

Supplementary Materials

6.1 Details of the initial paper searching and selection

6.1.1 Enrich the meaning of ‘demand-responsive station areas’ and establish the first theme for literature searching

Since overcrowding and emptiness are very particular issues that are barely addressed by any existing spatial design research, therefore if directly using ‘railway station area’ + ‘demand-responsive’ as the keywords for searching, hardly any relevant papers can be found, and no heuristics can be gained. An enriched meaning of ‘demand-responsive station areas’ is needed to serve as a basis for literature selection. This paper enriches the term’s meaning by reinterpreting the identities of ‘railway station areas’ and the nature of ‘overcrowding’ and ‘emptiness.’

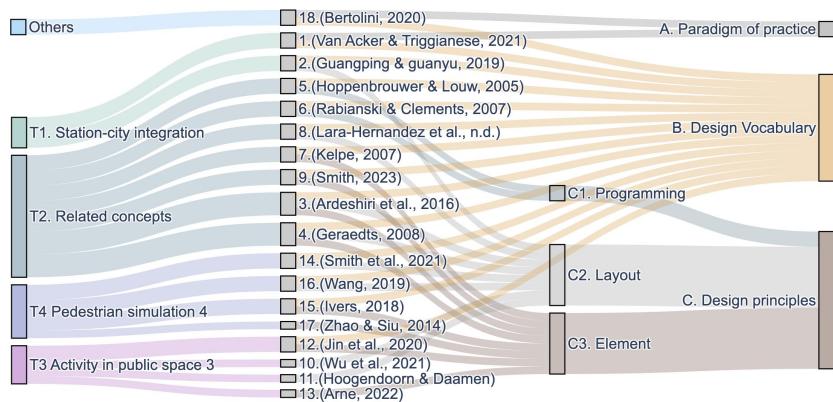
The identities of railway stations: According to [Bertolini and Spit \(1998\)](#), ‘railway stations’ are ‘nodes’ of the transport networks and ‘places’ of the cities, so stations are fundamentally ‘transport infrastructures’ for transportation activities and ‘public spaces’ for other leisure activities.

‘Station areas’ include the ‘station buildings’ and the outdoor ‘spaces,’ therefore, ‘open/urban/public space’ and ‘landscape’ are relevant. ‘Overcrowding’ can be seen as a type of ‘risk’ to the station system, which can be addressed by ‘resilience’ as a quality of the system. ‘Emptiness’ is a lack of use of public spaces, therefore ‘flexible’ use can be helpful. Both ‘resilience’ and ‘flexible’ mean a system that is capable of changing, and similar words can include ‘dynamic,’ ‘adaptive,’ ‘robust,’ ‘moveable,’ ‘reconfigurable,’ ‘multi-functional (in the time dimension),’ ‘temporary,’ ‘kinetic’, and so on. The combination of these concepts facilitates this paper in finding relevant literature (See the main text, Section [2.5.2 Literature](#), the first theme of searching) and cases.

6.1.2 Paper selection criteria

The papers that used as the heuristics for research-by-design meet at least one of the following criteria: 1) The papers are related to design aspects, including design qualities, programming/functions, layouts, spaces, elements, and so on. 2) The papers deal with demands and users in station areas. 3) The papers’ knowledge is preferably applicable on both building and outdoor spaces, otherwise too specific and not generalizable. In paper selection, we excluded plenty of papers that are purely about planning, or managerial solutions, which can hardly be transformed to spatial interventions.

6.1.3 Initial papers selected through each searching strategy and their relevance to the layouts and elements of design principles



6.2 Description of research-by-design

6.2.1 The usefulness of research-by-design

Research by Design (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 also facilitates our investigation of the **effects** of design interventions. It is common for the context and design solutions to be unclear 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.

6.2.2 The validation of the research by design method

To some readers who deal with more science-related and quantitative research, this research by design (RbD) method may raise the concern of bias, but in this paper we argue that it is not an issue. This research is for developing mean-end knowledge for designers; As design-related research, it is not about true or false (and therefore the main quality criteria is not heavily rely on validity, reliability, and generalizability, as in quantitative research ([Leung, 2015](#))), but about useful/practical or not ([Zwart and de Vries, 2016](#); [Nijhuis and Bobbink, 2012](#)).

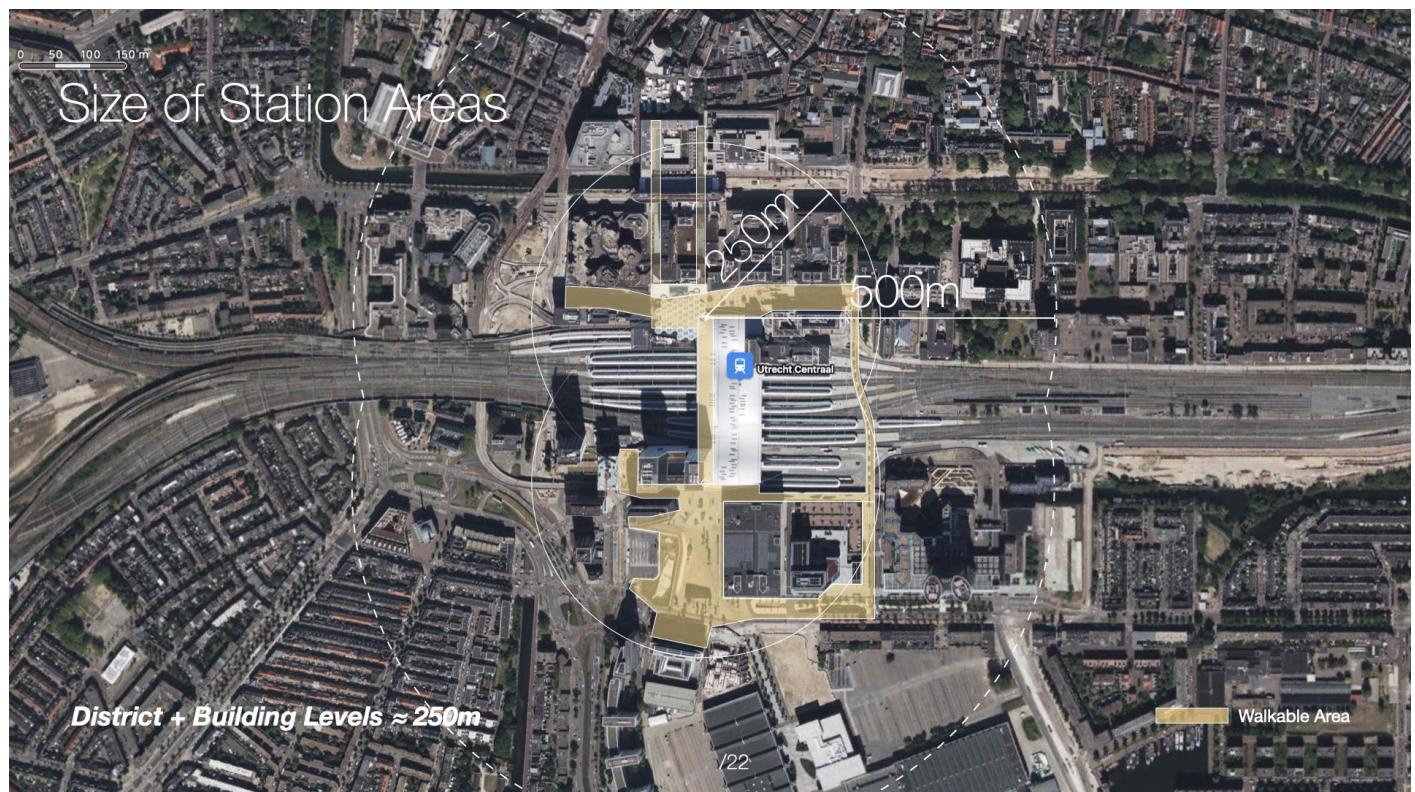
Design iterations seem arbitrary as it can iterates numerous times, while the minimum requirement is to iterate until requirements (design objectives) are met. RbD is useful as long as one effective solution is successfully found.

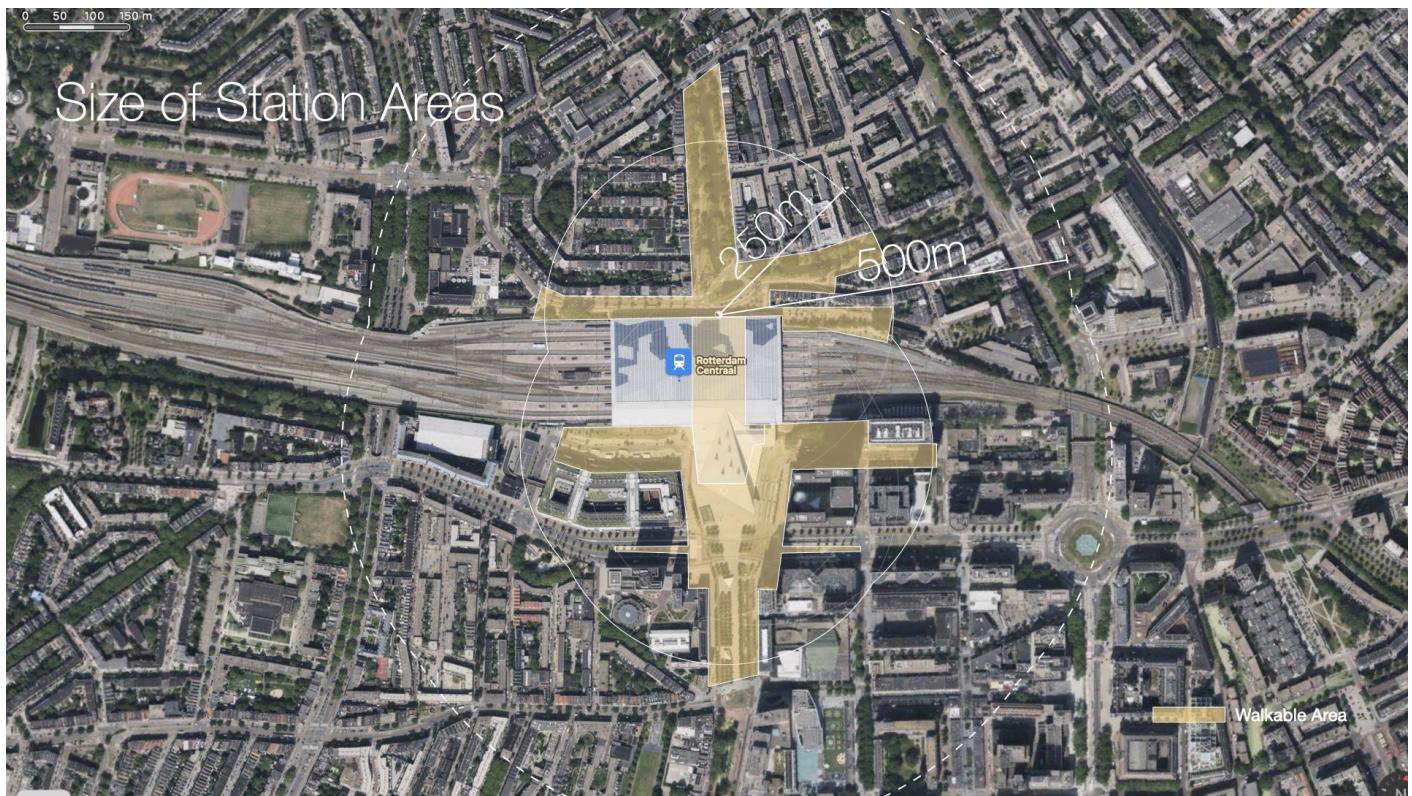
To further make the data processing clear and transparent, we documented the case comparisons we made in detail, so that readers can check to what extent have we explored with the selected cases, and how much still remain unexplored.

We reflected our outcomes internally by checking all the criteria with each principle, and we did expert interviews to further externally reflect on principles’ limitations.

6.3 The diagrams of station areas

As shown in the following diagrams, and the on-site visits, the station areas are hardly perceivable (by vision) outside the 250m range.





6.4 Initial station cases selected

Stations	Size	Demand fluctuation	Performance for fluctuation	Nation
Beijing West RS	Large	Large	Poor	China
Beijing South RS	Large	Large	Poor	China
Shanghai RS	Large	Large	Good	China
Rotterdam Central Station	Large	Middle	Good	The Netherlands
Utrecht Central Station	Large	Middle	Good	The Netherlands
Bijlmer Arena RS	Middle	Large	Good	The Netherlands
Zandvoort Station	Small	Large	Good	The Netherlands

6.6 The table for internal evaluation of design principles

(Internal evaluations of Design Principles)												
Index	Names of Design Principles	Meet Design Objectives?										Have Spatial Relevance ?
		Problem-oriented (Macro-level)				User (Passenger)-based (Micro-level)						
		Reduce Overcrowding ?	Reduce Emptiness ?	Add city value ?	Reduce conflicts of use between the station and the city?	Improve Safety (Overcrowding or Eyes-on-the-Street)	Improve Speed	Improve Ease (of Wayfinding)	Improve Comfort (of Facilities and Weather-Protected areas)	Improve (Visual) Experience		
1	Flexible use	✓#	✓#	✓#	○	✓#	#	#	✓#	✓+	✓ (Programming)	
2	Suitable general layouts of the station and city	✓#	✓#	✓#	✓#	✓#	✓#	✓#	✓#	✓#	✓ (Spatial Layout)	
3	Set apart non-transport function	✓+	○	○	✓+	✓#	○	✓+	○	✓#	✓ (Spatial Layout)	
4	Vibrate city environment by scattered mobility nodes	○	✓+	✓+	○	○	✓-	✓-	○	○	✓ (Spatial Layout)	
5	Increase accommodating capacity by scattering mobility nodes	✓+	○	○	○	✓+	✓-	✓-	○	○	✓ (Spatial Layout)	
6	Make events visible by aligning main paths and open spaces	○	✓+	○	○	○	○	○	○	✓+	✓ (Spatial Layout; Path/Flow)	
7	Human-oriented spaces	○	✓+	○	✓+	○	○	○	○	✓+	✓ (Spatial Layout; Flow)	
8	Connect with neighborhoods	✓#	○	✓#	✓#	✓+	○	○	○	○	✓ (Layout)	
9	Smooth level changes by landscape design (District level)	○	✓+	○	○	○	○	○	○	○	✓ (Spatial Element [District level])	
10	Smooth level changes by landscape design (Building level)	○	✓+	○	○	✓+	○	○	○	○	✓ (Spatial Element [Building level])	
11	Adaptive redundant spaces with path regulation	✓+	✓+	○	○	✓+	✓+	○	○	○	✓ (Spatial Layout; Path/Flow)	
12	Programming considering the time dimension	✓+	✓+	✓+	○	○	○	○	○	○	✓ (Programming)	
13	Shortcuts or optimizing paths	○	○	○	✓+	✓-	✓+	✓-	○	✓-	✓ (Spatial Layout; Path/Flow)	
14	Flexible buildings	✓+	✓+	○	○	○	○	○	○	○	✓ (Spatial Element [District level])	
15	Flexible building components	✓+	✓+	○	○	○	○	○	✓#	✓#	✓ (Spatial Element [Building level])	
16	Add installations and facilities	○	✓+	○	○	○	○	○	✓+	✓+	✓ (Spatial Element)	
17	Reconfigurable elements	○	✓+	○	○	○	○	○	○	○	✓ (Spatial Layout)	
18	Redundant spaces	✓+	✓-	○	○	✓+	✓-	○	○	✓-	✓ ([District level] Spatial Layout)	
19	Set apart bottlenecks	✓+	✓-	○	○	✓+	✓-	○	○	○	✓ ([Building level] Spatial Layout)	
20	City passage	○	✓+	✓+	○	○	✓#	○	○	○	✓ (Spatial Element; Path/Flow)	
21	Position city passages	✓#	✓+	✓+	✓#	○	○	○	○	○	✓ (Spatial Layout; Path/Flow)	
22	Reduce barriers to ease flow (District level)	✓#	✓+	✓+	✓#	○	○	○	✓+	○	✓ ([District level] Spatial Element; Path/Flow)	
23	Reduce barriers to ease flow (Building level)	✓#	✓+	✓+	✓#	○	○	○	✓+	○	✓ ([Building level] Spatial Element; Path/Flow)	
24	Stairs as stages or seats	○	✓+	○	○	○	○	○	○	✓+	✓ (Spatial Element)	
25	City axes	✓#	✓+	✓+	○	○	○	✓+	✓+	○	✓ (Spatial Layout; Path/Flow)	
26	Reconfigurable spaces	○	✓+	○	○	○	○	○	○	✓+	✓ (Spatial Element)	

Legend:	
○	No relevance
✓	Has relevance
✓+	Has relevance, with Positive effects
✓-	Has relevance, with Negative effects
✓#	Has relevance, and the effects depend on the contexts
#	Uncertain

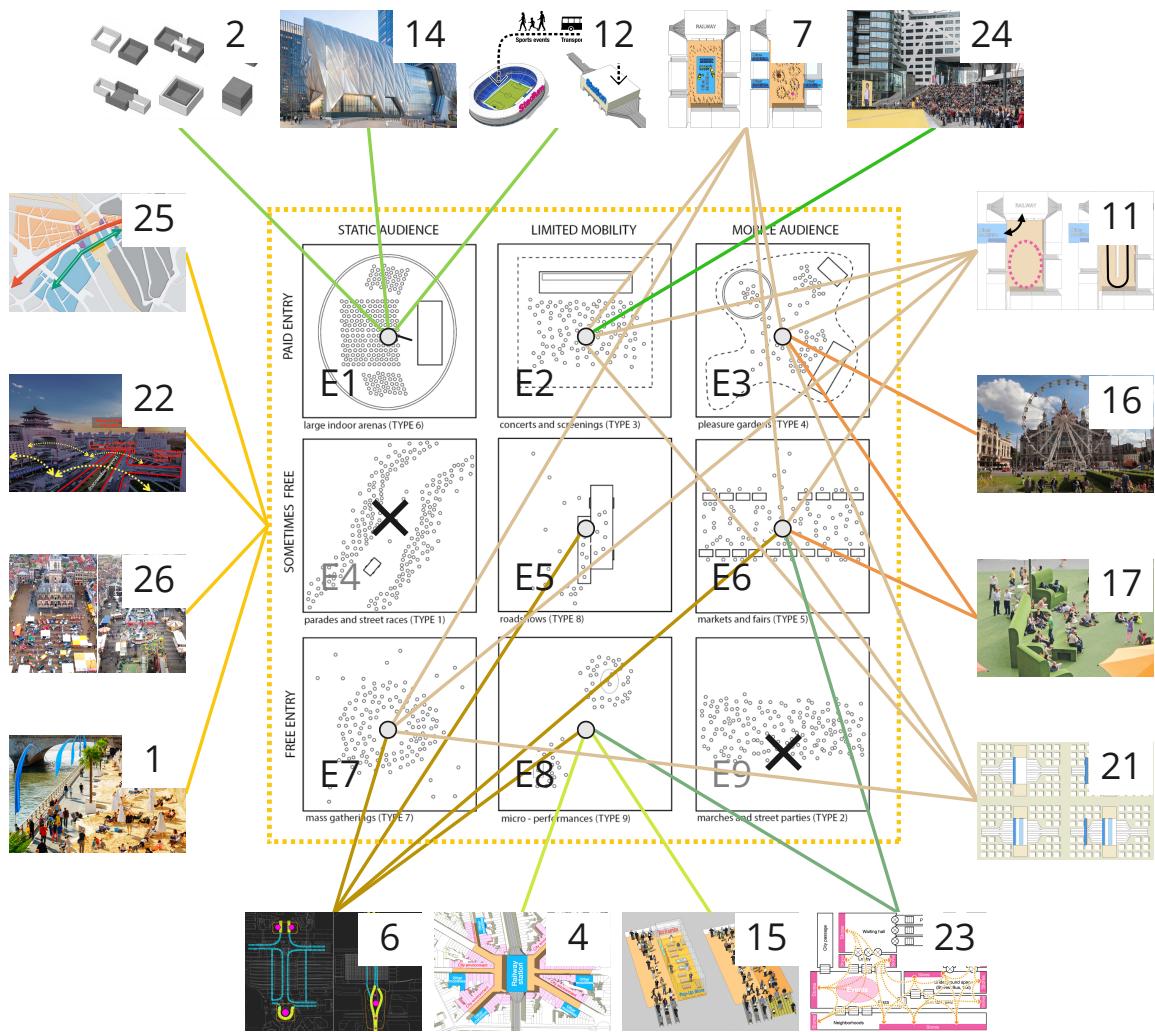
6.7 Relate design principles to an event typology

Events are an important aspect of this research, as they are the causes of fluctuations in station areas and are a solution to solve emptiness. As part of the exploration of design solutions, we investigated the relationship between event types and design principles.

In this research, we adopted an event typology developed by [Smith et al. \(2021\)](#). This typology is framed based on access and mobility, including nine types of events, including E1) large indoor arenas, E2) concerts and screenings, E3) pleasure gardens, E4) parades and street races, E5) roadshows, E6) markets and fairs, E7) mass gatherings, E8) micro-performances, and E9) marches and street parties. Two events - E4 and E9, primarily happen on streets, which are irrelevant for most spaces in railway stations, so we excluded (*) them (fig. 52).

The relationships between event types and design principles, are explained as follows (Note: 'E' stands for Event types, and 'D' stands for Design principles):

- Large open-air events with concentrated distributions, including E2, E3, and E7, need large coherent outdoor spaces and should not block city passages. Therefore, these events have relevance to design principles (DPs) [\(11\) Adaptive redundant spaces with path regulation](#), [\(7\) Human-oriented spaces](#), and [\(21\) City passages' positioning](#). (Links: [E2-D7](#), [E3-D7](#), [E6-D7](#); [E7-D7](#); [E2-D11](#), [E3-D11](#), [E6-D11](#), [E7-D11](#); [E2-D21](#), [E3-D21](#), [E6-D21](#), [E7-D21](#))
- For large events with performances - E2, [\(24\) Stairs as stages or seats](#) can be used. (Link: [E2-D24](#))
- Small spaces are common in a scattered layout ([D4](#)), and small events - E8 can be held in these small spaces. [\(15\) Flexible building components](#) can also be the small spaces to hold small events. (Links: [E8-D4](#), [E8-D15](#))
- For events that require user participation and are open-access, including E7, E5, E6, and E8, it is necessary to [\(6\) Make events visible by aligning main paths and open spaces](#). (Links: [E7-D6](#), [E5-D6](#), [E6-D6](#), [E8-D6](#))
- Small performances and markets can help promote a vibrant environment, and it is a prerequisite to [\(23\) Reduce barriers to ease flow at the building level](#). (Links: [E6-D23](#), [E8-D23](#))
- Large indoor arenas can be [Flexible buildings \(14\)](#). Flexible and Shared use between arenas and stations can be realized if the station areas are [Programmed considering the time dimension](#). The arenas should located in [Suitable general layouts of the station and city \(2\)](#). (Links: [E1-D2](#), [E1-D14](#), [E1-D12](#))
- In events E3 and E6, it is necessary to [\(16\) Add installations and facilities](#), which can be [\(17\) Reconfigurable elements](#). (Links: [E3-D11](#), [E6-D11](#); [E3-D16](#))
- For all possible events happening in railway stations, the event spaces should support flexible use and be configurable, and pedestrians should be able to walk smoothly to the event spots. Therefore, several design principles are relevant, including [\(22\) Reduce barriers to ease flow at the district level](#), [\(25\) City axes](#), [\(1\) Flexible use](#), [\(26\) Reconfigurable spaces](#). (Links: [All-D25](#), [All-D22](#), [All-D26](#), [All-D1](#))



Supplementary Material 2 - Sources of figures

N	Figure and Caption	Source
1	Overtourism and emptiness in railway stations areas.	Left - https://www.163.com/dy/article/DLED9I020524TFU4.html ; Right - https://www.sohu.com/a/386779398_640391
2	A conceptual basic unit of passenger flow.	By authors
3	The mechanism of overtourism and emptiness in Beijing West railway station area.	By authors
4	Spatial relevance shown by an example case of Beijing West Railway Station.	Original photo sources: Left - https://www.meipian.cn/ ; Right - https://upload.wikimedia.org/wikipedia/commons/5/5b/Beijing_West_Railway_Station_20170506_124557.jpg . Drawings by authors
5	Temporal scales.	By authors, inspired by (de Jonge and van der Voordt, 2002, p. 38, fig. 13)
6	Spatial scales of station areas.	By authors
??	Architectural and urban design proposals for Amsterdam Sloterdijk station.	Upper - (Triggiani et al., 2019); Lower - (Andrianos, 2023)
7	This paper is part of a PhD project at the intersection of three topics.	By authors
8	The process of developing design principles.	By authors
9	The station at the district and building levels.	By authors
10	The configuration of the station.	By authors
11	Data sources.	By authors
12	An example of research by design.	By authors
13	Sources of heuristics.	By authors
43	The design principles (patterns) within a network.	By authors
44	The design principles viewed from different perspectives.	By authors
14	Flexible use.	https://www.stadsstrand.nl/paris-plages/
15	Different general layouts of the station and city.	(Qi and Lu, 2019)
16	Set apart non-transport function.	https://www.santenco.nl/portfolio_page/stationsplein-oost/
17	Vibrate city environment by scattered mobility nodes (at the district level).	By authors
18	Increase transport capacity by scattered mobility nodes (at the building level).	By authors
19	Alignment between open spaces and main paths.	By authors
20	Human-oriented spaces versus vehicle-oriented spaces.	By authors
21	The old and the new Rotterdam central stations.	Upper-left - https://commons.wikimedia.org/wiki/File:Nieuw_Centraal_Station_in_Rotterdam_aangetast,_Bestanddeelnr_908-5455.jpg ; Upper-right - https://internaathetposthuis.nl/raldus.html ; Lower-left - https://indebuurt.nl/rotterdam/nieuws/salsa-doe-gbatis-mee-met-deze-gigadans-voor-rotterdam-centraal-311821/ ; Lower-right https://mvsaarchitects.com/en/news/nos-rotterdam-central-receives-a-score-of-8-and-is-the-most-popular-large-train-station/
22	Connect with neighborhoods.	By authors
25	Smooth level changes by landscape design at the district level.	https://m.thepaper.cn/newsDetail_forward_5348462
26	Smooth level changes by landscape design at the building level.	https://www.unstudio.com/en/page/12109/arnhem-central-masterplan
37	Adaptive redundant spaces with path regulation.	By authors
38	Path regulation using reconfigurable elements.	By authors

N	Figure and Caption	Source
27	Programming considering the time dimension (for flexible use).	By authors
28	Shortcuts or optimizing paths.	By authors
29	A changeable building - the Shed.	https://www.architecturaldigest.com/story/the-shed-finally-opens-new-york-city-hudson-yards
30	Changeable building components.	By authors
31	Add installations and facilities.	https://www.flickr.com/photos/87453322@N00/7561351848
32	Reconfigurable elements.	(Ivers, 2018)
33	Reconfigurable spaces.	Left - https://www.shutterstock.com/image-photo/vie-w-delft-market-square-nieuwe-kerk-1206141775 ; Right - https://nl.pinterest.com/pin/546342998538754823/
34	Redundant spaces or setting apart bottlenecks at the district level.	By authors
35	Redundant spaces or setting apart bottlenecks at the building level.	By authors
39	Position city passages (at the district level).	By authors
40	The city passages (at the building level).	https://www.amsterdam-viptours.com/blog/cuypers-passage/
23	Barriers that hinder the flow at the district level.	By authors
24	Reduce barriers to ease flow at the building level.	By authors
41	Stairs as stages or seats.	https://architectenweb.nl/nieuws/artikel.aspx?id=43948
42	Two city axes were planned during the redevelopment of the Utrecht Central Station area.	Structuurplan, Stationsgebied Utrecht, December 2006
45	Station typology implied by the cases.	By authors
47	The Utrecht Central Station area - 250m vs 500m.	By authors
48	The Rotterdam Central Station area - 250m vs 500m	By authors
49	The Beijing West Railway Station area - 250m vs 500m.	By authors
46	The literature selected and the relevance to the research findings.	By authors
50	Examine relevance and compare cases.	By authors
51	The evaluation of design principles.	By authors
52	The design principles related to the event typology.	By authors