, fig. 52). Secondly, we do interviews with field experts to reflect on the design principles.

3 Results

Our research resulted in two types of results: 1) the (over twenty) individual **design principles** and 2) the multiple **perspectives** to view these principles. In the following sections, we hierarchically present them for better clarity: first, we describe an overview of the principles, then introduce the multiple perspectives, and finally, the individual principles. These perspectives and principles can be checked on the interactive website we developed (<http://c1309928130.pythonanywhere.com/>).

3.1 Overview of the design principles

Within the time frame of this research, more than twenty design principles are developed. It is evident that more potential design principles can be found in future research following the same methodology. Literature, cases, and research-by-design all provide substantial heuristics for the final result (fig. 14). Different design principles have their varying strengths and limitations (Supplementary Materials, fig. 52).

Design principles	Source of heuristics				Reflections from experts
	Cases (station)	(non-station)	Literature	Research by design	
1. Flexible use -	Paris beaches (Paris Plages)	(Hoppenbrouwer & Louw, 2005)	-	-	-
2. Suitable general layouts of the station and city -	-	(Guangping & guanyu, 2019; Apply different layouts Shikata et al., 2013)	as contexts	-	-
3. Set apart non-transport function Utrecht new vs old;	-	-	-	-	-
4. Vibrate city environment - by scattered mobility nodes	-	-	-	Transformed from DP5 to a larger scale	-
5. Increase accommodating capacity by Beijing West vs Shanghai scattered mobility nodes	-	-	-	-	-
6. Make events visible by aligning Beijing West; Rotterdam new vs main paths and open spaces old	-	-	-	Virtually add events to see the effects	-
7. Human-oriented spaces Rotterdam new vs old	-	-	-	Virtually add events to see the effects	-
8. Connect with neighborhoods Beijing West; Rotterdam; Utrecht	-	(Peters & Tolkoff, 2016)	-	-	✓
9. Smooth level changes by landscape design Jiaxing (District level)	-	-	-	Transformed from DP10 to a larger scale	-
10. Smooth level changes by landscape design Arnhem (Building level)	-	-	-	-	✓
11. Adaptive redundant spaces Shanghai with path regulation	(Path regulations in) Airports; Shopping malls	-	-	Transformed from non-station case experience	✓
12. Programming considering the time dimension Guangzhou	TOD mixed-use practice	(Calthorpe & Poticha, 1993)	-	Transformed from higher-frequency events	-
13. Shortcuts or optimizing paths Beijing West	-	-	-	Design shortcuts as a new solution	✓
14. Flexible buildings -	The Shed; Stadium 974	(Ivers, 2018; Smith, 2023)	-	-	✓
15. Flexible building components -	-	-	-	Transformed from DP14 to a smaller scale	-
16. Add installations and facilities Antwerpen	-	(Ivers, 2018; Kelpe, 2007)	-	Transformed from non-station cases	✓
17. Reconfigurable elements -	-	(Ivers, 2018)	-	Transformed from non-station cases	-
18. Redundant spaces -	Allianz Arena	-	-	Transformed from non-station cases	-
19. Setting apart bottlenecks -	-	(Hoogendoorn & Daamen, 2004)	-	-	-
20. City passages Rotterdam; Utrecht; Bijlmer	-	-	-	-	-
21. Position city passages Rotterdam; Utrecht; Amsterdam	-	-	-	Apply this as a context for DP20	-
22. Reduce barriers to ease flow (District level) Beijing West; Rotterdam; Utrecht	-	-	-	Design	-
23. Reduce barriers to ease flow (Building level) Beijing West	-	-	-	Transformed from DP22 to a smaller scale	-
24. Stairs as stages or seats Utrecht; Cologne; Antwerp	-	-	-	-	✓
25. City axes Rotterdam; Utrecht	-	-	-	-	-
26. Reconfigurable spaces -	-	(Ivers, 2018)	-	Transformed from non-station cases	✓

Figure 14: Sources of heuristics. (Image source: by authors)

3.2 Perspectives to view the design principles

During the research process, parallel with the new principles being developed, various perspectives emerged. These multiple perspectives can be seen as theoretical lenses through which to view the design principles (DPs) or typologies of the DPs. The multiple perspectives provide diverse ways for designers to relate to the individual principles we developed. The perspectives also guide designers in finding new principles that follow the same way of thinking. In the following sections, we present these perspectives by [3.2.1 viewing design principles as patterns within a network](#) and as [3.2.2 principles about different station components](#), and [3.2.3 viewing design principles from other perspectives](#).

3.2.1 View design Principles as patterns within a network

We first arrange the resulting design principles in a **network** from the district level to the building level (fig. 15). This perspective is inspired by Alexander's pattern language ([Alexander, 1979](#), p. 314), whose structure is a network usually organized in a hierarchical **scalar** order. The cross-scale connections between principles are important because each principle relies on the smaller principles it contains, and sometimes also the larger principles in which it is contained. For example, to [Connect with neighborhoods \(8\)](#) at the district level, station areas should properly [Position city passages \(21\)](#) and, design [City passages \(20\)](#) at the building level; Maybe [City axes \(25\)](#) on a sub-city level are also needed. For another example, to generate leisure events, station areas can [Add installations and facilities \(16\)](#), but the space where these installations and facilities are located should be [Human-oriented spaces \(7\)](#).

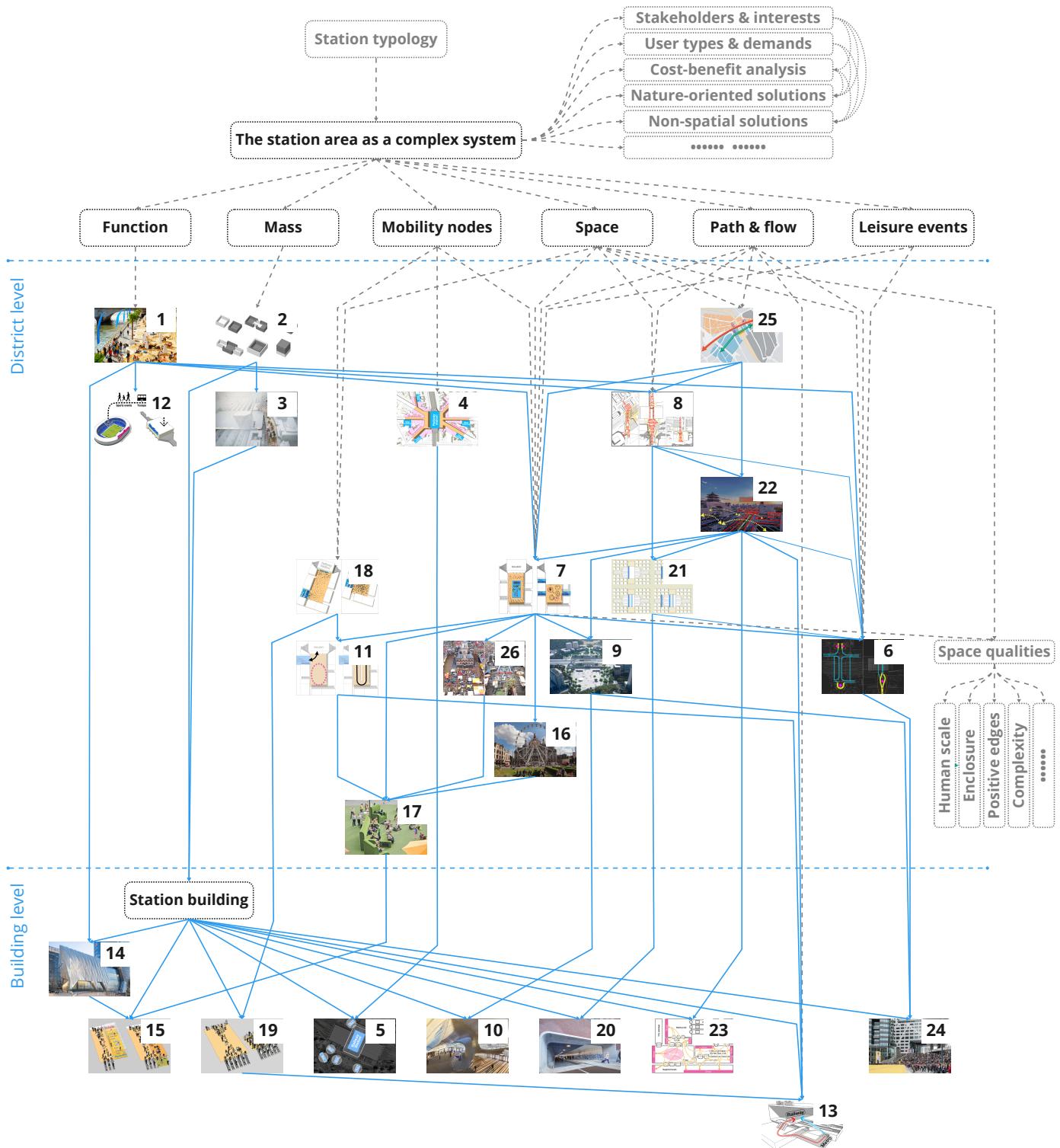


Figure 15: The design principles (patterns) within a network. (Image source: by authors)

3.2.2 View design principles as principles for different station components

The design principles can be categorized according to the component types of station areas which they deal with. On top of the aforementioned network, we already categorized the principles as related to **function, mass, space, flow & path, mobility nodes, and leisure events** (fig. 15), most of which are common perspectives used in urban, architectural, and railway station design.

As part of the built environment, station areas can be seen as function versus form, as the mass versus the void (space) (Rossi et al., 1982; Trancik, 1986), as constellations of mobility nodes (including railway platforms, bus stops, tram stops, bike parking, car parking, and so on) (van der Spek, 2003); Space users in station areas move along various paths generating pedestrian flow; Additionally, to be demand-responsive, station areas should also support leisure events during non-peak times when they are not used for transportation.

3.2.3 Other perspectives to view the design principles

The design principles can be viewed from more perspectives (fig. 16): From the problem-solving perspective – addressing **overcrowding and emptiness** – some principles address the former, some address the latter, and some address both. From a **spatial versus managerial** perspective, some principles are purely about spatial interventions, while others require managerial interventions; In this sense, principles can also be seen as **fixed and semi-flexible**.

The principles can also be seen as related to **different event types** (see *Supplementary Materials*, fig. 53). For instance, if there are **large** events (e.g., mass gatherings and concerts), then design principles **Adaptive redundant spaces with path regulation (11)** and **Human-oriented spaces (7)** should be adopted to reserve large open spaces that are event-supportive; While if the stations are designed in a scattered layout (to **Vibrate city environment by scattered mobility nodes (5)**), then possibly only **small** events can be held in station areas.

The design principles can be viewed as rules of **elements and layouts** (Liu, 2020); However, elements and layouts are actually similar unless a certain scale is chosen to analyze them. In the aforementioned network (fig. 15), the layout on a smaller level, can be the element on a higher level (e.g., **City passages (20)** can be parts of **City axes (25)**). In fact, just like a layout, an element ‘is itself entirely a pattern of relationships’ (Alexander, 1979, p. 89); it defines relationships between different entities, possibly on different scalar levels (e.g., Tunnels can be called ‘city passages’ only when they link different city areas, otherwise they are just meaningless floating cuboid geometries).

Still, more perspectives can be developed as long as they make sense to readers of this paper who want to use the design principles. For example: 1) naming a perspective ‘practice paradigms,’ as in planning practice, there has been a paradigm shift from **car-oriented to human-oriented** (Bertolini, 2020), and two of our design principles (Principles **Suitable general layouts of the station and city (2)**, **Human-oriented spaces (7)**) are related to these paradigms. 2) Naming a perspective ‘**Bottleneck-related**,’ as several design principles (Principles **Set apart bottlenecks (19)**, **Reduce barriers to ease flow (22 & 23)**) deal with the bottlenecks in the flow & paths. 3) Naming a perspective ‘**Passage types**,’ as passages can be of different types according to the entities they connect, such as connecting city areas to city areas, city areas to stations, or inner station areas to inner station areas.

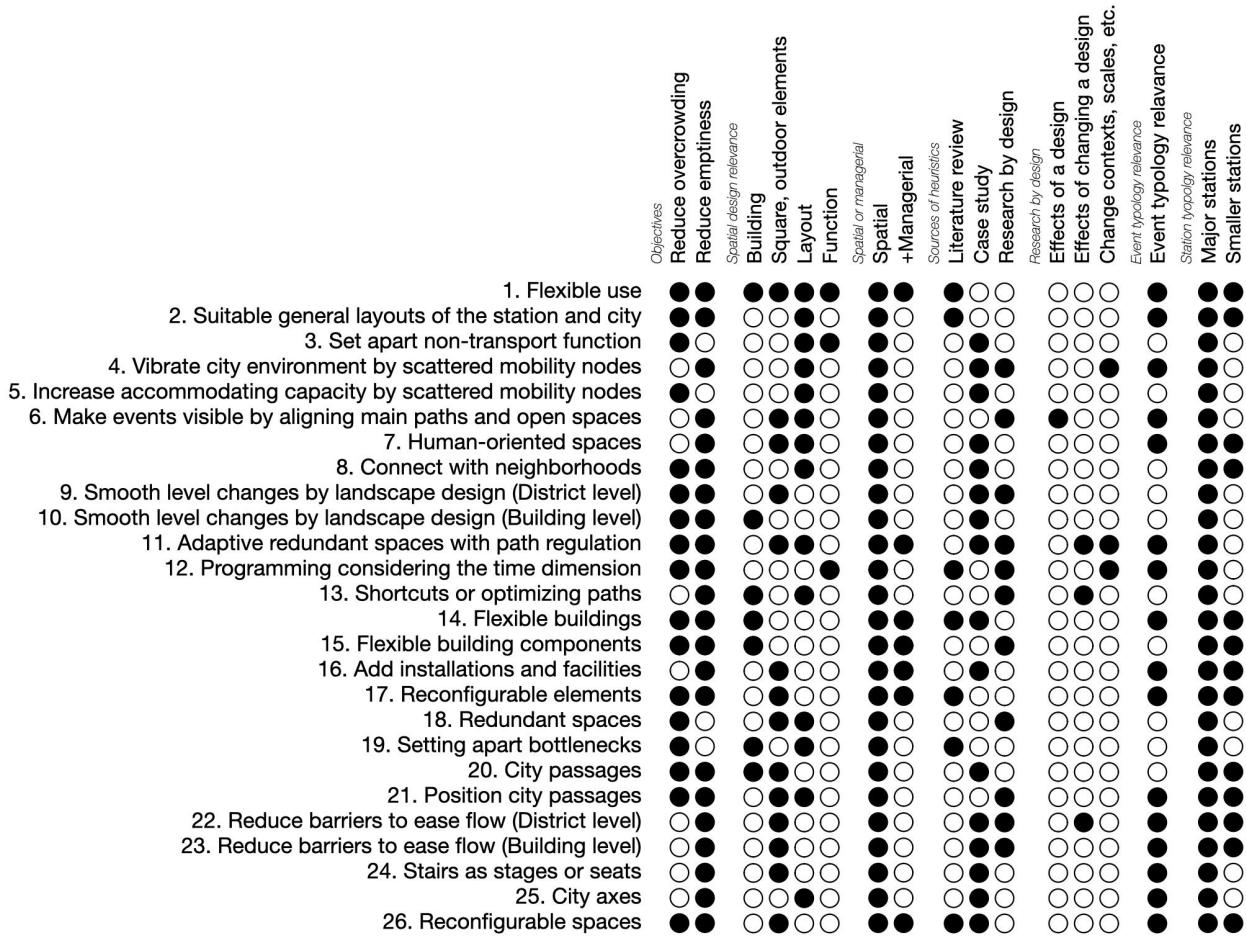


Figure 16: The design principles viewed from different perspectives. (Image source: by authors)

In summary, with the above multiple perspectives, designers can view the design principles and relate them using various logic; and researchers/designers can develop new principles following the same ways of thinking.

3.3 Design principles

In this section, we present each design principle in the form of **Context-Problems(/Potentials)-Solutions-Examples-Limitations(/Reflections)** whenever possible. All the principles are aimed at addressing the general overcrowding and/or emptiness problems, in the context of demand-responsive and station-city integration, as described in chapter 1 [Introduction](#). Some individual principles may aim at their own problems and contexts, which are detailed in the relevant description texts when necessary. Real-world examples are provided when available. For validation purposes, each principle is reviewed by field experts during expert interviews, and the comments are incorporated into the relevant description texts.

(1) Flexible use

Stations can suffer from fluctuations of use, including overcrowding during peak times and emptiness during non-peak times (See [1 Introduction](#)); Flexible use is a **solution** that deals with the overcrowding and emptiness (fig. 17).

Two types of spaces can be flexibly used, including 1) stations' own spaces and 2) city neighborhoods' spaces near the stations. In ideal scenarios, during stations' peak times or emergent times, redundant spaces are flexibly used for accommodating passengers; during non-peak times, redundant spaces are flexibly used for city leisure activities or events (such as open markets, outdoor music festivals, and carnivals).

Stations need to [Connect with neighborhoods \(8\)](#), so that spaces of both cities' spaces can be flexibly used by stations accommodating peak-time passengers. For non-peak-time leisure use, it is necessary to further [Reduce barriers to ease flow \(22\) & \(23\)](#), provide [Human-oriented spaces](#), with leisure events and [Make events visible by aligning main paths and open spaces \(6\)](#). Station areas need to also to be [Programmed considering the time dimension \(12\)](#) for flexible use of

spaces. Stations can even be designed as **Flexible buildings or building components (14) & (15)**, to have a responsive capacity for accommodating the peak time passengers.

In many **examples**, railway stations are flexibly used to facilitate city events or nearby stadiums, such as the Rotterdam Stadion Station (for Feyenoord Stadium), Victoria Station Manchester (for AO Arena), Zandvoort Station (for Formula 1 car racing events), Bijlmer Arena (for multiple nearby venues including Johan Cruyff Arena and Ziggo Dome).



Figure 17: Paris Beaches ('Paris Plages' in French) - Roads in Paris are flexibly used as beaches in the summer. (Image source: stadsstrand.nl)

'Flexible use' intrinsically incorporates the 'time dimension,' while some similar terms do not necessarily incorporate it. To better emphasize the time dimension nature, terms like 'flexible,' 'temporary,' 'reconfigurable,' 'adaptive,' and 'changeable' are more appropriate than terms like 'mixed-use,' 'multi-functional,' 'all-in-one,' and 'sharing.' Because the latter can mean something has multiple functions working at the same time, not necessarily at different times. In the practice of urban planning and metro station development, similar to 'flexible use,' the concept 'mixed-use' ([Rowley, 1996](#)) has long been promoted. But 'mixed-use' is not evident to readers as relates to time, even though a few scholars also incorporate the time dimension [Hoppenbrouwer and Louw \(2005\)](#) as the fourth dimension, beyond the 3D physical spatial dimensions, into the 'mixed-used' definition.

Flexible sharing with neighborhoods at least has two positive implications: 1. Given the same investment, station-city will have larger capacities. 2. Given the same capacities, smaller spaces are needed, which means less investment and less redundant space (and hence less emptiness during non-peak times).

Flexible use also has its **limitations**, as it can potentially add to the management efforts for stakeholders of stations and cities (e.g., see the chaos in Bijlmer Arena station when the management capacity is surpassed ([Aseniya, 2019](#))), and as it can exacerbate overcrowding and emptiness if time dimension is not considered.

(2) Suitable general layouts of the station and city

Stations and cities can be seen as being composed of different elements, such as the mass (buildings), the void (spaces), the facilities, the points of interest, and so on. Stations and cities have their own elements. These elements can be arranged in a suitable general layout (as a **solution**) to make the spatial allocation more understandable and rational. In different layouts, stations' and cities' elements can be 1) separated; 2) connected - e.g., Rotterdam Central Station and Utrecht Central Station, where stations [Connect with neighborhoods \(8\)](#) through [City axes \(25\)](#), and [\(20\) City passages and their positioning](#); 3) adjacent; 4) inserted; 5) stacked - e.g., Montparnasse Station, upon which are apartment and offices buildings, and rooftop parks; 6) mixed - e.g., Shibuya Station and Shinjuku Station, where stations' spaces and cities' spaces are inseparable (fig. 18) ([Shikata et al., 2013](#); [Qi and Lu, 2019](#); [De Wilde, 2006](#)).

Whether separating or mixing stations' and cities' elements depends on the specific project **contexts**. For example, mixing station transport function with city non-transport functions can intensify land use, increase commercial revenue, vibrate the spaces, and so on. However, this also potentially causes conflicting use between the stations and cities, and between passengers and non-passengers. Therefore, sometimes it is necessary to [Set apart non-transport function \(3\)](#).

These general layouts can be applied on different spatial scales. For example, at the district level, a whole station area can be viewed as a layout of station elements (e.g., station buildings and station squares) and city elements (e.g., city commercial districts, community buildings, and parks). At the building level, a station hall can be viewed as a layout of station elements (e.g., gated transfer areas, queuing areas, and waiting spaces) and city elements (e.g., coffee shops and souvenir stores). Applying these layouts will be helpful as long as the layouts facilitate designers' or stakeholders' understanding of the spatial configurations of station areas/buildings/elements.

These layouts have their **limitations** as 1) they can be meaningless or merely abstract concepts if they are not related to the actual functioning of the stations' cities' components, and 2) sometimes defining stations and city elements is hard work itself due to the elements having no clearly identifiable boundaries or having [Flexible use \(1\)](#).

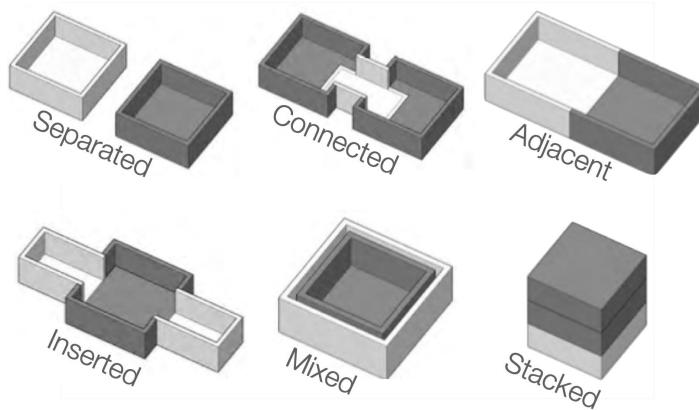


Figure 18: Different general layouts of the station and city. (Image source: [\(Qi and Lu, 2019\)](#)

(3) Set apart non-transport function

Setting apart the non-transport function (from the stations' function) is one option among several [Suitable general layouts of the station and city \(2\)](#). In the station-city integration practice and the related popular topic of transit-oriented development (TOD), mixed-use is a fundamental principle. However, mixing stations and cities, if not properly done, can make the station buildings unrecognizable and can result in conflicts between passenger flow and non-passenger flow. In this situation, setting apart the non-transport function becomes a **solution**.

Utrecht Central Station is one representative **example** of setting apart the non-transport function. Before the latest redevelopment, the Utrecht Central Station building was highly mixed with the adjacent Hoog Catharijne shopping mall building. This mixture raised complaints from passengers as the station building was unrecognizable, passengers felt lost once they got off the train arriving in this area, and the passage across the station building was always overcrowded with passengers and city users. During the latest development, a well-designed east plaza is added, separating the station building from the shopping mall building (fig. 19), endowing the station with a clear image identity.

As a design principle, setting apart the non-transport function has its **limitations**. The distinction between the separation of and mixing of stations and cities can be ambiguous, so the success of applying this design principle still depends much on the designers' experience.



Figure 19: The east plaza at Utrecht Stations separates the station building from the shopping mall. (Image source: [Santenco.nl](#))

(4) & (5) Vibrate city environment or increase accommodating capacity by scattered mobility nodes

A layout of scattered mobility nodes is useful in two **situations**. First, it lets railway passengers, who are potential customers of city stores, go through city districts so that the city environment will be vibrant. Secondly, it increases the accommodating capacity of the station during peak times. This is because passengers are more evenly dispersed to multiple sites instead of concentrating on a limited site, which reduces the probability of overcrowding or even stampedes. Scattered layouts can be applied at the district level or the building level (figs. 20, 21). For **example**, at the building level, Shanghai railway station has a layout of scattered mobility sites.

Scattered layouts have **limitations** as more mobility sites result in 1) harder wayfinding and 2) harder transferring between mobility sites. (Therefore, if a station has a light transfer load between different mobilities, it is fine to use a scattered layout of mobility nodes, While if it has a heavy transfer load between different mobilities, it is more appropriate to use a concentrated layout).

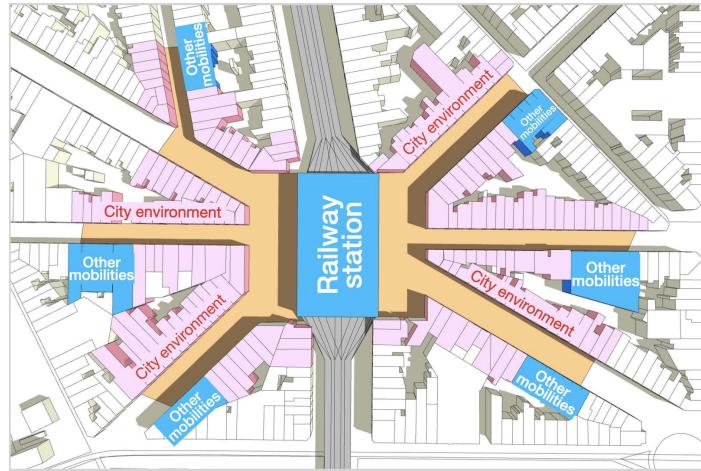


Figure 20: Vibrate city environment by scattered mobility nodes (at the district level)

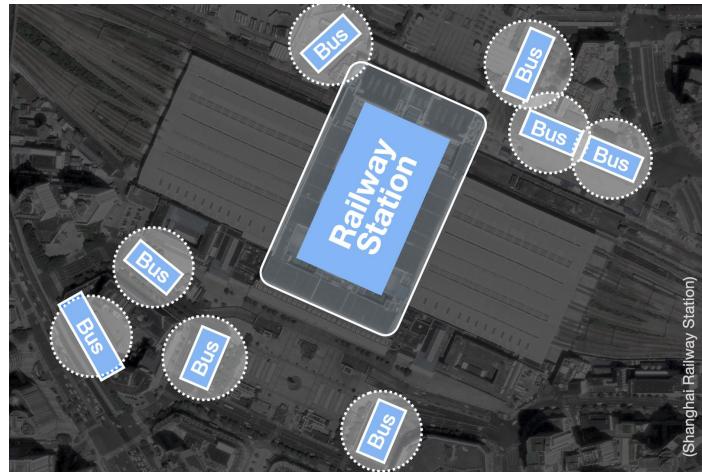


Figure 21: Increase transport capacity by scattered mobility nodes (at the building level)

(6) Make events visible by aligning main paths and open spaces

If a station suffers from emptiness, to vibrant the environment and reduce emptiness, leisure events can be organized; But not every space is supportive of leisure events. If events happen in some places that are invisible to pedestrians (e.g., due to level changes, street-level sight lines are blocked) or away from the main path, it will be hard for events to attract enough people, and therefore, the empty station spaces remain empty. In fig. 22, if events are held in both stations, the environment in the right scenario (a hypothetical scenario based on Rotterdam Central Station) will be energized significantly while the environment in the left (a hypothetical scenario based on Beijing West Railway Station) will not.

(Solution) The alignment between open spaces and event-goers' (leisure users') paths should be well-designed to make events visible or even accessible (for pedestrians to participate) - depending on the event types. In the design stage, designers can either align spaces with paths or vice versa, aligning pedestrians' paths with spaces.

Many different types of events can be held in station areas. For example, open markets, outdoor music festivals, carnivals, and so on. Besides these larger events, leisure activities can be seen as small-scale events. Events' visibility can be enhanced by using [Stairs as stages or seats \(24\)](#). Event-supportive spaces are usually [Human-oriented spaces \(7\)](#) that support [Flexible use \(1\)](#). The paths that event-goers (leisure users) are willing to walk through should be considered in a large network of paths, which can consist of [Connections with neighborhoods \(8\)](#) that [\(22 23\) Reduced barriers to ease flow](#), and [City passages and their positioning \(20\) & \(21\)](#).

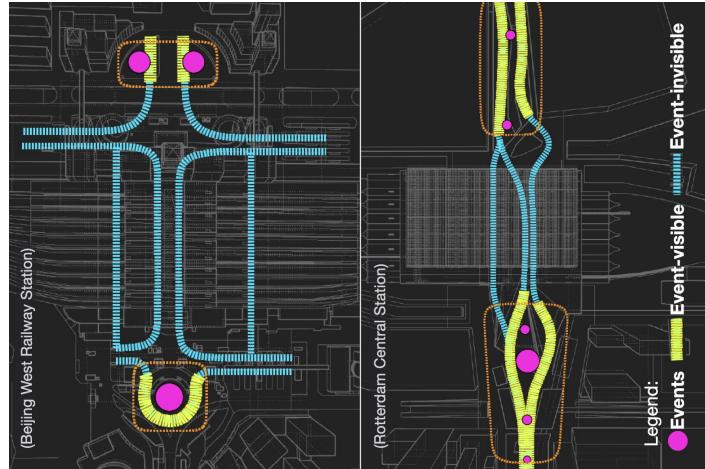


Figure 22: Alignment between open spaces and main paths. (Image source: by authors)

(7) Human-oriented spaces

It is debatable if station areas should prioritize human uses, as stations are fundamental transportation infrastructures, and hence, people would think of stations as primarily for vehicles. This debate exists in the urban planning field for the general urban environment and for other transport infrastructures, including streets ([Bertolini, 2020](#)).

In the past decades, there has been a paradigm shift from car-oriented to human-oriented planning; and for the design of railway station areas, at least in two **situations**, human-centered spaces should be a priority: 1) When station areas are shared with the cities and used by non-transport users (see principle [Flexible use \(1\)](#)), or 2) when it is necessary to organize leisure events to reduce space emptiness (see chapter [1 Introduction](#)).

To support city non-transport use or leisure events, station spaces should be attractive. However, the human experience is often neglected in the design of some stations, where **problematic** features make them unattractive to people, for example, 1) traffic elements dominating the spaces in railway station areas; 2) open spaces surrounded by traffic roads; and 3) station buildings and spaces being monolithic, which makes them visually boring and physically hard for people to move on foot for the long distance between facilities.

Human-oriented spaces, as a **solution** to achieve the above aims and avoid problematical features, should have good spatial qualities that enhance the human experience, as many as possible. Whether certain qualities are good usually depends on different cultural contexts, project contexts, different users with different evolving demands, and so on. It is impossible to exhaustively define all the qualities, which is perhaps why Alexander calls such qualities the 'quality without a name' ([Alexander, 1979](#)). Nevertheless, in the urban design field, scholars have explicated some common qualities (with spatial features), for instance: human scale; enclosed spaces with well-defined boundaries ([Sitte, 1889](#)); positive edges that promote social activities, urban life ([Gehl, 1987](#); [Whyte, 2001](#)), and recognition/identity of different areas ([Jacobs, 1961](#); [Lynch, 1960](#)); complexity/diversity of visual elements ([Ewing and Handy, 2009](#)).

Besides space qualities, spatial layouts also matter for human experience. In fig. 23-left, we try to illustrate some essential features of a human-centered space regarding the layout: it should be a coherent space at a core position in the station areas or the station buildings, free from traffic elements and intensive pass-by transport flow, so that people would like to stay. In contrast, the layout in Fig. 23-right does not have these features.

A significant **example** is the station plaza of the new Rotterdam Central Station, as against the old one (fig. 24). In the old scenario, the core area was occupied by transport elements, including trams, buses, car parking, and a metro station entrance building; Walkable spaces are located around this core area; Hardly any area is possible for people to stay. In the new scenario, the core area is designed for humans; Metro entrances, tram platforms, and bus stations are

moved aside; Car parking is located underground. During large events such as the Rotterdam Summer Carnival, the new station plaza is used without inference to the normal functioning of the station's transport operations. While in the old scenario, assuming there would have been an event, the old plaza was hardly possible to use unless all the transport elements stopped functioning.

Addressing high fluctuations of use towards demand-responsive station areas, human-oriented spaces can be supplemented with several smaller design principles, including [Smooth level changes by landscape design \(9\)](#), [Redundant spaces with path regulation \(11\)](#), [Add installations and facilities \(16\)](#) and [Reconfigurable elements or spaces \(17\) & \(26\)](#).

Human-oriented spaces can also support larger design principles such as [City axes \(25\)](#). In the Utrecht Central Station area, several well-designed outdoor (human-oriented) spaces were added along the city axis across the station, making the axis like a 'pearl necklace' ([de Vos and Mollenhorst](#)).

Human-oriented spaces have limitations as it may take 1) a higher cost to create such spaces and 2) certain good qualities in one case may not necessarily be good in another case.

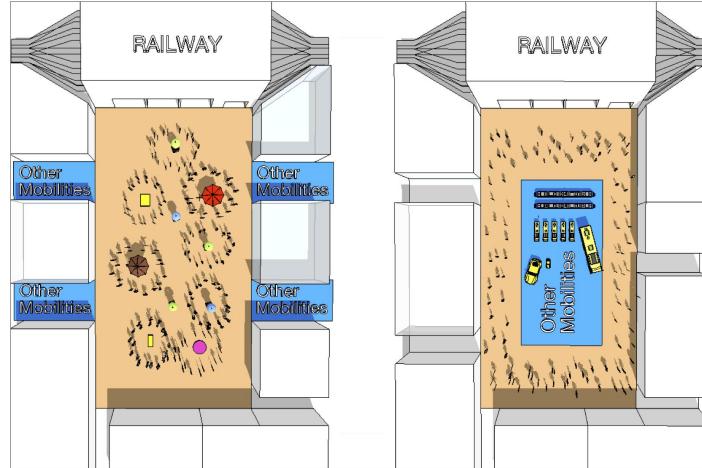


Figure 23: Human-oriented spaces versus vehicle-oriented spaces. (Image source: by authors)



Figure 24: The old and the new Rotterdam central stations. (Image source: Upper-left - [Wikimedia.org](#); Upper-right - [Internaathetposthuis.nl](#); Lower-left - [Indebuurt.nl](#); Lower-right - [MVSA Architects](#))

(8) Connect with neighborhoods

If a station suffers from overcrowding during peak or emergent times, it would be helpful to temporarily use the neighborhoods' spaces to accommodate stations' strained passengers (This can be seen as [Flexible use \(1\)](#) of spaces). In this [context](#), the station should first connect with its city neighborhoods (fig. 25).

The connections/linkages between a station and its city neighborhoods can be pedestrian paths, footbridges/skywalks, tunnels, and so on. Typically, these connections are smaller parts of longer paths, which often cause sudden

changes/variations in the width of the paths, and it is necessary to ensure that they are not bottlenecks that hinder pedestrian flow (Rzezonka et al., 2021). The connections should have enough capacity for passengers to pass during peak times. The connections can basically serve for pass-through usage, and passengers can use these connections when they have to (during peak times). Whereas more preferably, the connections can be designed in a pleasant way that **Reduce barriers to ease flow (P22)** (Unless the stations do NOT want attractive non-transport city users). Within the full pedestrian paths in which stations and city neighborhoods are connected, **City passages and their positioning (20) & (21)** can also be considered to promote pedestrian movement.



Figure 25: Connect with neighborhoods. (Image source: by authors)

(9) & (10) Smooth level changes by landscape design

Level changes are common in station areas due to many station buildings being multi-floor, or having topographic variations in the surrounding landscape. Using stairs naturally becomes a common approach for level changes (see also design principle **Stairs as stages or seats (24)** can also be considered). However, walking on stairs is not a smooth experience - it requires careful attention from pedestrians in case of falling down, and it is even more dangerous during overcrowding. To further advance **Human-oriented spaces (7)**, alternatives are needed.

As a **solution**, using landscape design (figs. 26, 27) helps to smooth the level changes, as compared to stairs. It would be useful, especially in flow-intensive areas, to prevent pedestrians from falling down. Landscape design can be applied at the district level (e.g., see fig. 26, the plaza in the early design proposal of Jiaxing Railway Station, China, by MAD Architects) or at the building level (e.g., the sloping floor in the station hall of Rotterdam Central Station and the spiral floor in Arnhem Central Station). When applied at the building level, it can sometimes bring fresh spatial experience (like in the Arnhem Central Station case, fig. 27).

Landscape design smoothing level change has **limitations** as it can be expensive, especially at the building level. (The design of buildings like Arnhem Central Station is usually related to the so-called 'parametric design,' which requires computer algorithms dealing with complex geometries with many engineering challenges). Simply using escalators could be a cheaper alternative. Landscape design smoothing level change may also cause confusion in wayfinding for people who are not familiar with such level-changing environments.



Figure 26: Smooth level changes by landscape design at the district level. (Image source: [ThePaper.cn](#))



Figure 27: Smooth level changes by landscape design at the building level. (Image source: [UNStudio.com](#))

(11) Adaptive redundant spaces with path regulation

Adaptive redundant spaces with path regulation should be used if a station has the following **dilemma**: 1) The station has **Redundant spaces or setting apart bottlenecks (18 19)** to reduce overcrowding during peak times; But 2) during non-peak times, the added long transfer distance by redundant spaces annoys passengers. Regulating paths **solves** the above peak-time redundancy and non-peak-time transfer efficiency dilemma. It is similar to **Shortcuts or optimizing paths (P13)**.

During peak times, it is a common practice to regulate the path by fences or lines (fig. 28) to ensure pedestrians move in an orderly queue, which prevents pedestrians from concentrating randomly, leading to stampedes. Instead of being regulated by fences or lines, which are quite intrusive elements, paths can also be regulated by more user-friendly, even interactive design elements, such as urban furniture, water bodies, fountains, potted plants, art installations, stalls, and so on (They are also **Reconfigurable elements (17)**) (fig. 29). To further satisfy the waiting passengers in the regulated zigzag paths, it is beneficial to create a pleasant environment of staying, compensating for the longer waiting time than usual.

During non-peak times, the path-regulating elements can be removed to let pedestrians move freely. **Human-oriented spaces (7)** is a prerequisite for redundant space to be adaptively used during non-peak times.

Path regulation has its **limitations** as it can easily raise complaints from passengers or nearby citizens; therefore, it should be used sparingly with strong necessity. In Chinese station cases, path regulations (using fences) are more commonly seen during peak times. In Dutch cases, it is less common.

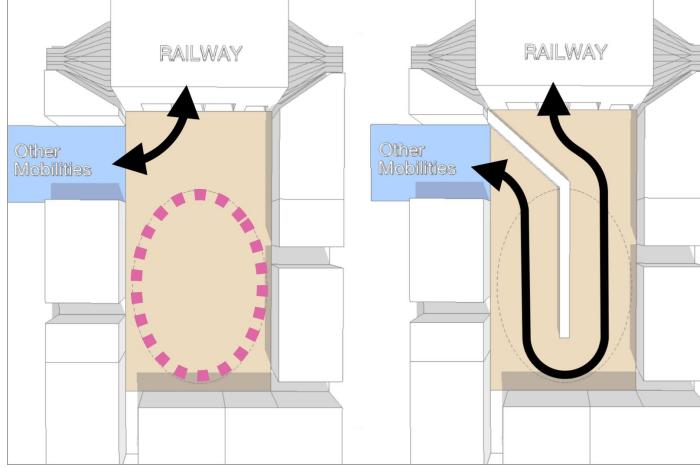


Figure 28: Adaptive redundant spaces with path regulation. (Image source: by authors)

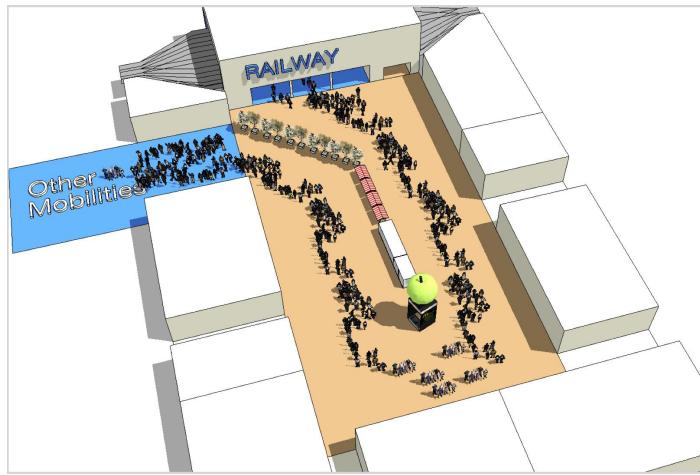


Figure 29: Path regulation using reconfigurable elements. (Image source: by authors)

(12) Programming considering the time dimension

To reduce overcrowding and emptiness in stations, **Flexible use (1)** is needed, and one planning strategy (**solution**) is programming station areas considering the time dimension (fig. 30).

City spaces and infrastructure can be programmed next to railway stations to promote flexible use. For example, Green parks and pedestrian-friendly streets, if located next to stations, can be temporarily restrictedly used by stations exclusively - for accommodating waiting passengers during railway peak times or for evacuation during emergent times. Similarly, large infrastructures such as sports stadiums and music venues, since they are usually not used on a daily basis, can be shared with stations for railway peak time use. In an **example** case of Guangzhou, China, multiple sports stadiums were planned for backup use of railway stations if any emergency occurred during Chinese New Year times ([Agency, 2016](#)). This makes sense in this culture, as during the Chinese New Year, there are surges of railway passengers ([McCarthy, 2018](#)) who want to go to their hometowns for family gatherings, while at the same time, sports stadiums are mostly empty.

During non-peak times, the city spaces and infrastructures can be used as normal for their original non-transport leisure activities. Or, they can even take advantage of the railway as a more sustainable means of transportation ([Newman and Kenworthy, 1999](#)). For example, in Amsterdam, the Netherlands, several stadiums are planned next to Bijlmer Arena railway station, promoting the use of the railway.

Programming has its **limitations**, especially for events with frequency from multi-weekly to yearly (which are our focuses in this research). We rarely saw programming strategies for this kind of event. In contrast, for more frequent events with a frequency between daily to weekly, such as commuting (which is an issue more for metro stations instead of railway stations), there are common programming strategies that have long been established, for instance, mixing housing/hospitality with offices.

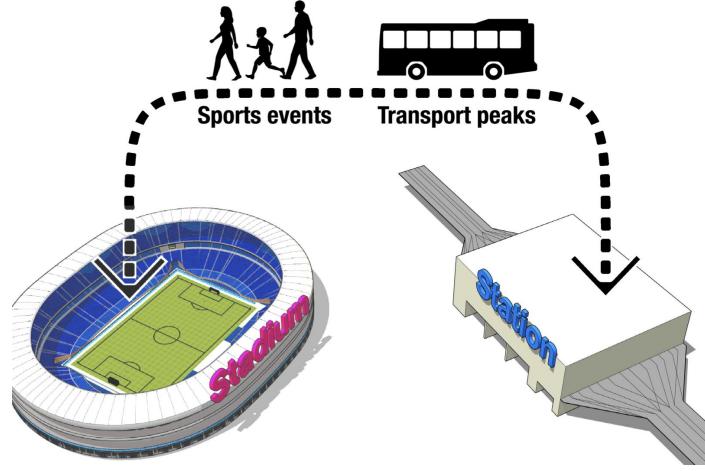


Figure 30: Programming considering the time dimension (for flexible use). (Image source: by authors)

(13) Shortcuts or optimizing paths

In some stations, the transfer between certain mobilities can be effect-consuming due to lengthy paths and procedures. For instance, at Beijing West Railway Station, if a passenger comes out of the metro and wants to go to the railway, he needs to check out from the metro, walk along the lengthy paths with level changes, and then check in at the railway with a strict security check and ticket check (fig. 31). (**Solutions**) If there are shortcuts - direct links between the metro and the railway - in the paths (fig. 31), the passenger can save transfer distance and be relieved from double security checks (He already had a security check when he entered the metro system). This kind of shortcut, linking the metro and railway directly, has been realized at Beijing South Railway Station, which is a counterpart of the Beijing West Railway.

Shortcuts in paths are similar to [Path regulation for adaptive redundant spaces](#). Their difference (in this research) is that shortcuts are more for (indoor) buildings, and path regulation is more for outdoor spaces (fig. 15).

From a temporary perspective, the shortcuts can be applied during non-peak times for shorter transfer distances, while shut down during peak times for safety (as a lengthy path has more redundant spaces to accommodate strained passengers, preventing overcrowding).

Adding shortcuts has **limitations** as it means adding extra ingress/egress paths, in which extra electronic systems are needed, increasing costs for railway companies. It also adds more complexity for the system and for the users. The well-designed [Human-oriented spaces \(7\)](#) along the normal paths will be missed if passengers choose the shortcuts over the normal paths.

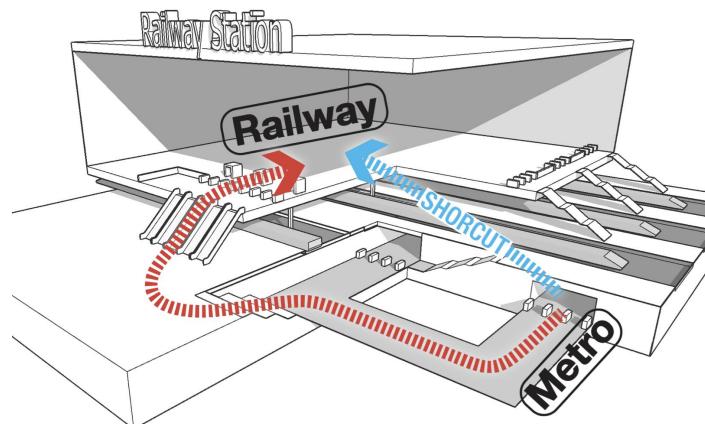


Figure 31: Shortcuts or optimizing paths. (Image source: by authors)

(14) & (15) Flexible buildings or building components

If a station has huge fluctuations of use, to support [Flexible use \(1\)](#), they can be designed as a flexible building or a building with some flexible components (figs. 32, 33). Besides 'flexible buildings' ([Geraedts, 2008](#)), various types of

buildings titled with concepts enable a certain degree of flexibility. These concepts include ‘changeable,’ ‘movable,’ or ‘temporary buildings,’ ‘multi-functional’ (in temporal dimension), ‘reconfigurable,’ ‘kinetic’ ([Parametric Architecture, 2024](#)), and so on. These buildings have the flexibility either by changing their use (functions) or their existence (assemblage) during different times.

Although architects have long proposed flexible buildings or even flexible cities ([Parametric Architecture, 2024](#)), real-world-built examples are rare due to the high cost and maintenance (**Limitation**). A few (non-station) **examples** include 1) The Shed, which has a movable hall as an event venue; and 2) Stadium 974, which is a stadium made of containers and can be assembled and shipped (see also the design proposal by [Smith \(2023\)](#)). For station cases, there are examples such as 3) temporary station buildings during the construction of the main new station buildings (e.g., in the Rotterdam Central Station case). In Shanghai South Railway Station and Beijing West Stations, many redundant checking machines are allocated in the gate areas, which can be used during peak times for higher capacity.

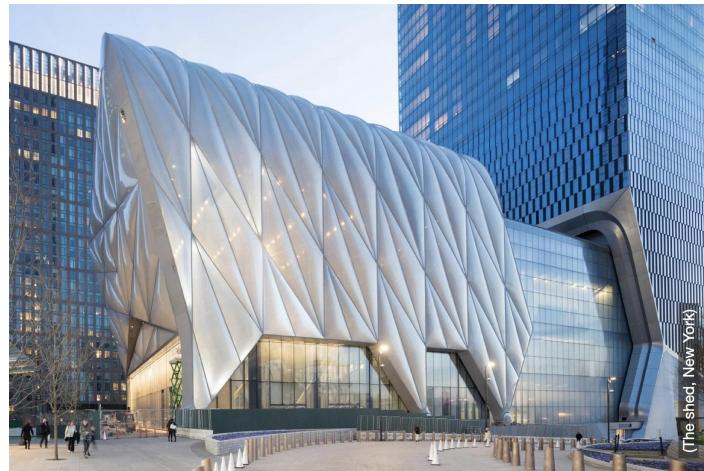


Figure 32: A changeable building - the Shed. (Image source: [Architecturaldigest.com](#))

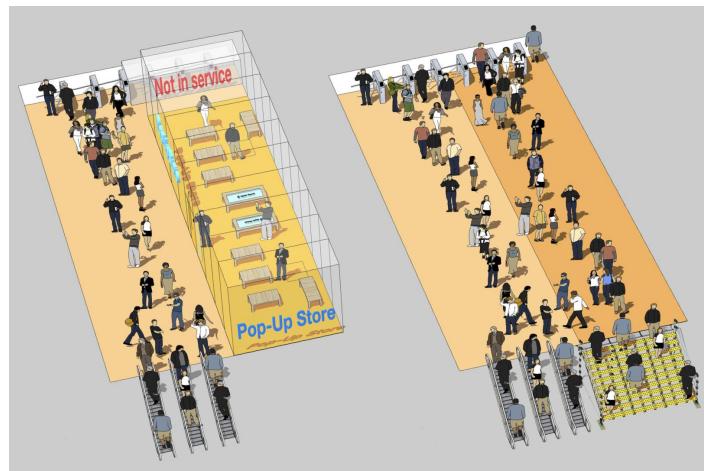


Figure 33: Changeable building components. (Image source: by authors)

(16) Add installations and facilities

If a station’s spaces are huge and boring and the station suffers from emptiness during non-peak times, then it is necessary to convert the spaces into **human-oriented spaces**, where installations and facilities (fig. 34) can be added (**solution**).

Installations and facilities can 1) stimulate events, 2) reduce the size of huge empty spaces to make them more human-scale, and 3) make the scenes visually diversified (i.e., complexity). Installations can be interactive (e.g., ferris wheels) or just visually interesting (e.g., big inflatable art installations ([Ivers, 2018](#))). Installations and facilities can also be **Reconfigurable elements (17)**.

Examples of installations can be found at various stations. For instance, at Antwerpen Central Station, a Ferris wheel is occasionally set up in the front square. Similarly, Rotterdam Central Station frequently features different art installations, both in the front square and inside the station hall.

If the installations and facilities are not attractive by themselves, then they can deteriorate the space quality (**Limitations**). For instance, in the Antwerpen Central Station case, when the ferris wheel is installed, the corresponding facilities, such as ticket-selling points, can make the square messy. On the street level, pedestrians' views are much blocked by these facilities, and the beautiful facade of the station is less visible to pedestrians. Similarly, on the South Square of Beijing West Railway Station, many staircases, soldier standing points, the roofs of sunken atriums, police car parking points, and so on, also block pedestrians' views.



Figure 34: Add installations and facilities. (Image source: [Flickr.com](#))

(17) & (26) Reconfigurable elements or spaces

Reconfigurable elements or spaces can be used for several **purposes**: 1) to vibrate the environment if station spaces are empty during non-peak times; 2) to [Regulate path \(17\)](#) during peak times; 3) to further develop [Human-oriented spaces \(7\)](#), making these spaces more diverse with elements; and 4) to make [Installations and facilities \(16\)](#) more flexible. Reconfigurable spaces or elements are similar to [Flexible buildings or building components \(14\) & \(15\)](#); Their difference is that the former is about outdoor spaces, and the latter is about (indoor) buildings.

Reconfigurable elements can be reconfigured into different layouts for different use scenarios. This reconfiguration can be implemented either by event organizers or by users through spontaneous activities (e.g., people who use urban furniture will move the furniture by themselves). Reconfigurable elements can be urban furniture (fig. 35), potted plants, art installations, stalls, and so on ([Ivers, 2018](#)).

Reconfigurable spaces, which may be filled with reconfigurable elements, can be used as venues for different events/activities (fig. 36). For **example**, Bryant Park in New York is constantly reconfigured as a music venue, tennis courts, a grassland, and an ice skating rink ([Ivers, 2018](#)). Delft Market Plaza is reconfigured for various markets, open-air concerts, amusement parks, and so on.



Figure 35: Reconfigurable elements. (Image source: ([Ivers, 2018](#)))



Figure 36: Reconfigurable spaces. (Image source: [Shutterstock.com](#))

(18) & (19) Redundant spaces (at the district level) or setting apart bottlenecks (at the building level)

In station areas, pedestrians move between different mobility sites, from origins to destinations, and possibly through some bottlenecks (Section 1.1.1). If the station has surges of passengers during peak times; and if mobility sites or bottlenecks are too close, then the strained passengers will quickly add up to overcrowding. In this **context**, it is necessary to add redundant spaces or, equivalently, set apart bottlenecks ([Hoogendoorn and Daamen, 2004](#)) (between origins to destinations, between different mobility sites, or between bottlenecks) (figs. 37, 38).

Redundant spaces reduce overcrowding in two ways: Firstly, redundant spaces are extra spaces that accommodate strained pedestrians. Secondly, redundant spaces make pedestrians walk longer, and since different people walk at different speeds, the surges/peaks of pedestrians at the origins will be smoothed when the pedestrians arrive at their destinations (fig. 39). Redundant spaces can be set at the district level or at the building level. One **example** of redundant spaces being used is the Allianz Arena Munich. From the nearest train station to the stadium, it takes over 1km distance to walk. The massive space in between is redundant space that can accommodate a large number of people.

Redundant spaces have several **limitations**. Firstly, despite redundant spaces being necessary for safety concerns (i.e., to prevent overcrowding) during peak times, the long distances added by the redundant spaces can be unacceptable for passengers during non-peak times. In this situation, temporary **Shortcuts or optimizing paths (P13)**, should be adopted, or make the spaces as **Adaptive redundant spaces with path regulation (11)**. Secondly, overcrowding (or the more extreme - stampedes) is a tricky issue that is associated with many causes that are not yet fully understood by existing scientific research ([de Almeida and von Schreeb, 2019](#)). Redundant spaces may not fully function if the crowd of people, due to crowd psychology, still concentrates in front of the destination areas (despite there being redundant spaces outside destination areas) ([Jin et al., 2020](#)). In this situation, on-site management regulations are still needed to disperse people more evenly across the spaces.

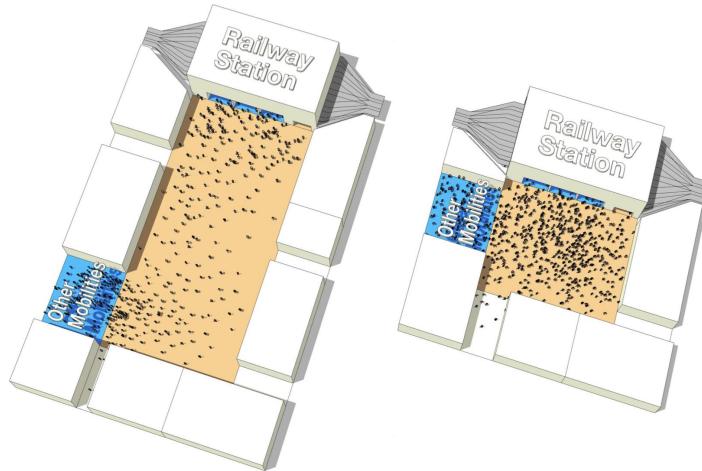


Figure 37: Redundant spaces at the district level. (Image source: by authors)

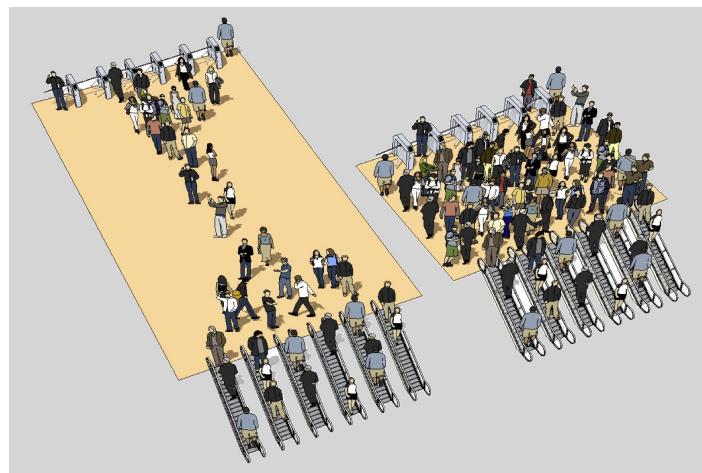


Figure 38: Setting apart bottlenecks at the building level. (Image source: by authors. Inspired by the research conclusion in ([Hoogendoorn and Daamen, 2004](#)))

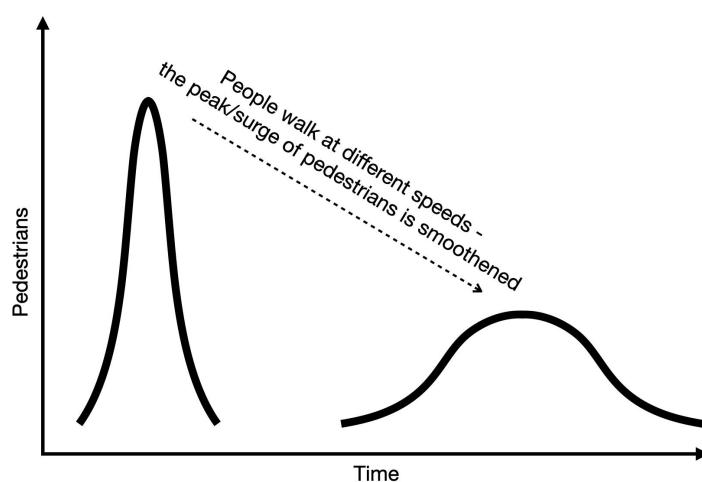


Figure 39: The peak of pedestrians is smoothed since people walk at different speeds. (Image source: by authors)

(20) & (21) City passages and their positioning

It is common for railway tracks to cut city areas apart. It is necessary 1) to enable passengers to easily move from one side of the station to the other side of the station during their transfer, and 2) to enable city users to pass through the station areas so the areas will be vibrant. In this context, well-designed/planned city passages and their positioning become **solutions**. If stations are already [Connected with neighborhoods \(8\)](#), the city passages across railway tracks will also help to form larger coherent pedestrian paths at the district level, or [City axes \(25\)](#) on an even larger scale.

At the district level, city passages across railway tracks should be positioned according to the city's neighborhood conditions (fig. [40](#)). City passages may link the most dense neighborhoods/communities/city areas to maximize their usage. City passages should avoid bringing interference between transport passengers and city leisure users. If the passages are mainly for leisure users to pass by, then their positions should avoid areas where passengers intensively move. If the passages are mainly for transport passengers, their position should avoid areas where leisure users would stay or gather. If there are areas reserved for leisure events, to make events more visible or even interactive for pedestrians, the paths should be aligned close to these areas (see principle [Make events visible by aligning main paths and open spaces \(6\)](#)).

At the building level, city passages can be designed with fine details, with enough lighting, and not too dark to make people feel unsafe (fig. [41](#)). Beyond city passages that link different city areas across railway tracks (city-to-city), there can be other types of passages that link station to city and station inner areas to station inner areas (e.g., the internal footbridge on platforms at the Railway Central Station). These passages also provide convenient movement and ease transfer. Passages are common in Dutch railway stations, for **example**, Amsterdam Central Station, Utrecht Central Station, and Rotterdam Central Station.

The more passages, the more choices for pedestrians to pass through, but it takes financial cost to build passages (**Limitations**). In addition, for large railway stations at the building level, it is often quite difficult to vertically arrange the passages with many other elements, including railway platforms, the ground, and stations' internal passages.

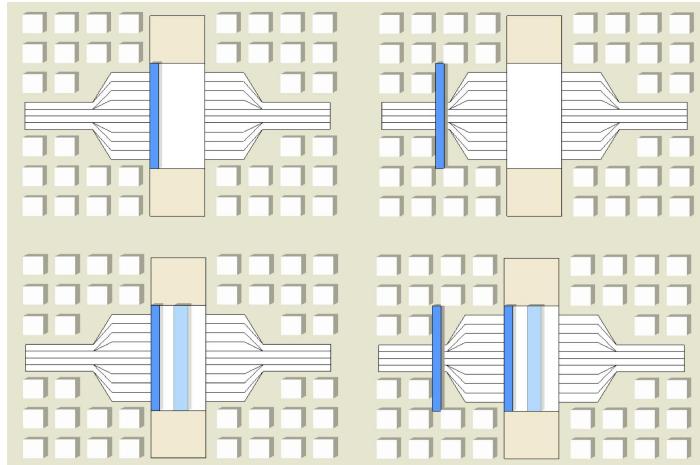


Figure 40: Position city passages (at the district level). (Image source: by authors)



Figure 41: The city passages (at the building level). (Image source: Amsterdam-viptours.com)

(22) & (23) Reduce barriers to ease flow

Barriers to flow should be reduced, especially in the following **contexts**: 1) When stations suffer from emptiness, there is a need to promote the flow of people (leisure users from the city neighborhoods), letting them use the redundant station spaces for public life, leisure activities, events, and so on. 2) When **City axes (25)** (in which the stations are located) are planned to promote the flow. 3) When stations are already **Connected with city neighborhoods (8)**, but due to the connections' qualities being poor, only passengers driven by strong motives would pass through the connections, while leisure users are not willing to use the connections.

Problematic barriers of flow are usually in the following forms with respective reasons: 1) Stairs as barriers. Pedestrians need to make efforts to overcome level changes, and much attention is needed to walk on the steps in case of falling down; 2) Lengthy, narrow, and boring paths; 3) Tunnels, skywalks/footbridges - Pedestrians need to make efforts to overcome level changes - Pedestrians would rather walk on the ground if possible. Tunnels are usually quite dark, making pedestrians feel unsafe. Skywalks/footbridges are unpleasant to walk on if they are non-weather-protected, without shading from trees or building canopies; 4) Walking areas that are interfered with by intensive vehicle traffic - Pedestrians feel unsafe to walk through, and much attention is needed to prevent being hit by a car; 5) Strict security checking points (Common in Chinese stations) - Too much effort is needed to pass through them; and 6) Ticket gates - They make gated areas inaccessible for people without tickets. Barriers can lead to commercial stores in station areas being shut down during non-peak times, since city leisure users, as potential customers, are not willing to overcome barriers to explore the stores.

Various interventions can be taken to reduce barriers to ease flow at the district level (fig. 42) or at the building level (fig. 43), depending on the barrier types. Firstly, use ground-level paths as much as possible, to avoid level changes, and to continue the street-level qualities of the overall environment. Secondly, **Smooth level changes by landscape design (9) & (10)**. (This is particularly useful with small level changes; For large level changes, using escalators is usually more appropriate). Thirdly, for lengthy boring paths, design them like **Human-oriented spaces (7)**, make them more pleasant with leisure facilities, otherwise use **Shortcuts or optimizing paths (P13)**. Fourthly, if footbridges/skywalks are adopted, create street-like qualities, such as weather-protected shading and convenience facilities. Fifthly, separate traffic roads from pedestrian paths, e.g., horizontally make alignment between the pedestrian flow and traffic flow to avoid overlapping, or vertically submerging traffic roads underground or elevating traffic roads. Sixthly, security checks and ticket gates are primarily management issues. For spatial design considerations, possibly **Shortcuts or optimizing paths (P13)** can help. Lastly, consider **City passages and their positioning (20) & (21)** if station areas are cut apart by railway tracks.

If barriers are reduced, the flow of leisure users should not cause severe interference to passenger flow. In addition, every measure has a (financial) cost (**Limitation**), reducing barriers should bring larger benefits than costs.

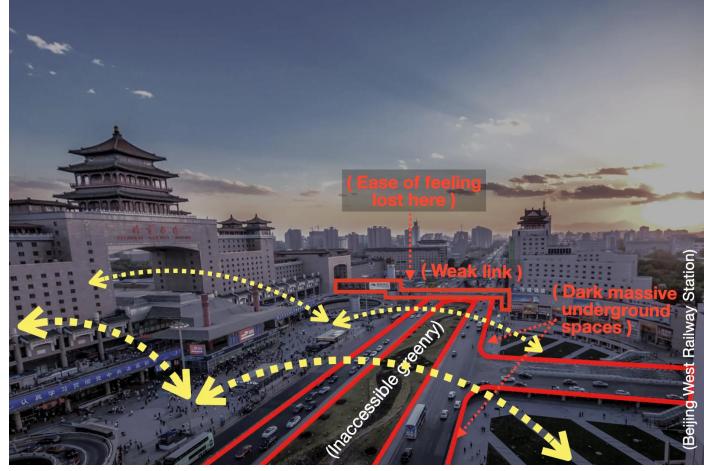


Figure 42: Reduce barriers to ease flow at the district level. (Image source: Drawn by authors; Background image source: Meipian.cn)

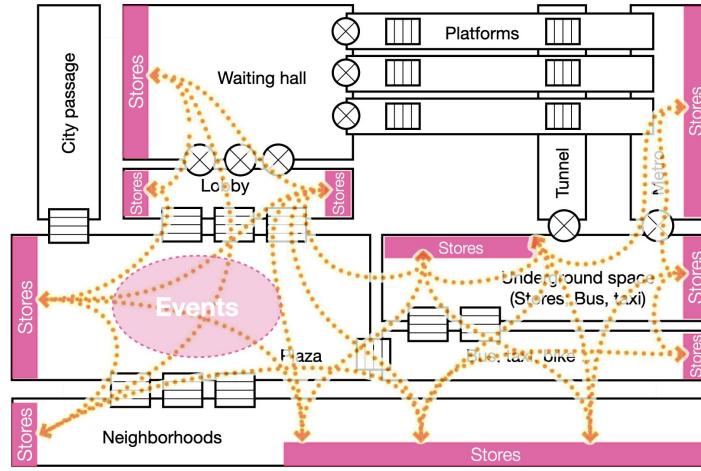


Figure 43: Reduce barriers to ease flow at the building level. (Image source: by authors)

(24) Stairs as stages or seats

Stairs are common building components that primarily address level changes, and some stairs also serve for symbolic functions, as to elevate buildings (or building entrances) to make the buildings look more grand (e.g., the [Spanish Steps](#)).

Typically, in station areas, stairs should be avoided as much as possible because they hinder the flow of pedestrians and may even result in people falling down. This issue is especially problematic if the flow passing the stairs is intensive. To address small level changes, instead of using stairs, it is better to [Smooth level changes by landscape design \(9\)](#) & [\(10\)](#). To address large level changes, instead of using stairs, it is better to use escalators. Given the same width, escalators have a larger capacity than stairs, and escalators, if not running, can still be used as stairs ([Fruin, 1971](#)).

However, in some situations, large stairs still exist in station areas, such as those designed as backups of escalators for evacuations - like the grand stairs at the west of Utrecht Central Station. Or, stairs just happen to exist in the station areas - like the grand stairs of the Cologne Cathedral in front of the Cologne Central Station, and the indoor stairs in the hall of Antwerpen Central Station.

If grand stairs exist, and if leisure events are expected as a measure to reduce emptiness, then the grand stairs can be designed as potential performance stages or audience seats (**Solution**). Using stairs takes advantage of the level change to leverage the see-and-be-seen relationship between audiences and performers (see also Principle [Make events visible by aligning main paths and open spaces \(6\)](#)). Such usage has been seen in various real-world **examples**, such as the grand stairs at the west side of Utrecht Central Station used during open-air exhibitions (fig. 44), [the grand stairs in the hall of Antwerpen Central Station used for music festivals](#), and the grand stairs in front of Cologne Central Station used as stages for demonstrations. Of notice, grand stairs should be **limitedly** used as they are typically unfavorable elements in the station areas, as mentioned in the beginning of this section. Moreover, even if stairs are indeed used for

events, the frequency of use is still questionable.



Figure 44: Stairs as stages or seats. (Image source: [Architectenweb.nl](#))

(25) City axes

If station areas suffer from emptiness, city axes, which are a common planning strategy in urban planning and urban design fields, can be used. City axes help to emphasize the connections, concentrate the flow of leisure users, and energize the environment. City axes also make the spatial structure of certain areas recognizable to decision-makers, thereby also promoting collaborations for different stakeholders to align the important spaces and facilities, for creating memorable experiences for users when they move in the environment. City axes have been successfully implemented in (re)development projects of some station areas, for **example**, the Utrecht Central Station area (fig. 45), the Rotterdam Central Station area, and the Delft Station area.

City axes should be supported by smaller design principles to ensure pedestrians can really move within them. These smaller principles include: (stations) [Connect with neighborhoods \(8\)](#), [Reduce barriers to ease flow \(22\) & \(23\)](#), and properly design/plan [City passages and their positioning \(20\) & \(21\)](#).

Moreover, city axes usually should be space-based (e.g., the Paris Historical Axis) instead of building-based (e.g., the axis of the Forbidden City in Beijing). Building-based city axes only work symbolically to demonstrate order, power, or spiritual values, and can hardly contribute to real space usage because people cannot move on the axes ([Limitation](#)).



Figure 45: Two city axes were planned during the redevelopment of the Utrecht Central Station area. (Image source: [Structuurplan, Stationsgebied Utrecht, December 2006](#))

4 Discussion

4.1 Contributions

This paper has two contributions to the design knowledge body: First, **contently**, it provides more than two dozen design principles that facilitate designers to address overcrowding and emptiness issues of station areas. This paper also provides multiple associated perspectives, which can be used to view the principles in different ways, and be used as theoretical lenses to help designers investigate new principles. The research outcome also enriches the content of relevant academic discussions, such as urban open space, responsive landscape, with a 'loose-fit' feature (Thompson, 2002); and traffic space is public space (Bendiks and Degros, 2020).

Second, **methodologically**, this paper provides a seven-step methodological framework, which can be generalized to develop other types of design principles. This methodological framework has its only values as compared to similar frameworks/workflows in literature. For example, compared to Christopher Alexander's way of developing his pattern language - through over eight years of project practice (Alexander, 1977), evaluate principles by feelings - our framework is more practical for much shorter time frames thanks to multiple data sources being used, and produce more objective outcomes thanks to expert reflections. Compared to the way van der Hoeven and Juchnevic (2016) developed their design principles, our framework is a new alternative.

4.2 Non-design interventions

Many purely managerial (non-design) interventions are discovered during the research process. Some of these interventions can be more effective than spatial interventions, some can be more costly, and some can be fantasies at the current time. Providing as a takeaway knowledge, We report the following managerial interventions, which can be used to avoid the peaks of passenger flow, or to avoid overcrowding/stampedes:

Managerial interventions: 1) Reschedule holidays for the public; 2) reduce physical security checks and apply more AI and data technology for pre-assessing passengers. 3) Use city terminals - like those for the airport - to modify the logistics of long-distance travelers' packages and relieve the security checks at the station buildings; 4) manage regional-level transportation (e.g., there is a coordination of scheduling trains between several railway stations in Amsterdam city when there are sports events near Bijlmer Arena station, preventing people from coming to the stations when the station capacity is surpassed); 5) shutdown stations; 6) when organizing city-level events, use multiple scattered event spots - so that there will not be an over-concentration of massive people at one spot during special times such as when it is raining; 7) manage user expectations - notifying passengers that during peak time there will be longer transfer time than usual; 8) in certain railway stations, passengers are restricted from entering the station buildings (so the overcrowding can be prevented) until a specific time before their train's departure. For instance, during our site visits in December 2022 at Beijing West Railway Station, passengers were not permitted to enter the station more than 6 hours prior to their scheduled departure time; at Shanghai Railway Station, this time limit was 2 hours.

4.3 Station typology implied by the cases

Considering that station is the type of building with the most variety (Richards and MacKenzie, 1986, p. 52)), a typology is usually of concern in studies of stations (e.g., see (Peters and Novy, 2012)), and meanwhile, a universal typology is hardly achievable. In this research, we take two factors that are most fluctuation-related for case selection - fluctuation contexts and performance addressing fluctuation (see Section [Cases](#)). With the selected cases' other features listed below, the cases imply a certain station typology. Through these features, we can better tell how generalizable the research outcomes are.

Some features of the selected cases: 1) Continental or national contexts - China and the Netherlands; 2) Size of stations and cities - the selected cases cover small to large cities and stations (fig. 46). Stations' size affects their roles in the cities (Van Acker and Triggianese, 2021), and cities' size affects mobility patterns. Size affects the complexity of stations and the cost of spatial-managerial interventions; 3) Security check - which resulted in barriers and potentials for Chinese stations during fluctuations; 4) Flow pattern - in Chinese stations, the flow of egress and ingress is separated in different paths (like airports), while in Dutch stations, it happens in the same paths; 5) The way public spaces are used - more diverse leisure activities/events happen in Dutch cases than in Chinese cases.

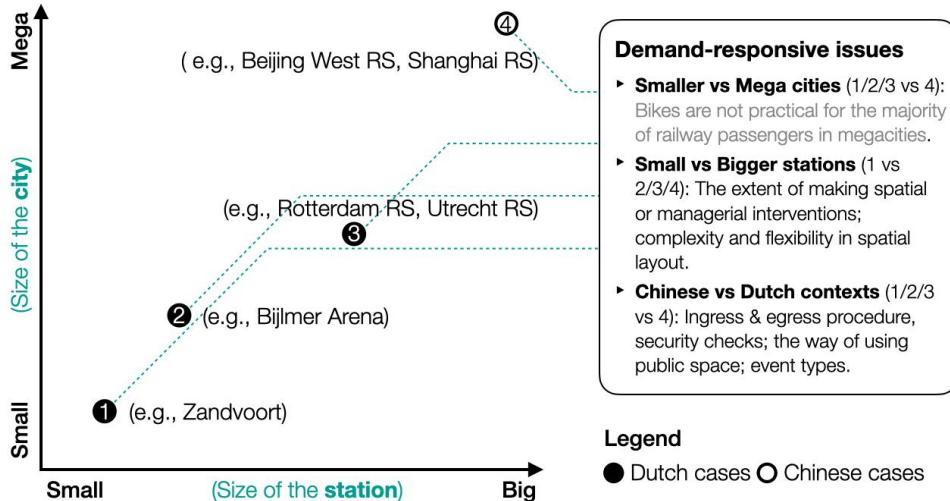


Figure 46: Station typology implied by the cases. (Image source: by authors)

4.4 Limitations and future research directions

This paper exhibits several limitations and future research directions: 1) There can be hidden limitations of some design principles that we do not yet know. 2) With the same selected cases, there are more pairs of comparisons between them, yet not examined by us due to the project's time frame (We documented to what extent we have examined in [Supplementary Materials](#), fig. 51). 3) More cases of different continental and national contexts can be researched in the future.

During our interviews with field experts, they pointed out more limitations and future directions: 1) the design principles in this paper are mostly about the spatial form of districts or buildings, while other things are less investigated: programming, user types, spatial qualities, nature-based solutions, and cost-benefit analysis of solutions.

5 Conclusion

In the introduction, we proposed two research questions: 1) What are the design principles for demand-responsive railway station areas? and 2) What is a practical way to develop design principles?

The first question is answered by the resulting design principles. These design principles are interconnected, covering a wide range of components of the station areas, and can be viewed from various perspectives.

The second question is answered by the seven-step methodology framework for developing design principles. Design principles can be effectively identified through research by design based on multiple data sources.

Supplementary Materials

1. [The detailed descriptions](#) (of the literature, cases, research by design, evaluations, the range of station areas, design principles' relevance with events, and so on).
2. The [interactive website](#) for displaying the design principles from different perspectives (<http://c1309928130.pythonanywhere.com/>)

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