Graduation Research Paper
Master of Architecture
Explore Lab

PUBLIC | TRANSPORT

“A research into the double role of the station. How can stations become an integral part of the city?”

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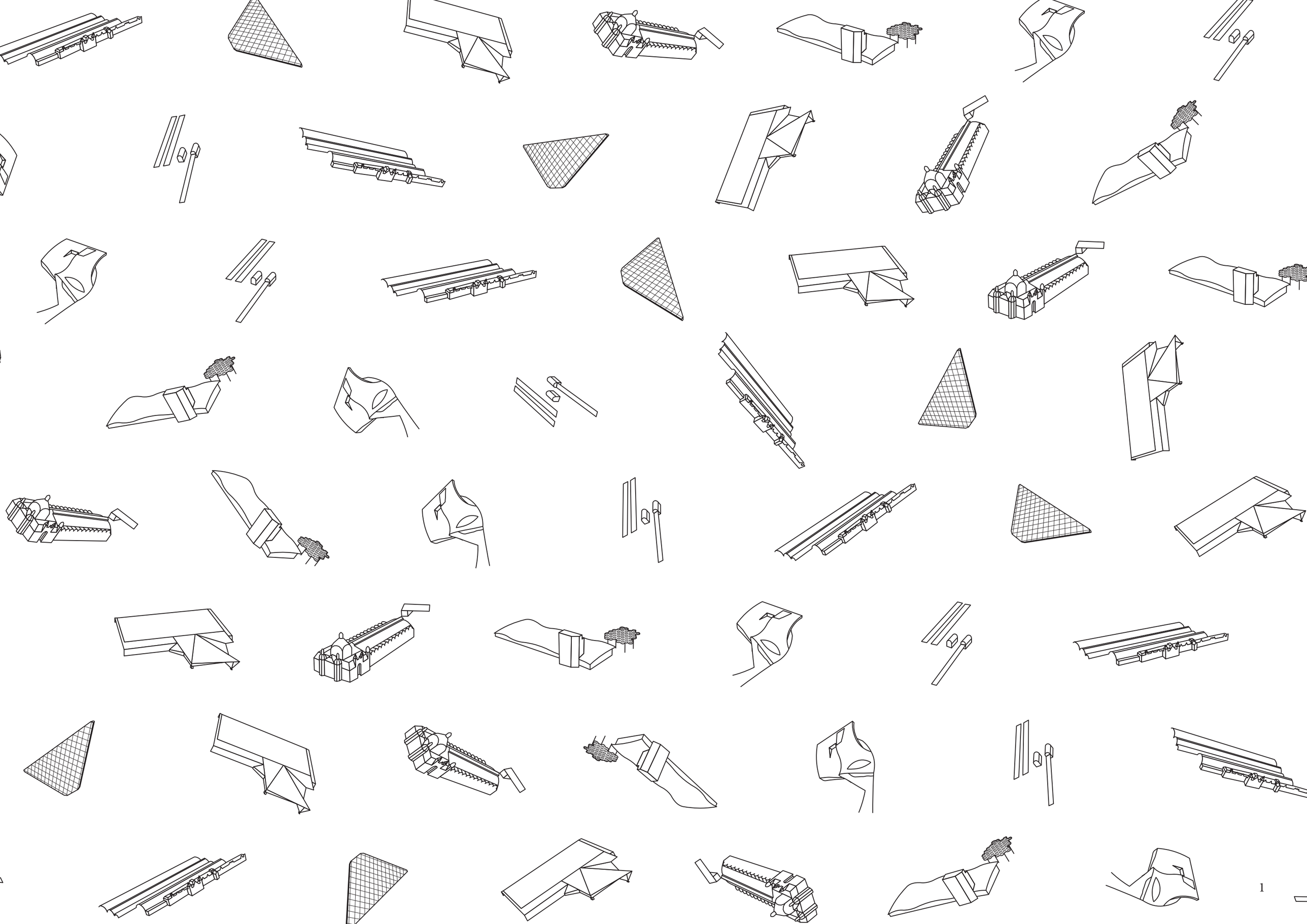
Researcher:
Robin Koelmans
4482557
TU Delft, Arcadis

Research mentor:
Kjai Tjokrokoesoemo
TU Delft, De Zwarte Hond



Key Words
Station design, living station, urban station, station integration, public space, modalities, multimodal hub, public transportation, spatial configuration.

Abstract
Public transportation is on the rise due to increasing ecological concerns, a more efficient use of space and an improved city-planning featuring transport oriented development (TOD). As a result, new modalities emerge and stations are getting busier which can lead to a narrow design focus on the nodal function of the station, neglecting other aspects of the station.

Due to the fact that many stations are located at central locations within cities, they have a strong influence on the quality of city life around them. Traditionally, the station has been seen solely as a node (connecting all the different modalities efficiently; moving people). Nowadays paradoxically, the station is seen increasingly as a place in its own right as well (by being an active part of the city; inviting people to stay). By diminishing the station's barrier-effect and by implementing public functions within the station's realm, the station can be integrated better within its surrounding city, creating an urban station that enhances city life.

The evolving role of the station has been the subject of many recent studies. However, the research mostly remains to be theoretical. More practical design principles and requirements may help in achieving the ambitions regarding creating an integrated urban station. Literary research was performed into the multiple facets of station design, which led to the formulation of six design principles for contemporary urban station design. The main research question is as follows:

"Are the six design principles: multimodality, functional mix, connectivity, spatial quality, visibility & flexibility apt contributors to the integration of an urban multimodal station within its surrounding cityscape?"

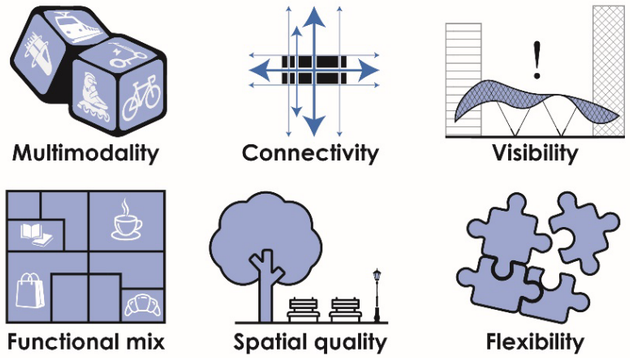
In recent years, many stations have been redesigned with special attention to this node-versus-place-paradox, focusing more on the station as a place. This research aims to analyse seven important international multimodal railway stations in The Netherlands and Belgium to see how these stations handle their complexity and aim to integrate within their surrounding city.

The aim is to test the proposed design principles via the analyses of these seven chosen stations: Amsterdam Centraal, Schiphol Airport, Rotterdam Centraal, Antwerpen Centraal, Utrecht Centraal, Arnhem Centraal and Amsterdam Zuid. The analyses are drawn on Nolli maps, in order to gain insight into the public realm surrounding the station and the connections between the two.

As the results point out, the chosen design principles appear to be fitting for creating a well-integrated urban station. However, six design spaces have been formulated in addition to the design principles, each accompanying respectively one principle. The spaces act as an addition to the programme of requirement as provided by the commissioner, embodying the different design principles into explicitly formulated spaces.

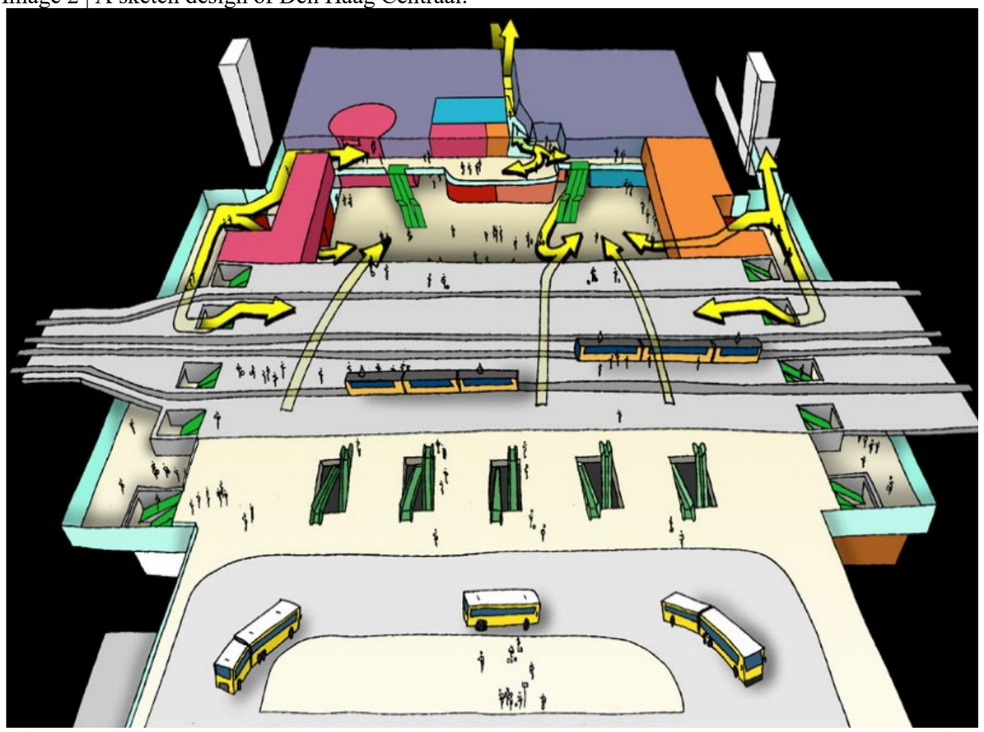
Further research is advisable. Especially multimodal station from France, Germany or England can give crucial new insights as the stations are generally larger and their urban surroundings are often more densely populated. Further research into the airport city concept can also prove worthy, as the development in airports is a few years ahead on the developments around urban stations, airports can provide valuable examples and case studies.

Image 1 | The six proposed design principles:



Own illustration.

Image 2 | A sketch design of Den Haag Centraal:



This image shows anticipated passenger flows in a sketch design for Den Haag Centraal in 1999. In the back, coloured blocks depict shops and restaurants. Both roles of the station come together, but the weight of the drawing still lies at the station as a node.
A courtesy of Benthem Crouwel Architects.

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Image 3 | A render of a potential hyperloop system from Delft Hyperloop:

Retrieved from: EW Magazine, 2022.

Prologue

Before you lies my graduation thesis of the Master of Architecture, that I studied at the Faculty of Architecture and the Built Environment at the TU Delft. I graduated with the studio Explore Lab, in which I had to define my own graduation project. The project I chose was the renovation of Amsterdam Zuid train station, which currently faces major reconstructions in order to triple capacity. I defined a new design for this station and implemented hyperloop as a potential new viable modality for international travel.

Hyperloop (see image 3) could reform European transportation as it could offer a sustainable but fast alternative to flying. Hyperloop exists of an air-tight tube that has a near-vacuum environment within it in order to minimize air resistance. Within this tube, a carriage, or pod, moves without physically touching the tube. Magnets enable the pods to stay in the middle of the tube whereas electromagnetic propulsion enables the pod to accelerate and move through the tube. Due to the lack of physical connections between the pod and the tube, there is no rolling or sliding resistance and due to the low pressure environment inside the tube there is a minimal air resistance, resulting in a highly efficient way of transportation.

A certain system could enable European citizens to travel across the continent on a daily basis, which would result in a highly connected union. Primarily, it is expected that business men and women will want to use this system, because of their tight international relations. However, hyperloop could also enable new flows of tourism and can play a role in connecting academies, healthcare facilities and families & friends throughout Europe.

With many recent technological breakthroughs, hyperloop is getting closer to reality at great speed and this makes it crucial to experiment with designing hyperloop facilities. As most research pertaining to hyperloop covers the technological and physical aspects, there is still a lack of understanding its societal aspects. However, in order to make hyperloop into a success, it is crucial to make it an appealing and comfortable way of travelling. As the research in this paper will point out, travel experience depends on a multitude of factors. By being the interface between society and mobility, a station's design is a crucial part of the travel experience and thus has an unneglectable impact on the success or failure of any hyperloop system.

Amsterdam Zuid is located at the heart of the Dutch biggest international business district: the Zuidas. Because of this, NS, ProRail and the Dutch Ministry of Infrastructure and Water are planning to shift the international train connections from Amsterdam Centraal to Amsterdam Zuid to better facilitate the international business district. Implementing hyperloop would be a next step in sustainably connecting Amsterdam Zuid (and subsequently The Netherlands) to the whole of Europe and strengthening the competitive position of the Zuidas.

As a result, Amsterdam Zuid will become an extremely complex infrastructural node, connecting many different flows of people on a relatively small area. On top of this, the station is located in the middle of the city. So besides the functional and infrastructural challenge, the station also faces spatial and social challenges because it separates, or connects, both sides of the city.

This thesis aims to explore the role of the station in general, analysing both the nodal and the public function of the station. The focus lies on the public function of the station. By being a central part in the city with an unsurpassable connectivity, stations possess a great potential for enhancing city life and therefore have a great societal impact. However, the reality is that many stations create unsafe and low quality (public) places and have a barrier effect towards their surrounding neighbourhoods, as will be elucidated in this thesis.

Therefore, this thesis aims to give six practical design principles that aim to integrate the station within its surrounding cityscape and create a safe, comfortable and attractive public place at the heart of the city. A place where travelling and city life merge. These design principles can be used either when designing a new station, or when redesigning an existing station. I sincerely hope you enjoy reading this thesis and I hope that it brings you new insights. Let's dive in! :)

1. Introduction

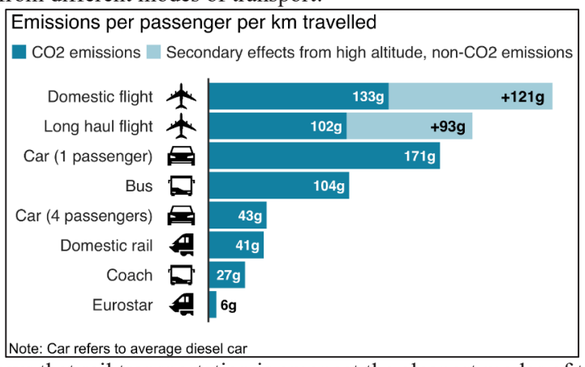
In this introduction, a literary research has been performed. It offers the literary background for the performed analyses later on in this paper. The first section establishes that patronage of public transportation will increase over the coming years due to several reasons. The second section shows that the increase in public transportation usage, may lead to an enhanced focus on the nodal function of the station. The third section will further elaborate on the public function of the station, it will describe the challenges and the role of the station within the city and will feature an inspiring example of the airport city concept. The literary background provided by these three sections, which were the result of the literary research, led to the formulation of six design principles that are believed to be crucial when integrating the station within the city. The research question is presented in the fourth section, aiming at testing the six formulated design principles. Finally, in the fifth section, the structure of the remainder of this paper will be described.

1.1.Increase in public transportation

Due to several factors, an increase in the usage of public transportation is to be expected. In fact, Prorail (2021-III) expects an average increase of 30-40% in domestic train travels in the coming years. The most important reason for this is the growing environmental concern and societal pressure on governments and citizens to decrease their ecological footprint (United Nations, 2015).

The train is among the cleanest modes of transportation, in clear contrast with air traffic, but also cleaner than private car usage (Ministerie van Infrastructuur en Waterstaat, 2010; BBC, 2019: BEIS/ DEFRA, 2019). Image 4 shows that in general, collective and public transportation are a more sustainable alternative to private transportation.

Image 4 | Emissions from different modes of transport:



The image shows that rail transportation is amongst the cleanest modes of transportation.
BBC. (2019). *Climate Change: should you fly, drive or take the train?*

A second reason for the increase of public transportation has to do with urbanisation. For centuries, cities have been growing larger and more dense. Within the inner-city's dense spaces, there is no space for huge amounts of private cars. Walking, cycling and using public transportation take substantially less space per traveller than driving a car (Nixon, D. V., 2014; Fietsersbond, 2020). Therefore, cities increasingly promote active and collective public transportation (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). In fact, one of the main reasons for Amsterdam's famous Noord/Zuidlijn to be built, was the aim of reducing motorised traffic within the cramped inner city, this was as early back as 1994 (GVB, 1994). See image 6 from the Fietsersbond on page seven for a spatial analysis per modality.

A third reason can be found by governments and city planners. New building projects are to be built within the city in order to densify the existing built area and to create more liveable quarters (Ministerie van BZK, 2020). The government stimulates concentrating this densification around public transportation hubs (also named TOD or transport oriented development) in order to minimize car usage and enhance the quality of city life (Bertolini, L., 2008; Zacharias, J., Zhang, T. & Nakajima, N., 2011; Olaru et al., 2019; Ministerie van BZK, 2020).

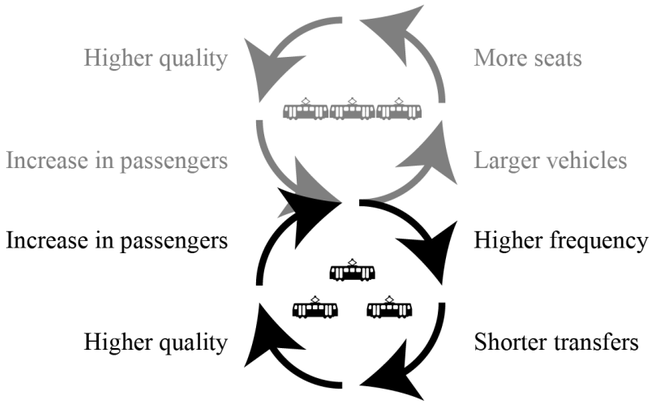
Currently, NS and Prorail are implementing 'Programma Hoogfrequent Spoorvervoer' on several important corridors (Ministerie van Infrastructuur en Milieu, 2011; Ministerie van Infrastructuur en Waterstaat, 2019; Prorail, 2021-III). This programme results in higher frequencies, where certain lines operate every ten minutes.

This forms the fourth reason, as there is an interesting phenomenon in public transportation: 'induced demand' (Givoni, M. & Dobruszkes, F., 2013). When the use of a certain transportation service increases due to external factors, it forces the need for a higher capacity. This in turn can lead to either higher frequencies on the line, or it leads to bigger/ longer vehicles, see image 5.

When the frequency increases, this leads to a higher quality of the transportation service offered. In turn, this attracts even more travellers, starting the loop all over again (Ministerie van Infrastructuur en Waterstaat, 2010). Similarly, the increased size of vehicles results in more available seats. This also increases the quality of the transportation service, especially during high occupation rates where travellers would have to stand if they were in smaller vehicles.

In summary: expansions to public transportation do not just satisfy the needs of current travellers, they also improve overall service quality and thus attract new travellers.

Image 5 | Increased passengers diagram:



Own illustration.

As described, several factors are responsible for an increased patronage of public transportation. It is conceivable that in the future patronage of public transportation will increase even further as new modes of transportation become available (Givoni et al., 2013). New modes, such as E-bikes and hyperloop for example, could further broaden the range of transportation services offered and thus attract new travellers.

To illustrate this point, separate studies focusing on Thailand and Sweden predicted a strong increase in the demand for hyperloop travel in the next few years, at the expense of air and car travel (Jiang, 2010; Agrawal & Pravinvongvuth, 2021). However, the increased patronage and implementation of new modalities come along with new space requirements in existing stations. If stations turn out to be unable in handling new and bigger passenger flows, they will need to be renovated. Hence, a better understanding of the station is required. The next chapters will elaborate more on the different spatial and functional claims that come together in a modern urban station.

Image 6 | Public space usage by different modalities/ activities:

In this image, it becomes clear that cars use big parts of public space. Space that could have been used for better purposes, enhancing city life.
Fietsersbond. (1979). *Van wie is de ruimte?*

1.2.The station as a node

In the seventies and the eighties of the twentieth century, the focal point for station design was creating efficient spaces for a quick flow of travellers (Spoorbeeld, 2012-I). Although a very singular approach disregarding all other aspects of the station, it addressed one of the main functions of the station: the station as a node. In this section, the nodal function of the station will be further elaborated.

Image 7 | The network behind the node.

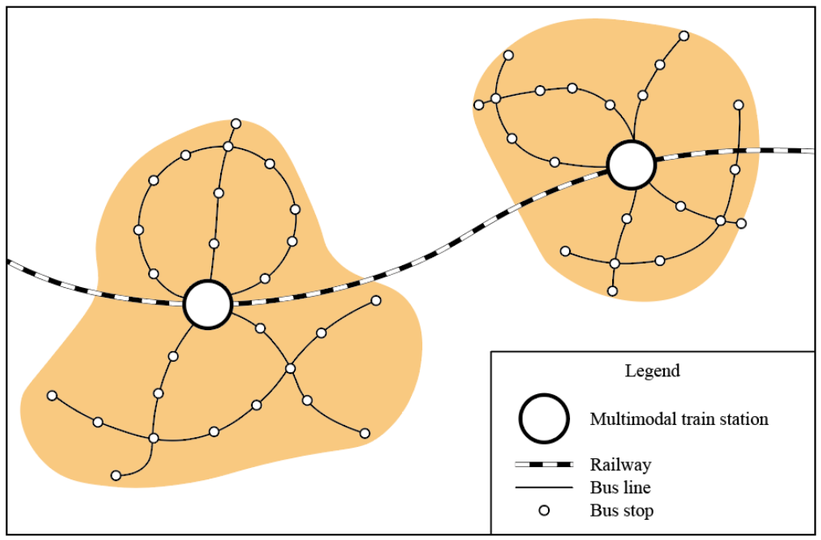
Own illustration.

1.2.1. Multimodality

A station can be seen as the node where different modes meet (Keijer, M. J. N. & Rietveld, P., 2000; Zhang, W., Nian, P., Lyu, G., 2016). The modes represent different modalities or modes of transportation, whereas the node is the place where these modalities are interconnected. Within the station, transfers take place by foot. In that sense, the station is a (pedestrian) network in itself, connecting all different modalities.

In most stations for example, trains and buses are connected. The bus has finer branches stretching through the city whereas the train runs in between different cities, see the graph below. Together the two networks are complementary and intertwined, they transport travellers together and transfer a portion of their travellers to one another.

Image 8 | Relation between train and bus networks:



Own illustration.

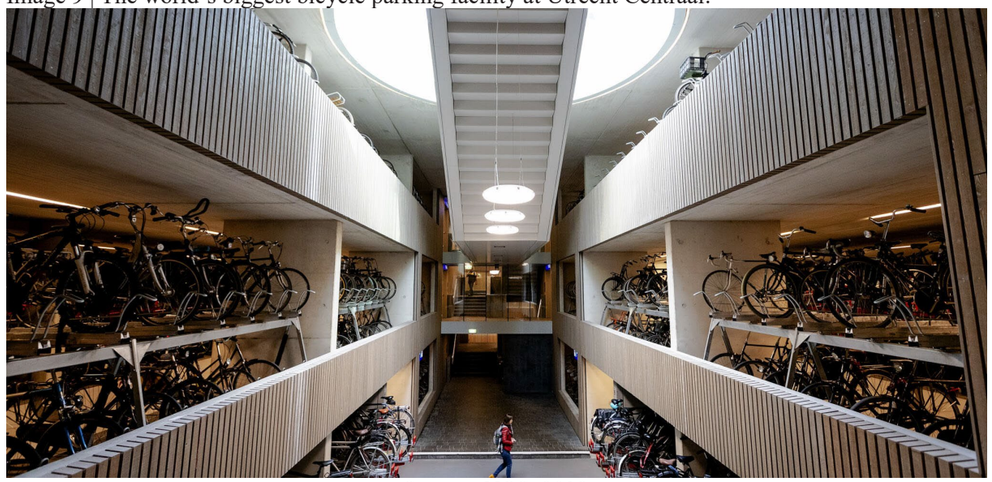
In recent years, an increasing interest has been shown in the multimodality of the station (Spoorbeeld, 2019). Kachousangi, Van Oort & Hoogendoorn (2018, page 58) write that:

"Intermodal transportation can be defined as seamless transferring of passengers or goods from one place to another by using several means of transport, including walking or cycling. This concept aims at optimizing travel efficiency by taking advantages of different modes against minimizing their negative impacts as well as improving the efficiency of the total transportation system by integrating different transport modes and services together"

A great example of this phenomenon is the fact that more and more stations feature large sheltered bicycle parking facilities (Spoorbeeld, 2019; AD, 2020; Prorail, 2021-V). These facilities are often highly accessible and allow passengers for a smooth transfer between bicycle and train (Van Mil et al., 2021). In fact, around half of the train travellers arrive at their station of departure by bicycle (AD, 2020; Prorail, 2021-V). In The Netherlands, these two modalities are imminently interlinked to one another (Rietveld, P., 2000).

The next image shows the world's largest bicycle parking facility at Utrecht Centraal (NOS, 2019). 12.500 bicycles can be parked, divided over three floors. The bicycle parking facility is one of the many that have been implemented in the Dutch stations over the past years.

Image 9 | The world's biggest bicycle parking facility at Utrecht Centraal:



Source: NOS, 2019.

1.2.2. The pedestrian network | The network behind the node

Apart from bicycles, emergence of other new modalities such as E-steps and E-bikes on local scale and hyperloop on (inter)national scale, further complexifies the station. As Phil Roberts (Lee, U., Hyun, Y. M., Jeon, H. J. & Park J. R., 2018, p. 130) describes: *"One challenge with multimodal hubs is stitching each mode of transportation into a cohesive whole."*

The complex station is connected internally by a pedestrian network, see image 7. This pedestrian network is also described as the pedestrian zone by Bureau Spoorbouwmeester (Spoorbeeld, 2012-II) in their publication on the domains of the station. It is the connecting element of the station.

Within the station, all travellers are equal in the sense that they travel from one modality to the other by foot. Accordingly, it is important that the pedestrian zone within the station is designed around the pedestrian flows that run through the station in order to facilitate smooth transfers.

As described in the first section, a 30 to 40% increase is to be expected in national passenger transport over rail. Also, an increasing emphasis on multimodality and the emergence of new modalities such as hyperloop, could enact a renewed focus on the nodal function of the station as was the case in the seventies and eighties, aiming to design an efficient transfer machine.

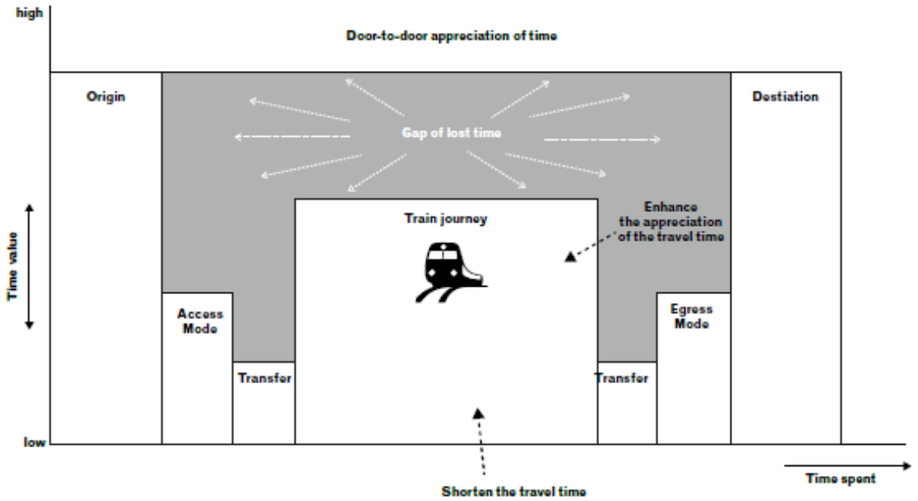
1.2.3. Time well saved versus time well spent

Although efficient routes are at the core of every station design, they are not the only factor playing a role when creating a successful station (Spoorbeeld, 2012-I; Spoorbeeld, 2012-II). With the main user of the station being the traveller, it is important that the station is designed around the needs of this traveller. Providing him or her with a pleasant travel experience, as pleasant travel experiences greatly benefit patronage of public transportation (De Wilde, S., 2015; Triggianese, Cavallo, Baron & Kuijper, 2018).

In fact, the experience of a journey is largely dependent on two factors: the time that the journey takes, and the experience during the travel time (Triggianese et al., 2018). Efficient routes may enable shorter transfers and faster vehicles enable shorter travel times. They contribute to 'time well saved'.

However, a pleasant waiting experience at a station or a comfortable trip both contribute to 'time well spent'. As travel times will never reduce to zero, it is important that the time spent during the travel is of high quality, see the graph below.

Image 10 | 'Time well saved' versus 'time well spent':



Source: Triggianese, Cavallo, Baron & Kuijper, 2018.

As the graph hereabove shows, both the saving of travel time and the spending of travel time in a qualitative way, contribute to a better travel experience. An efficient transfer is beneficial to a short travel time, but a station that is solely designed to facilitate efficiency lacks quality for people that need to wait at the station (Hernandez, S. & Monzon, A., 2016). Not all trips connect smoothly and thus a portion of travel time is often spent waiting at or walking through the station. Hence, a well-designed station with qualitative spaces and comfortable waiting areas is crucial when realizing a high quality transfer and thus a more positive perception of the time spent during travelling, which in turn can lead to a better patronage (Yoh, A., Iseki, H., Smart, M., Taylor, B. D., 2011; Hernandez et. al, 2016).

1.3.The station as a place | Six design principles

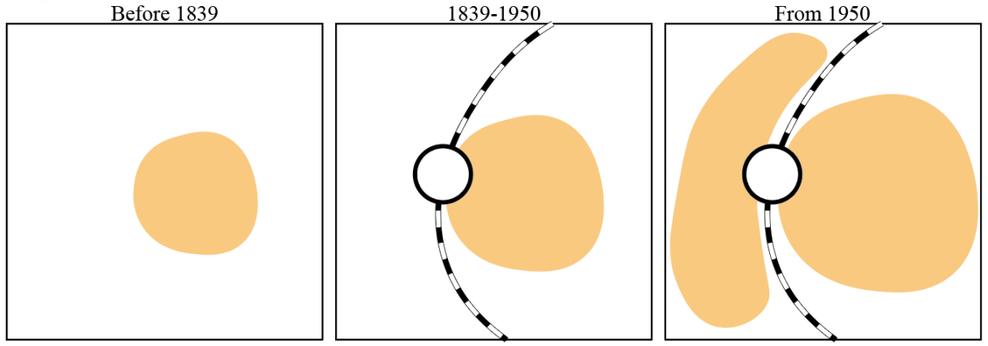
The previous chapter gave more insight in the nodal function of the station. It concluded with the notion that it is not just a fast and efficient travel that benefits the experience of the traveller. A comfortable and pleasant experience is just as important. In this chapter, this will be elaborated further. Six underlying design principles will be presented.

In the last thirty years more attention has been given to spatial quality and a comfortable stay for travellers in and around the station. This was to counter the fact that the mere functional stations from the seventies and eighties induced boredom and unsafe feelings among travellers (Spoorbeeld, 2012-II). In general, there has been a shift in public transportation towards a more user-oriented policy, aiming to improve the experience for travellers (Ministerie van Infrastructuur & Waterstaat, 2010).

However, it's not just the travellers that benefit from a high spatial and public quality in and around the station. Historically, stations have been placed outside the city. While cities expanded, especially after the second world war due to the rise of private car usage and new ideals regarding housing, the stations that were placed besides the city became part of its extending centre, see the image below.

Because of the station's position within the city, citizens living near the station and pedestrians passing by the station also benefit from a safe and high quality public station area (Spoorbeeld, 2016). Especially because often the area surrounding a station has a monofunctional character and creates unsafe feelings among pedestrians that walk through it during quiet hours (Spoorbeeld 2012-I; Spoorbeeld 2012-II). Therefore, the following six principles will focus on both the traveller and the inhabitant, aiming to create a well-integrated station within the city: an urban station (Triggianese et al., 2020).

Image 11 | The expansion of a city around a station:



Own illustration.

1.3.1. The design principles

In this section, six design principles will we introduced that aim to integrate the station within its surrounding cityscape. In the following sections, every design principle will be described more in-depth, accompanied with literary argumentation. In chapter three (Results), these design principles will be tested in the seven international multimodal stations that are described in chapter two (Method) to see if they are accurate.

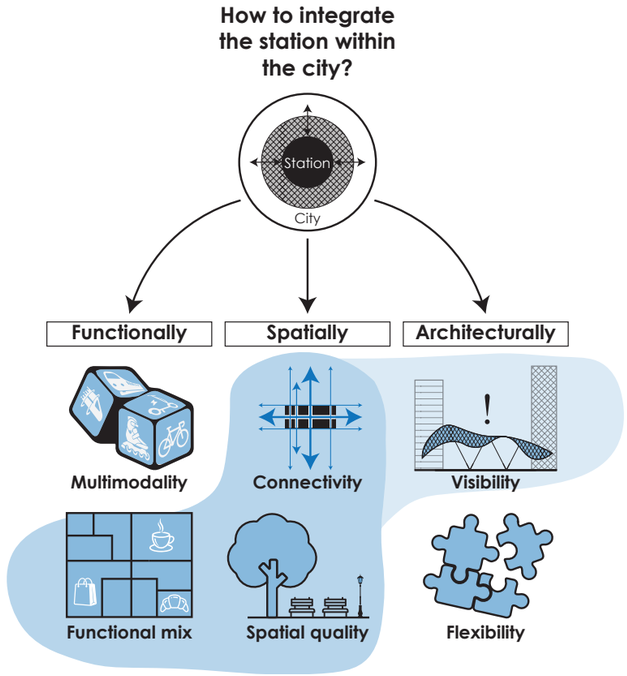
The six design principles have been placed in three categories, see image 12. The first category is functionality. The nodal function is the station's primary function and in the configuration of the different modalities within the station's complex (nodal set up), a lot can be done for the liveability in and around the station. The promotion of active transport is a key element for this design principle, as pedestrians and cyclists exist more in harmony with city life than automobiles.

Secondarily, the station has an important function as a public place within the city, ideally offering a wide range of public functions. If these functions are not just directed towards travellers, but towards other target groups as well, this enables the station to be occupied by all kinds of people, not just travellers. In summary: a diverse functional mix enables the station to attract citizens 24/7.

The second pair of design principles is focused on the spatial design of the station. Firstly, connectivity aims at reducing the physical barrier-effect with which the station and the railway divide their surrounding city. In order to do so, connections need to be restored and new connections can be added. Stitching together the urban grids on both sides of the tracks.

Secondly, spatial quality aims at minimizing the social barrier-effect. By facelifting the station area through the implementation of high quality materials, good lighting and plentiful comfortable seating, the area becomes inviting for people to stay and enjoy the scenery. This in turn leads to enhanced social control, creating a sense of safety.

Image 12 | The six design principles:



Own illustration.

Functional mix, connectivity and spatial quality work together very well when creating successful urban spaces. Primarily, an attractive functional mix creates a desire for citizens to enter a certain area. Secondly, connectivity enables citizens to reach this area, by making it easily accessible and removing barriers. Thirdly, a high spatial quality in an urban space offers citizens an opportunity to spend more time in its pleasant atmosphere. In return, the presence of diverse groups of citizens creates an even better atmosphere and provides the surrounding public functions with a sales market. In image 12 this interrelation between the principles is being illustrated by the dark blue background.

Focusing on the buildings architectural characteristics, the last pair of principles comprises visibility and flexibility. For a station building that adopts urban spaces and public functions and that aims to integrate seamlessly within the surrounding cityscape, visibility is of great importance in order to recognize the station as such. On one hand, this is an answer to the station's societal importance, on the other hand it is a way of giving identity to the spaces surrounding the station. Larger stations can be landmarks within cities, such as Rotterdam Centraal and Amsterdam Centraal.

By turning the urban station into a landmark, or by keeping its already existing landmark features, stations can stimulate place making. In fact, this adds a fourth principle to stimulate the creation of a successful city space. People are often drawn to landmarks and they provide a great scenery for cultural and societal manifestations, as will be described further on in this paper.

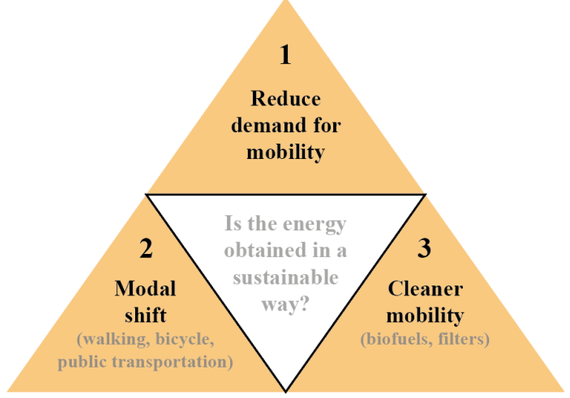
Lastly, flexibility aims at making the station robust and fit for ever-changing programmes. Whereas the other five principles aim at creating a vivid station area filled with city life, flexibility aims at securing this city life during the operation of the station when restorations need to happen. As the example of Amsterdam Centraal will point out, station buildings are in operation for long times. During their operation, technological break throughs change the transportation sector and create a need for the station to adapt. By creating a station with a flexible structure and a so-called over-dimensioning, station buildings can be more easily transformed over time. Also, the implementation of the Plug-&-Play-concept enables station retail mix to change throughout the exploitation phase without the need for renovation works. Saving lots of nuisance and securing city life in and around the station throughout its operation.

1.3.2. Multimodality

Multimodality aims to combine different modalities within one journey, creating the need for transfers. It aims at using the advantages of different modalities whilst minimizing their negative impacts on for example the journey itself, the urban surroundings or the climate as a whole (Kachousangi et al., 2018). The organization of the station can help in creating comfortable spaces and in achieving climate goals. The latter is of greater importance than ever for the transportation sector.

In light of the climatological challenges, the *trias mobilica* has been formulated, see image 23. It is a derivative from the *trias energetica* (Korff de Gidts, 2020). The first action point asks for a reduction in demand for mobility. Obviously, the most sustainable way of living, is not using transportation at all, but that's not in the scope of this research. The third action point is about improving existing mobility and reducing emissions and energy usage, luckily this happens a lot with for example electric vehicles, but also this is not in the scope of this research. However, the second point regarding modal shift, is highly relevant for this research.

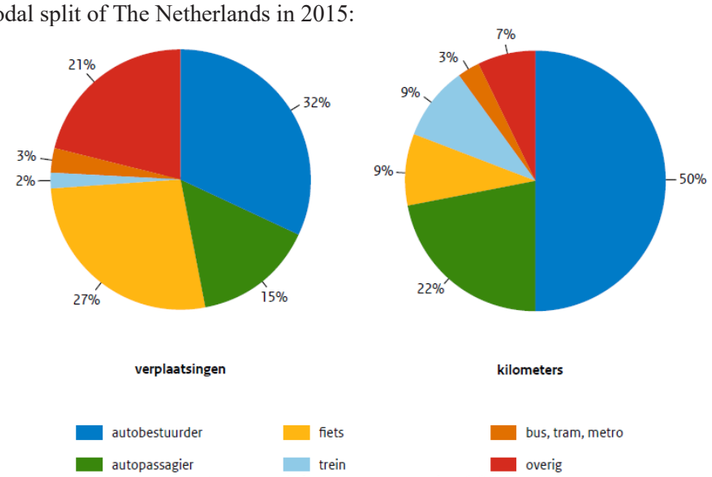
Image 13 | Trias Mobilica:



Own illustration, based on Syndesmo (2019) and Korff de Gidts (2020).

In order to better understand this, it is important to understand the term: 'modal split'. Modal split is being defined as the division of travellers over the available modalities (Wegenwiki, 2021). The modal split for The Netherlands in 2015 has been displayed in image 24 on the following page. Although trains only represent two percent of the taken trips, they represent nine percent of the travelled kilometres. However, the car is the main modality in both trips taken and kilometres travelled.

Image 14 | Modal split of The Netherlands in 2015:



Retrieved from Wegenwiki, 2021.

Modal shift is the phenomenon in which the division of the travellers changes, some modalities gain patronage while others lose it. For example: if more people would start choosing the train over the car, this would entail a modal shift and would reduce traffic nuisance and pollution in the city.

Some modalities are cleaner than others, see once more image 2 in the introduction for your reference. Active transportation is without doubt the most sustainable way of transportation. Walking and cycling are active modes of transportation, the required energy comes from physical exercise instead of fossil fuels or electricity. A modal shift can contribute to a more sustainable transportation sector by stimulating active transportation. Not only would this be more sustainable, it also creates for more liveable quarters.

Accordingly, Bureau Spoorbouwmeester's publication on the new station quarter (Spoorbeeld, 2019) aims at creating a hierarchy of modalities. In this publication, the pedestrian is the main priority within the public realm (Keijer et al., 2000; Zacharias et al., 2011), followed by the cyclist as runner-up (Keijer et al., 2000). Public transportation is number three on the list, followed by shared mobility. The list concludes with private cars.

This order on one hand prioritizes transportation on the base of sustainability. On the other hand, it prioritizes transportation on the spatial impact: as described walking and cycling takes less space than driving a car. In that sense, the modal shift is not just intended to meet sustainability goals, it is also intended to improve spatial quality in the station area. By stimulating active transportation, the area becomes more liveable and feels safe (Gehl, 2011; Sim, 2019). As a result, this enables the design of comfortable places where people can stay.

By being the interface between travellers and transportation services, stations can play a pivotal role in creating a modal shift, for example by stimulating active access and egress transportation. In the way that a station and its surrounding cityscape is designed, travellers can be appealed to walk the last part of the journey or to take the bike, saving a rather polluting trip from a fossil-fuelled car (Keijer et al., 2000). By improving the station and its surrounding, the travel will also be more pleasant and this may help in attracting more travellers choosing public transportation in general (Yoh et al., 2011; Hernandez et. al, 2016).

In recent station development in The Netherlands, such as the 'Nieuwe Sleutelprojecten', the aforementioned tendency of multimodality is clearly visible. The Nieuwe Sleutelplrojecten comprise six stations that faced large renovation works in the past decade: Rotterdam Centraal, Breda, Arnhem Centraal, Utrecht Centraal, Den Haag Centraal and the still to be renovated Amsterdam Zuid. Bureau Spoorbouwmeester (Spoorbeeld, 2016) explicitly changed the programme of requirements for these stations by adding a sublime accessibility by bicycle (and thus good bicycle parking facilities) as a requirement. In general, the renovated stations feature stylish contemporary designs, a facelift for the area surrounding the station and an increased capacity for handling a growing amount of travellers.

1.3.3. Functional mix

Besides housing an array of different modalities, stations increasingly house public functions (Bertolini, 2008; Zacharias et al., 2011). Or, as Jerry Lok (2014, p. 6) put it: '*At a station, one can catch more than just a train'*. In several publications from NS and ProRail, it is described that stations are becoming destinations in their own right by housing public functions (Lok, 2014; De Wilde, 2015; NS Poort, 2016; Van de Brink, 2017; ProRail, 2020). Initially, these functions have been directed towards the traveller, as is the case in most Dutch stations nowadays (Ministerie van Infrastructuur & Waterstaat, 2010).

Bureau Spoorbouwmeester states that the current atmosphere at the station is mainly the result of a continuing commercialization on one hand and a minimalization of unsafety and criminality on the other hand (Spoorbeeld, 2012-I). It is important that stations provide a feeling of safety so that both passers-by and travellers feel at ease in the area (Spoorbeeld, 2012-I; Spoorbeeld, 2012-II; Triggianese et al., 2019). A programme that attracts people 24/7 can induce a feeling of safety, as it improves social control (Gehl, 2011; Sim, 2019). This can be achieved by creating a favourable functional mix that results in human activity throughout the day (Triggianese et al., 2018).

Also, transportation hubs such as train stations (De Wilde, 2015) and airports (Kasarda, J. D. & Lindsay, G., 2011) see a business case in offering more than just transportation services. At these hubs, there is a continuous flow of potential buyers right at the doorstep of businesses within these hubs, resulting in relatively high profits per square metre (Kasarda et al., 2011; De Wilde, 2015).

Business, leisure and other functions are being incorporated in transportation hubs and turn these hubs into destinations in their own right. NS Stations stated that it is their objective to turn their station areas into the bustling hearts of the city, were living, working, leisure and transportation intertwine (Lok, 2014; De Wilde, 2015; NS Poort, 2016; Van de Brink, 2017; NS Stations, 2019; ProRail, 2020).

Stations have a huge, often neglected, potential for hosting activities and functions for the city (Spoorbeeld, 2012-II), see image 15 & 17. Rather than becoming a non-place because the station only functions as a transfer zone from one destination to the other (Augé, M., 2009), the station could well become a destination in its own right (Triggianese et al., 2018; Triggianese et al., 2019; Triggianese et al., 2020). Cavallo (Triggianese et al., 2018, page 45) writes the following about this:

"With regard to railway nodes, higher frequencies of transportation, the accommodation of different flows of traffic, the increased variety of functions as well as number of users, and the necessity of attractive public spaces, is requiring stations and station areas to be repositioned and to transform towards much strongly integrated and interactive public (transportation) poles in their urban context."

Similarly, Triggianese (2018) writes that stations offer different urban amenities for citizens besides providing interchanges in mobility. Conceicao (2011) takes this further and states that the station building fuses with its urban surroundings, see image 16. Stimulated on one hand by eliminating the barrier effect and by implementing public functions on the other hand, the station is no longer a conventional building, but also not a conventional urban space.

In accordance with this, Bureau Spoorbouwmeester's publications (Spoorbeeld 2012-I; Spoorbeeld, 2012-II, Spoorbeeld, 2016; Spoorbeeld, 2019) refrain from using the term 'station building' whenever describing stations, instead they use 'station quarter', being an integrated urban space or area with a mobility function.

Lastly, Bureau Spoorbouwmeester states that stations should have a certain 'over-dimensioning' in order to facilitate the unforeseen (Spoorbeeld, 2012-I; Spoorbeeld 2012-II). With its central position within the city and its sublime accessibility, there is a great potential for stations to host larger public events and functions, see image 17.

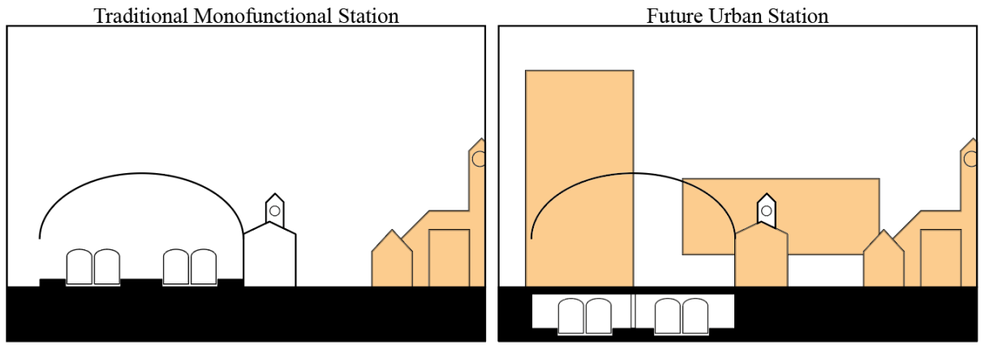
The desire to make places from stations and to integrate functions in stations is encouraged by demand from policy makers and developers. Multimodal stations generally attract new businesses and offer a good climate for investments (Bertolini, 2008; Triggianese et al., 2018; Triggianese et al., 2020). Because of the appeal that stations have on businesses, they are being used as a strategic tool to transform cities. Triggianese (2018, page 79) writes that: "*…railway stations are on top of the agenda of policy makers, acting again as a key element to anticipate future transformations of the city and its territory, …"*.

Image 15 | An art studio at Rotterdam Centraal's concourse:

Own image.

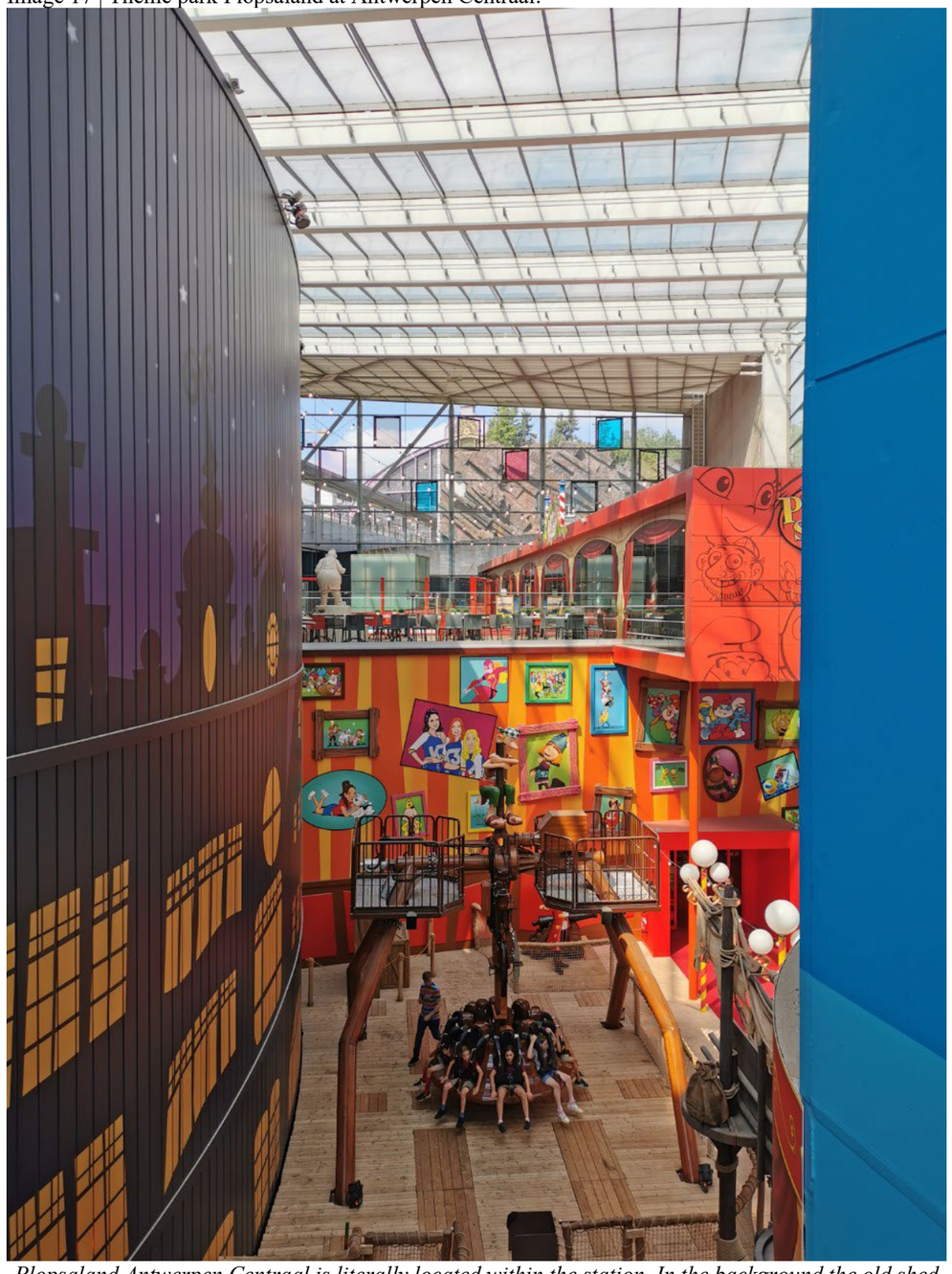
It seems that the station of the future is no longer a singular transfer hub, it becomes a vivid urban centre as displayed in image 16. Besides this, the archetype of the station as a building, will not remain. The future station is both a node and a place, a transfer hub intertwined within the urban cityscape, ideally leaving no barrier. Throughout this research, the term 'urban station' will refer to this new typology of a station.

Image 16 | The traditional station versus the future urban station:



Own illustration.

Image 17 | Theme park Plopsaland at Antwerpen Centraal:



Plopsaland Antwerpen Centraal is literally located within the station. In the background the old shed roof is visible, but the platforms extend all the way to where the picture is taken, behind the purple curved wall.
Own image.

Incorporating public functions in the station creates an urban station that has a strong functional connection to the city, as these functions attract not just travellers but also citizens living around the station. Essentially, the station becomes a destination in its own right, similarly to the airport city. In the remainder of this paragraph, the airport city concept will be described and similarities between airport city and urban station will be pointed out.

The phenomenon that describes airports as having increasingly urban features is called 'airport city' (Kasarda et al., 2011; Kasarda, J. D., 2013; Schiphol, 2016; Schiphol, 2022). Airports aim at integrating business, real estate, commercial services and recreational amenities together with aviation within the airport city complex. Kasarda (2013, page 24) writes the following about this:

"Regardless of process, airports continue to transform from primarily air transport infrastructure to multimodal, multi-functional enterprises generating considerable commercial development within and well beyond their boundaries."

As a result, successful airports spur further urban developments in their vicinity, resulting in the forming of an 'aerotropolis'. Kasarda et al. (2011) write that the mutual relationship between infrastructure and urban development has been ever since the first human settlements emerged. So transportation hubs are not just the result of urban developments, they are a stimulator of new urban developments as well.

Looking at the previous sections, a very similar tendency has been emerging regarding train station development and the urban station. It appears that both originally monofunctional transfer hubs are becoming important locations in their own right, consequently spurring further city development around them (note that transport oriented development is both a direct cause and expression of this).

1.3.4. Connectivity

Although stations aim at connecting different regions and different people, paradoxically they also form a barrier between them (Zacharias et al., 2011). Railway tracks and station buildings often form a barrier between different parts of the city (Conceicao, 2011; Triggianese et al., 2018; Spoorbeeld, 2019). Hence dividing the old city centre and the suburbs, as is shown on the right square in image 16 and 18.

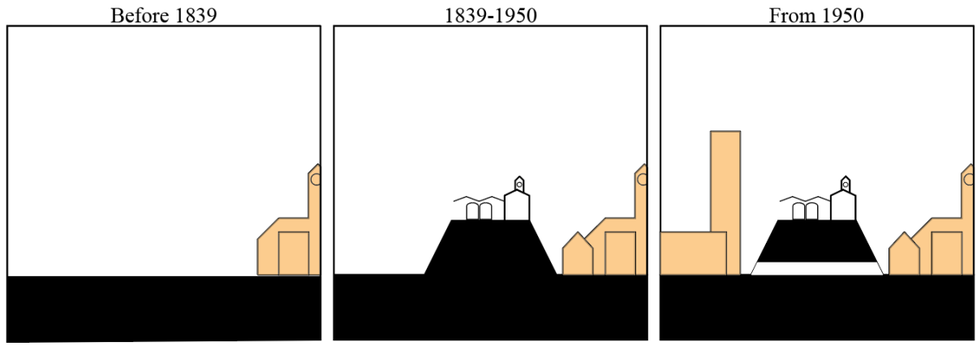
As Richard Ingersoll (Lee et al., 2018, p. 12) states in the introduction of '*INFRASTRUCTURE. Road Kill. On the violence and pacification of infrastructure.*':

"The imperative for efficient, fast and hygienic services, for the movement of vehicles, water and waste, resulted in ruthless damage to the land and the urban dwellers."

This publication writes about the aggression of infrastructure: how it divides and separates urban areas, diminishes liveability and spatial quality and creates a lot of pollution and nuisance. It states that infrastructure always takes from the city, but it rarely ever gives back. This is accepted somehow, because infrastructure is seen as a necessary evil. It then advocates that when planning for an infrastructural intervention, being it a highway or a railroad, designers and city planners should aim to satisfy the needs for inhabitants of the surrounding urban areas as well. They should try to improve the situation, rather than worsening it.

Looking at railways in The Netherlands, it becomes clear that much of the current railway infrastructure complies with this view. Tracks form kilometre-long barriers, isolating urban areas from their neighbouring city and creating unsafe low-quality spaces. Usually, only a few connections are present between both sides of the tracks and they are generally primarily focused on cars and severely lack spatial quality. As a result, there is a lack of comfortable connections, especially for pedestrians and cyclists. Gehl (2011) and Sim (2019) write that especially these pedestrian and cyclist connections are most crucial when aiming at enhancing liveability and city life. Moreover, pedestrian and cyclist connections have a strong connection to the Dutch railway network (Keijer et al., 2000), which should be facilitated.

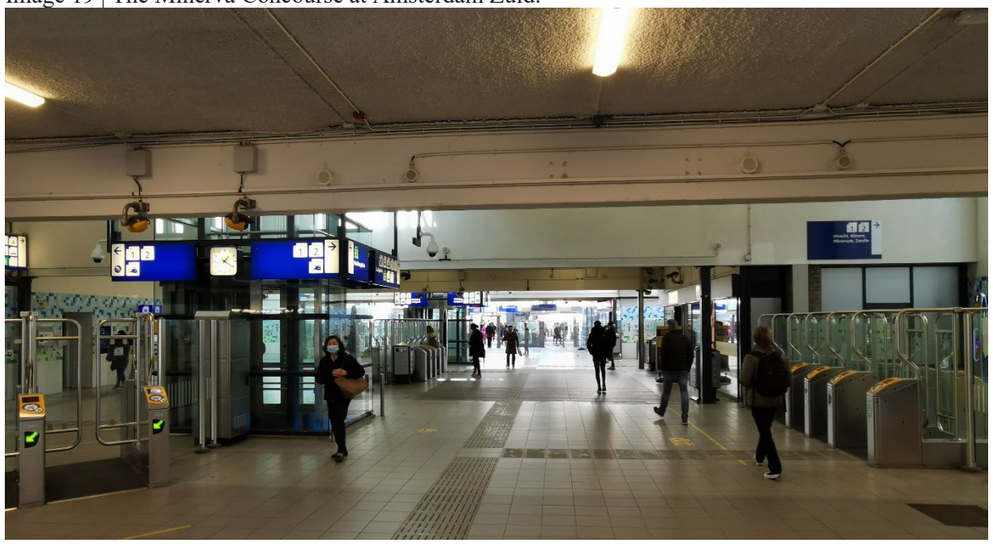
Image 18 | The barrier-effect of the railway:



Own illustration.

In several cities, such as Delft, a completely new station has been built and the train tracks have been put completely underground. This diminishes the barrier-effect of the railway. But this is not always feasible. In other cases, such as Amsterdam Zuid, the tracks remain elevated on a dike and form a wall. The Minerva Concourse that runs under the tracks connects not just the different modalities, but also both parts of the city that are separated by the tracks and the highway, see image 19. The case of Amsterdam Zuid will be described more thoroughly in the third chapter (Results).

Image 19 | The Minerva Concourse at Amsterdam Zuid:



Own image.

In recent years, station design in The Netherlands shows a clear tendency in restoring connections between both sides of the tracks, especially in the new designs known as the 'Nieuwe Sleutelprojecten'. Improving, restoring and even creating new connections enables stations to play a pivotal role on pacifying the aggression of railway architecture and infrastructure, besides the design of the multimodal configuration and the functional mix of the station as described earlier. A balance has to be sought between giving way for the civilian and giving way for the traveller, as they both impose different requirements on the public spaces in and around stations. Connectivity on the large scale by means of public transit such as trains should not go at the cost of connectivity at the small scale, being connections for pedestrians and cyclists. Prioritize these target groups when designing a station area.

1.3.5. Spatial quality

Besides creating physical connections in, around and through the station, it is just as important that these connections create an appealing environment for their users. A physical route that exists solely for the purpose of utilitarianism, creates a breach of perception, as is the case with the viaducts (image 20) and the Minerva concourse (image 19) at Amsterdam Zuid station.

Two parts of the business area at the Zuidas, both with well-designed public spaces and high spatial qualities, are separated by the railway. Viaducts connecting both sides are constructed out of concrete without any regards to aesthetics. In chapter 3 (Results), this will be analysed more thoroughly.

Image 20 | The viaduct over the Beethovenstraat at Amsterdam Zuid:

Own image.

Apart from creating qualitative connections and a safe atmosphere (Sundling, C. & Ceccato, V., 2022), public spaces generally invite people to stay. The use of high quality materials, an appealing design, the use of greenery and the placement of sufficient comfortable seating (Whyte, 1988) can create a place where people simply enjoy being (Gehl, 2011; Sim, 2019; Sundling et al., 2022). For an urban station, this sort of spaces is crucial for integrating the station within the city (Triggianese et al., 2018; Triggianese et al., 2020).

In the 'Nieuwe Sleutelprojecten', the creation of high quality urban spaces is already in full swing, see for example the station square at Rotterdam Centraal (image 38) or the Ijhal (image 31) at Amsterdam Centraal in chapter three (Results). Apart from the spatial quality, connections are actively being restored, public functions are being implemented and the stations give broad way to pedestrians and cyclists.

1.3.6. Visibility

Where the previous four design principles aim at seamlessly connecting the station and its surrounding urban cityscape, this design principle has a different aim. A station is originally a public building and public buildings generally stand out from their urban context. This can be due to their size, their materialization or for example their location.

Apart from this, stations have always been buildings that left a mark in cities. Not just because of their aggressive infrastructural veins, but more even because of their societal function. Stations are both a gateway to and from the city, a point of arrival and of departure. People reconnect or part at the station and it is one of the few places where all different groups of society come together (Binney, M., Hamm, M. & Foehl, A., 1984; Jenkins, S., 2017).

Stations were the first urban structures in the city to surpass the size of large cathedrals that held the throne ever since Medieval times (Jenkins, 2017). Hence, they are often placed in the same category of city buildings as town halls, palaces and of course the cathedrals. In fact, 25 (104 out of 408) percent of the Dutch station buildings has been registered as either a national or regional monument.

The societal impact of stations will only increase in the coming decennia (Triggianese et al., 2018; Triggianese et al., 2020) and the appearance of the station should reflect this in order to further touch and inspire people. Moreover, the station should entail a celebration of (sustainable) travel, bridging gaps and connecting people on all scales. From a more practical point of view, a visible station fosters natural wayfinding and creates an identity (Spoorbeeld, 2019).

By turning the urban station into a landmark, or by keeping its already existing landmark features, stations can stimulate place making (Castello, L., 2010). A great example of the latter is London's St. Pancras International (image 21) that has been renovated after almost being demolished. The area surrounding the station is rapidly developing into a bustling neighbourhood. People are often drawn to landmarks and they provide a great scenery for cultural and societal manifestations (Way, M. A., 2004; Castello, L., 2010). On top of this, place making enhances safety in the area (Way, 2004).

Image 21 | London's monumental St. Pancras International after its renovations:

Own image.

1.3.7. Flexibility

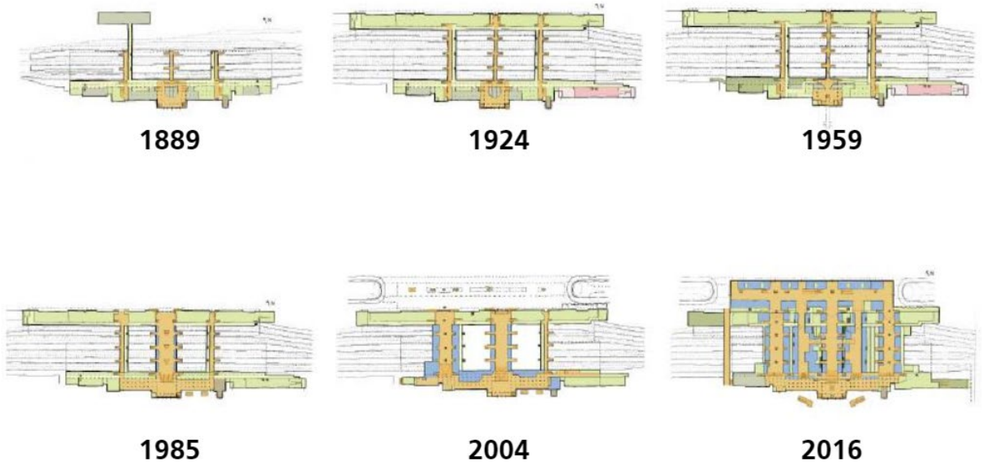
As the previous five principles focus on the generation of liveable and well-integrated station areas, flexibility aims at ensuring liveability during the exploitation phase of the station. Large renovation works pose a threat to city life by turning urban spaces into construction sites. Due to the complexity and size of some construction works, public spaces can be gone for over a decade, having a huge impact on city life.

At Amsterdam Zuid for example, a station that is currently being renovated as the last Nieuwe Sleutelproject, construction works take place for at least the coming twelve years. Although a very promising new project will be realized, aiming to stimulate city life in the area, paradoxically huge parts of the station area have been turned into construction sites for years. Limiting the urban space to only a small part for an area that is already very densely used by being a central business district.

Because Dutch stations have to remain operational through renovation works and all, there is a limitation to what works can be undertaken. Simultaneously, transportation continuously evolves and adapts: modalities come and go. The recent emergence of E-bikes is likely to lay a new space claim on stations resulting in alterations. Likewise, the possible emergence of hyperloop might create a major design problem on how to be fitted in our existing infrastructure. In the current fast-paced society, flexibility in stations is more important than ever (note that in image 22, renovation works happen increasingly frequent over time).

Amsterdam Centraal is an interesting example, as it has been in operation since 1889 (Binney et al., 1984; ProRail, 2021-IV). In the 133 years since its opening, a lot has changed in the rail transportation sector and in the society as a whole. Although the building had to undergo numerous alterations (see image 22), big parts of the station's design from 1889 (such as the main building and the classical arched roofs over the tracks) are still very much visible. Although the renovation works were very invasive, just as is the case with Amsterdam Zuid, it would have been unthinkable to construct an entirely new station whilst operating services and thus a robust and flexible station building is crucial.

Image 22 | Amsterdam Centraal: the station that never sleeps.



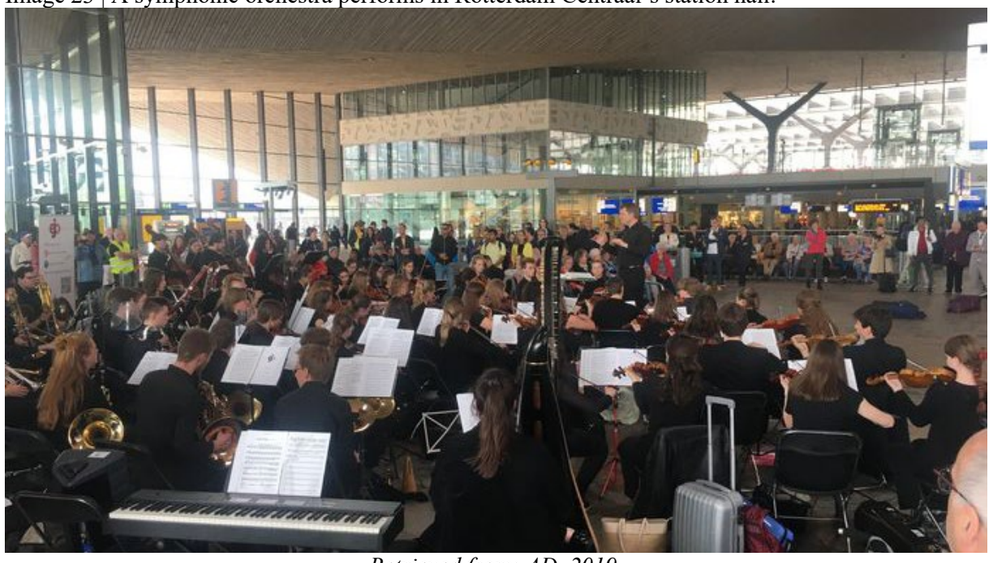
Alterations to Amsterdam Centraal's floorplan throughout its operation. Although the most recent renovations happened in 2016, new renovations are already being undertaken, focusing on the addition of new bicycle parking storage facilities and broadening the platforms in order to increase train travel capacity for the implementation of Programma Hoogfrequent Spoor (PHS). Note that follow-up times between renovations decrease over time.
Retrieved from: De Wilde, S., 2015, p. 51.

In order to create flexibility, two things can be done. One can either create a building that is (slightly) too big, this is called over-dimensioning (Spoorbeeld, 2012-I; Spoorbeeld 2012-II). In order to prepare for the unforeseen, over-dimensioning enables the addition of new space claims within the existing complex without having to do large interventions. The advantage here is that construction costs are much lower during the construction phase than later on, during the exploitation phase (Love, P. E. D., 2002). In the meantime, this excess space can be used for a multitude of functions, providing the station with extra circulation space, creating a place to wait or housing a temporary public function such as a pop-up stores (NS Stations, 2019).

Due to the over-dimensioning of Rotterdam Centraal's station hall, the station has been the stage of several cultural activities. Quite regularly, there is an exposition in the hall. The station hall even formed the stage for a symphonic orchestra, see image 23.

The other method is using flexible constructions so that the complex can easily be extended or shrunk whilst maintaining one clear visual language. Although, alterations will need parts of the station to be turned into building sites, works can happen faster, reducing nuisance and costs.

Image 23 | A symphonic orchestra performs in Rotterdam Centraal's station hall:



Retrieved from: AD, 2019.

Apart from alterations to the station as a whole due to changes to modalities or public spaces, retail mixes at stations change continuously and this results in regular renovations on the smaller scale: the retail unit. A Smullers has different need than a Sissy Boy, because it needs many frying pans and an ice cream machine. It needs a sink for cleaning fatty utensils. If a Smullers were to move into a station, the retail unit should be renovated entirely. In order to smoothen this process and pose no restrictions on retail moving in, around and out of the station, NS Stations created the 'Plug-&-Play-concept' (Lok, J., 2014).

Essentially, the Plug-&-Play-concept means that all retail units should be fit for any possible use. During the construction phase, it is relatively cheap and simple to put all the different wires, circuits, groups and ducts into place. By doing this in advance, it saves the need for reconstruction works during the exploitation phase of the retail units. This in turn saves time and money.

As described, flexibility ensures faster and smoother transitions, both on the scale of the station and on the scale of the retail unit within it. This saves time and money, but most importantly however, this saves nuisance for both the travellers and the citizens that live, work or move through the station area. Aiming at ensuring a continuous vivid station area.

1.4. The integration of the station within the city | Research question.

Previous sections explored both the station as a node and the station as a place, see image 13. It showed that an increased patronage of public transportation and the emergence of new modalities lead to a stronger focus on the nodal function of the station. It also explored how many stations occupy a central position within the city without really adapting to this as stations often form a barrier and seclude different parts of the city from one another.

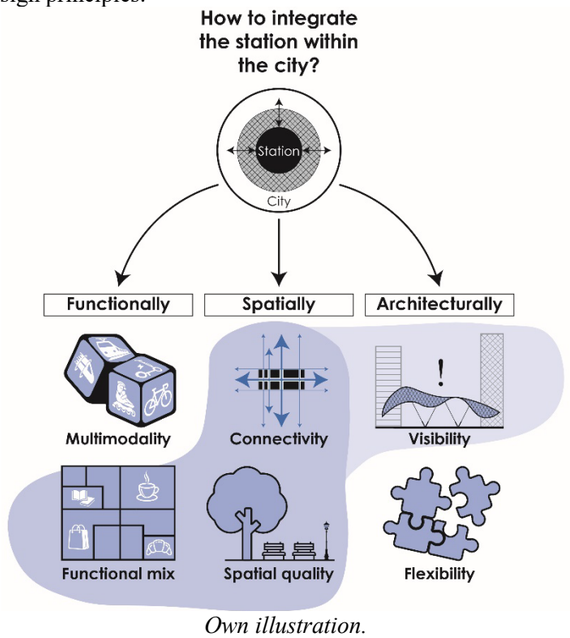
Image 24 | The double role of a station:

Own illustration.

Given the great accessibility and the central location of stations, there is a great potential in transforming singular transfer-oriented hubs into vibrant multifunctional centres. Crucial in achieving this is diminishing the barrier-effect and really integrating the station within the city. The ambitions are clear: the station is to be integrated seamlessly within the city. But this is not without a challenge, as Olindo (Triggianese et al., 2020, page 3) writes that: *"... the main challenge for the design of living urban stations is to configure them as integral, active part[s] of the public field of the city, ..."*.

While there has already been a lot of publishing on this subject, a lot of which has been integrated within this literary review, there seems to be a lack of practical design instructions. If the described ambitions are to be realised in station architecture, it is crucial that concrete and attainable design principles are to be formulated. Hence, the following six principles have been formulated:

Image 25 | The six design principles:



Own illustration.

These choice for these six design principles is based partly on the literary research, as well as interviews with industry professionals and preliminary design exercises and analyses. In order to assess the validity of these six design principles, they will be tested, resulting in the main research question being:

"Are the six design principles: multimodality, functional mix, connectivity, spatial quality, visibility & flexibility apt contributors to the integration of an urban multimodal station within its surrounding cityscape?"

By performing many different plan analyses of several multimodal stations and by keeping in mind the literary background as described in this introduction, the proposed six design principles will be evaluated on their presence in current stations. If proven accurate, the principles can help station designers and alike to create more liveable station quarters.

1.5. Structure of the paper.

In the next chapter (Method), the chosen locations for the plan analyses will be presented along with the reasons why they were chosen. Also, the method will be described: what analytical drawings will be made and what information should they provide? After this, the actual plan analyses are detailed in chapter three (Results). Zooming in on the station as a place and attaining whether the design principles are visible in current station design.

In chapter five (Conclusion), the six design principles will be verified based on their accurateness. For designers that aim to create an urban station, it is advisable to use these design principle as they are crucial for creating more liveable station areas that are in harmony with the surrounding cityscape.

Finally, in the sixth chapter (Recommendations), recommendations will be made pertaining to the limitations of this research and what could be advisable for future research. In the appendix, all analyses can be found in chronological order for further reference.

2. Method

The research within this paper aims to collect qualitative data, meaning the results will be expressed in words rather than numbers. This is conceivable due to that fact that many of the chosen parameters (such as functional mix and spatial quality) are not suited to be expressed in numbers.

In the introduction, a literary research has been performed, providing a literary background for station design and describing six design principles that aim at integrating the station within the city. These six principles have been derived from the performed literary research in combination with interviews with industry professionals, preliminary design exercises and analyses. The aim of the qualitative research is to assess whether these proposed design principles (the hypothesis) are accurate and complete through answering the formulated research question. This happens through the analyses of case studies, in which seven international multimodal stations will be analysed.

Nolli maps will form the background for the analytical drawings in order to gain insight in the relation between the station and its surrounding public realm. Nolli maps are a special type of map that depict the public spaces (white) in an area in contrast to the private spaces and built area (black). These maps do not consider interior and exterior, only do they consider publicly accessible and private spaces (Ji & Ding, 2021). Nolli maps are named after Giambattista Nolli, who drew the first map of this kind in 1748, depicting Rome's public realm (Verstegen & Ceen, 2013).

Due to the use of the Nolli maps as a background, it becomes easier to compare stations on the basis of their relations with the surrounding urban context and on the basis of their internal functionality. In order to do so, seven different layers are drawn over the Nolli map in order to depict the following aspects:

1. The spaces used by the different modalities that are part of the station.
   This layer gives insight into the configuration of modalities within the station complex (nodal configuration).
2. Important transfer routes through the station.
   This layer gives insight into the pedestrian zone within the station complex. Transfer routes are generally high in pace and are predictable as they are dependent on the station's timetable.
3. The OV-chip-gated areas.
   The OV-chip-gates enclose an area that is called the travellers' domain. Although a station is a public building, one can only enter the OV-chip-gated areas when in possession of a valid transportation ticket or OV-card with sufficient funds.
4. Bicycle lanes in the station area.
   Bicycle lanes connect the station's bicycle parking to the city's cycling grid.
5. Public routes running through the station and/or connecting it to the city.
   The public routes show pedestrian flows that are unobstructed by OV-chip-gates. Travellers are likely to use these routes to, but these routes are part of the public domain rather than the travellers' domain.
6. Public functions in the station.
   This layer depicts the public functions present in the station. This is mostly retail: a small supermarket, some to go snacks or flowers, aiming to satisfy the needs of travellers.
7. Public spaces in the station.
   The public spaces oppose the OV-chip-gated areas and are usually characterized by a high spatial quality and abundant public functions in their vicinity. The public spaces are the spaces where the station has the most citylike characteristics, in line with the six design principles.

The Nolli maps have been retrieved from OpenStreetMap and have been modified in Illustrator in order to create a more simple and readable layout, suitable for adding new layers on top of it. All analytical drawings have been added in illustrator as well. Due to a standardized layout and scale, analytical drawings can be easily compared.

In the next paragraph, the seven chosen station locations will be introduced and described. An overview with several characteristics is displayed in the table at page 29, accompanied by a picture of each station on page 30. From page 31 on, the results will be described.

2.1.The seven station locations | Case studies

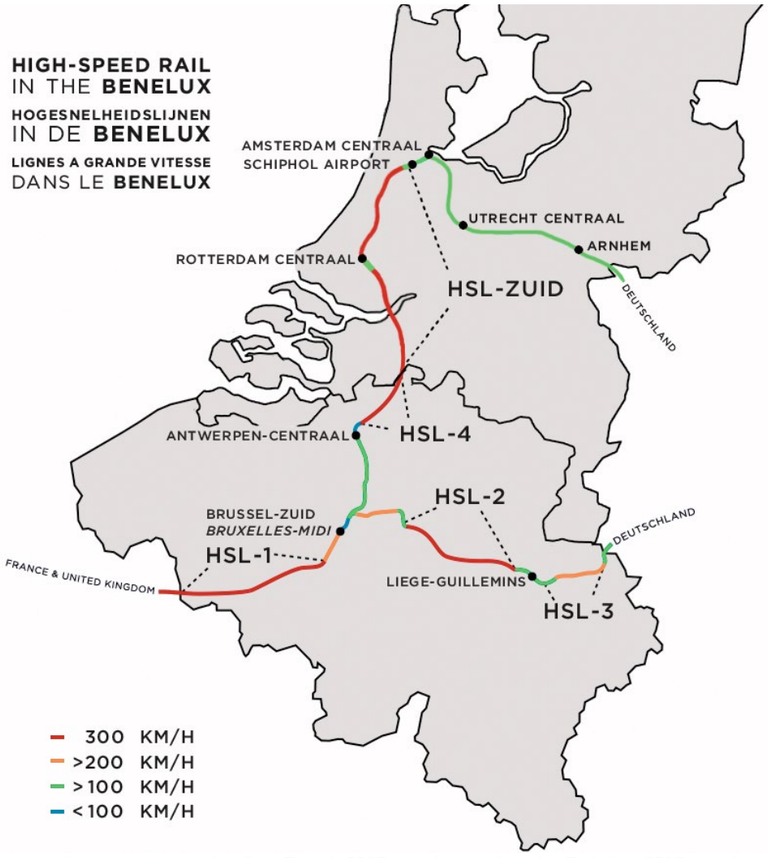
In this research, seven case studies have been studied. These case studies comprise seven international multimodal stations within The Netherlands and Belgium. These stations are located in highly urbanized areas. A limited availability of ground floor space and an abundance of public functions lead to interesting configurations.

Six stations are located on both the HSL-Zuid (Amsterdam Centraal - Schiphol Airport - Rotterdam Centraal - Antwerpen Centraal) and HSL-Oost (Amsterdam Centraal - Utrecht Centraal - Arnhem Centraal), see the image below. HSL-Zuid and -Oost are the main high speed railway corridors between The Netherlands and The United Kingdom, France, Belgium and Germany, Austria and Switzerland respectively.

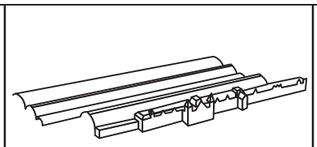
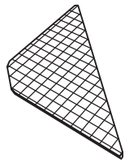
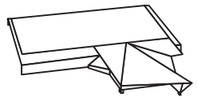
In addition to the aforementioned six stations, Amsterdam Zuid is the seventh station that has been analysed. International connections from Amsterdam Centraal will move to Amsterdam Zuid (Trouw, 2018; Spoorpro, 2018) and therefore both stations currently undergo major renovation works (ProRail, 2021-I; ProRail, 2021-II; ProRail, 2021-IV). In the new situation, Amsterdam Zuid will be part of the Dutch international high speed rail network.

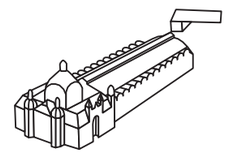
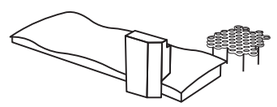
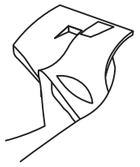
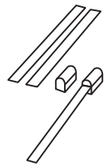
At the next page, all seven stations are displayed in a graph, giving an overview with some characteristics of each station (number of daily passengers, amount of tracks, number of shops, et cetera). The graph is followed by a photo of each station on page 30.

Image 26 | High speed rail in the Benelux:



The chosen stations comprise the five Dutch HSL-stations, plus the Belgian HSL-station Antwerpen Centraal and the soon-to-be HSL-station Amsterdam Zuid, the last is not shown in this picture.
Retrieved from Wikipedia, 2021.

	 Amsterdam Centraal	 Schiphol Airport	 Rotterdam Centraal
Daily travellers (NS only)	199.510 (2nd in NL)	98.071 (5th in NL)	101.732 (3rd in NL)
Platforms	6	3	7
Platform tracks (Total number of tracks)	11 (15)	6 (6)	13 (15)
Trains per hour	34 (-> 57)	56	54
Other modalities			
Number of shops	75	55	32
Gross floor area	22.400m²	22.000m²	4.700m² (station hall)
Located	In the city center	Underneath the airport	Next to the city center
Special features	Amsterdam Centraal is the main station for the city of Amsterdam. The station acts as a two-sided terminus station. Currently, all international high speed lines stop at this station. But in the near future the Eurostar, Thalys and Intercity Direct to Brussels will move to Amsterdam Zuid in order to increase the stations capacity for national trains.	Schiphol Airport is the direct link between the Dutch biggest international airport and the (inter)national train services. The station is situated directly under Schiphol Plaza: a large indoor shopping area linking both the station and the airport together and providing a nice place to stay for both travellers and visitors.	Rotterdam Centraal is part of the Nieuwe Sleutelprojecten, a group of six Dutch stations that faced large renovations over the past two decades. Characteristic for this station is its large roof that covers part of the station square and creates a spacious station hall. This hall is the centre of the whole node, connecting directly to all modalities.

 Antwerpen Centraal	 Utrecht Centraal	 Arnhem Centraal	 Amsterdam Zuid
39.628 (5th in BE)	207.360 (1st in NL)	45.690 (12th in NL)	68.699 (7th in NL)
8	8	4	2
14 (14)	16 (21)	8 (10)	4 (4)
24	77	33	35
70	45	20	13
No data	25.000m²	21.750m²	1.750m² (-> 5.400m²)
In the city center	Next to the city center	Next to the city center	In the periphery
Antwerpen Centraal is an interesting casestudy due to its vertical configuration. The station's fourteen tracks are divided over three floors, all connected by a large atrium. From every level, the classic shed roof is visible, providing travellers with a sense of place. Also, the ground floor of the station is entirely used for retail, continuing city life throughout the station complex.	Utrecht Centraal is the biggest station of the Netherlands. The station hall is placed over the tracks and acts as a concourse simultaneously, linking all platforms and both sides of the city to eachother. Also, the station features the world's largest bicycle parking, providing a smooth connection from bicycle to train, which comprises 50% of acces trips.	Arnhem Centraal is entirely designed around pedestrian flows running through the station. Large ramps and curves eliminate the need for stairs and corners, creating smooth and comfortable walkways. Routes are guided by natural light in order to guide travellers towards their destination, improving natural wayfinding.	Amsterdam Zuid is the second station for the city of Amsterdam. It is located in the centre of the Zuidas, the Dutch biggest international business district. Soon the station will feature international trains to the south, but first large renovation works are due in order to give the station a facelift and increase its capacity. The station will become a new entrance to the city.

Amsterdam Centraal

Schiphol Aol Airport

Rotterdam Centraal

Antwerpen Centraal

Utrecht Cat Centraal

Arnhem Centraal

Amsterdarrdam Zuid

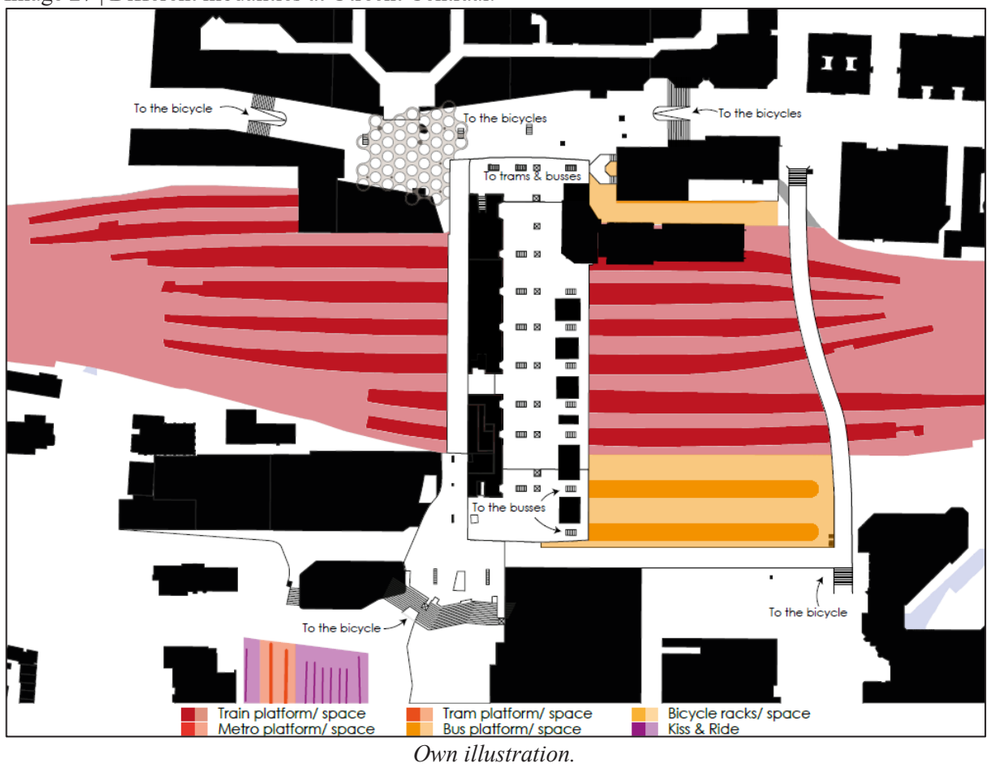
3. Results | Analyses of the stations

In this chapter, the stations will be analysed on the background of the Nolli map that has been drawn for each location. For this research, a large amount of analytical drawings has been produced. The analyses are divided over six different paragraphs, each comprising one of the formulated design principles. For each design principle, it will be assessed whether these principles are visible in the designs of the case studies. In order to keep a clear structure within the paper, only a few exemplary drawings are shown within each paragraph. In the appendix, all analyses are included for further reference.

3.1. Multimodality.

As described in the introduction, in recent years stations face a tendency to implement multimodality. Multimodality combines different modalities within one journey, creating the need for transfers. It aims at using the advantages of different modalities whilst minimizing their negative impacts on for example the journey itself or the climate as a whole. In this paragraph, multimodality as a design principle will be tested via the drawn analyses.

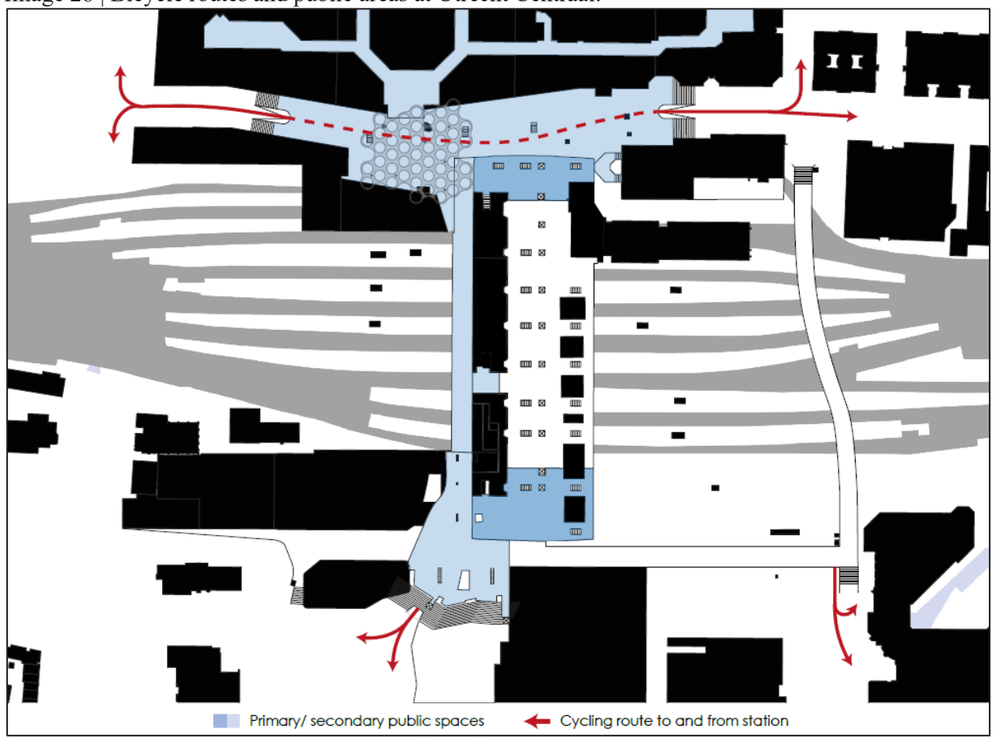
Image 27 | Different modalities at Utrecht Centraal:



Own illustration.

Utrecht Centraal is a station with many different modalities coming together, see image 27. Especially trains and busses occupy the ground floor, but in order to keep a continuous and comfortable pedestrian zone, the station features a safe and open first floor (see also the blue-coloured spaces in image 28). This first floor extends all the way from shopping mall Hoog Catherijne on the Eastside of the station to the Beatrixtheater on the Westside of the station and connects the inner city to the central business district.

Image 28 | Bicycle routes and public areas at Utrecht Centraal:



Own illustration.

Image 29 | The largest bicycle parking in the world at Utrecht Centraal:

Source: Trouw (2019).

In fact, Utrecht Centraal is unique in the way that the station hall is placed over the tracks, rather than besides them. Utrecht Centraal's station hall is visible in both image 27 and 28 as the white area in the middle of the image. At most through stations, such as Rotterdam Centraal and Amsterdam Centraal, the station hall is positioned between the inner city and the tracks, connecting the street to the concourses leading up the tracks. By placing the station hall over the tracks instead, it functions as the main concourse at the same time. Connecting the trains to the other modalities on both sides of the station complex. In order to facilitate a publicly accessible route to both sides of the tracks as well, there is a separate walkway parallel to the station hall, see image 28.

But it is not just the pedestrian that has its dedicated spacing in the urban realm around the station, the cyclist is offered the world's largest bicycle parking facility, see image 29 and 9 in the introduction. Right under the elevated pedestrian zone, there is plenty of room for cycling paths and parking. By using a multi-layered cityscape, both pedestrian and cyclist can coexist without crossing each other's paths.

A station complex can be rather large, which is especially the case for Utrecht Centraal. As described, a station and its railway tracks can form a barrier within the city. Fly-unders and crossovers can mitigate this problem, but especially for cyclists, height differences can be a real challenge and take a lot of space. Looking at image 28, it becomes apparent that at Utrecht Centraal, there are in fact many different bicycle parking facilities with different entrances on each side of the station. This way, it is ensured that cyclists can always easily access the station's parking facilities, park their bike and hop on another mode of transportation.

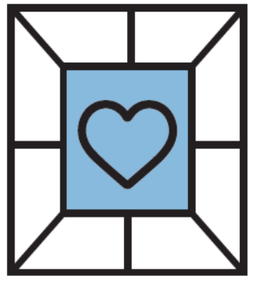
By providing both efficient and high quality places for pedestrians and cyclists, Utrecht Centraal really facilitates travellers to pick active transportation as their access and egress transport. It is conceivable that a hierarchy of different modes as seen at Utrecht Centraal may influence the modal split and the comfort of travellers for the better.

"Multimodality: Offer a wide range of transportation services, stimulate active access and egress transport and reserve sufficient space for walking, bike lanes, bike sheds, et cetera."

As described, Utrecht's, Amsterdam's and Rotterdam's central station feature a station hall. In fact, Amsterdam Zuid is the only exception. At Antwerpen Centraal, this hall is placed at the end of the tracks, as this is common for terminus stations. At Rotterdam Centraal, the station hall is located between the station square connecting to the city and the central concourse leading up to the tracks.

In this station hall, all modalities come together, see image 39. Trams, buses and kiss and ride are located next to the hall, whereas the central concourse is a direct extension of the station hall. Underneath the hall, the metro station and bicycle parking facilities are located. In fact, the station hall is a node within the station's pedestrian network, as it links all important destinations within the complex together.

This leads to the following public space being defined: a central square. The central square plays a pivotal role in connecting the station internally, but also forms the gateway from city to station and from station to city. The central hall provides travellers with a Ideally, all modalities can be reached easily from the central square.

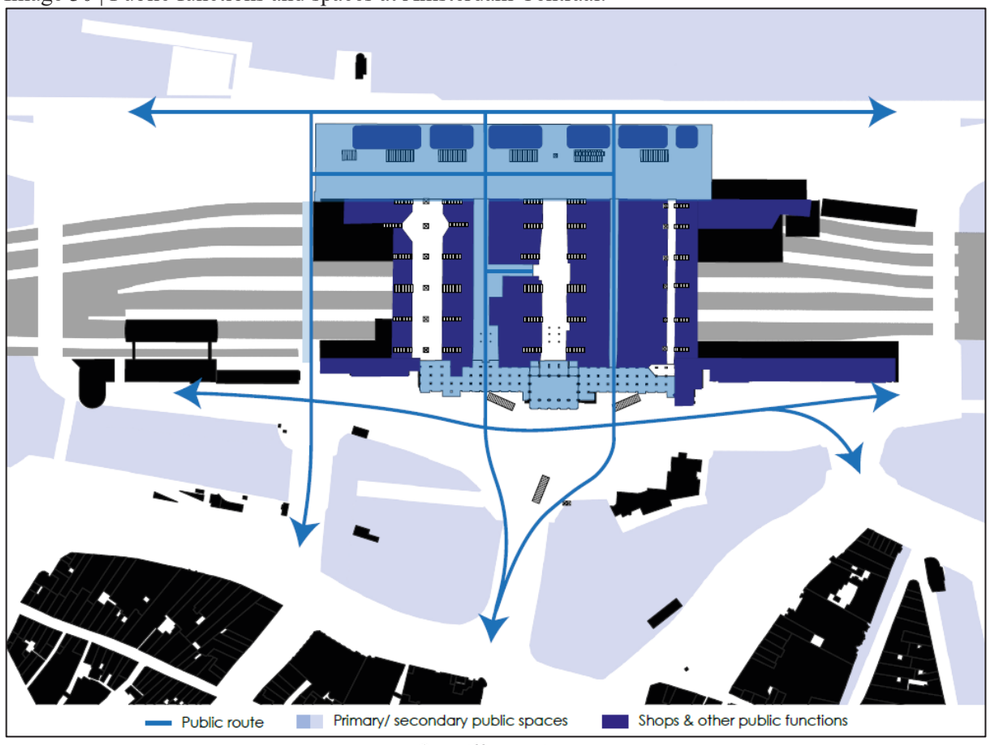


"Central square: this is the heart of the station, everything comes together here. Also, it is the gateway from city to station and vice versa."

3.2. Functional mix.

As described earlier in this paper, a functional mix that attracts different target groups throughout the day can stimulate social control and can induce a feeling of safety in and around the station. Also, transportation hubs such as train stations and airports see a business case in offering more than just transportation services. Business, leisure and other functions are being incorporated in the hubs and turn these hubs into destinations in their own right. In this paragraph it will be assessed whether the design principle of functional mix is present in the selected case studies.

Image 30 | Public functions and spaces at Amsterdam Centraal:

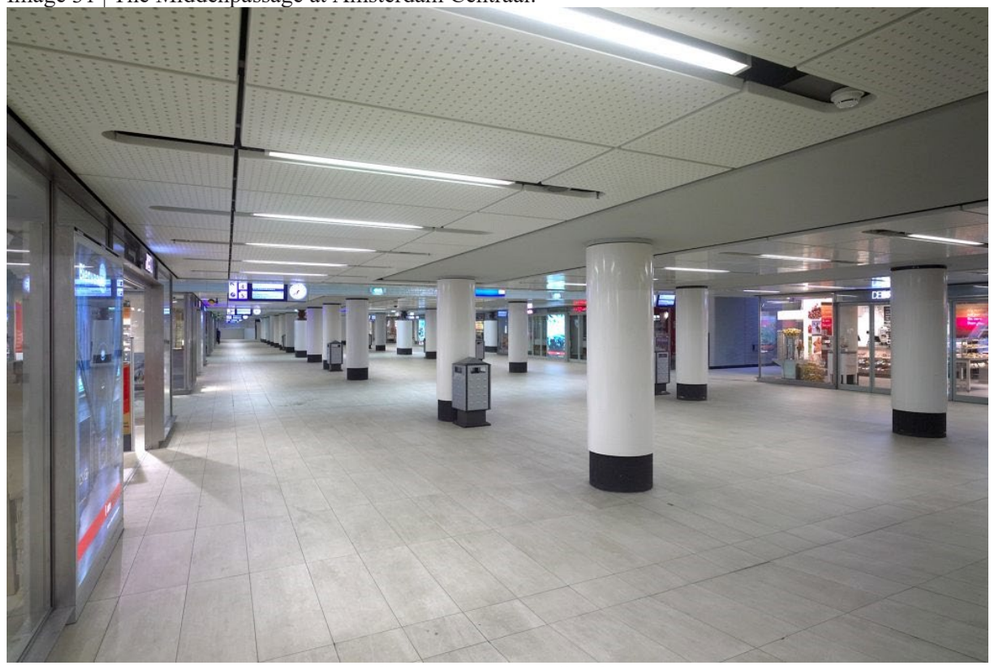


Own illustration.

Amsterdam Centraal may well be the Dutch station with the most public functions in it, thanks to its latest renovation works adding two new concourses. Image 30 shows that five different concourses run underneath the tracks. Three of these concourses (in white) are closed by OV-chip-gates in order to create a dedicated transfer zone for travellers. These concourses have functions that really address the target group of travellers: AH To Go, Smullers, Etos and a floristry, among others. This is a basic formula for many stations.

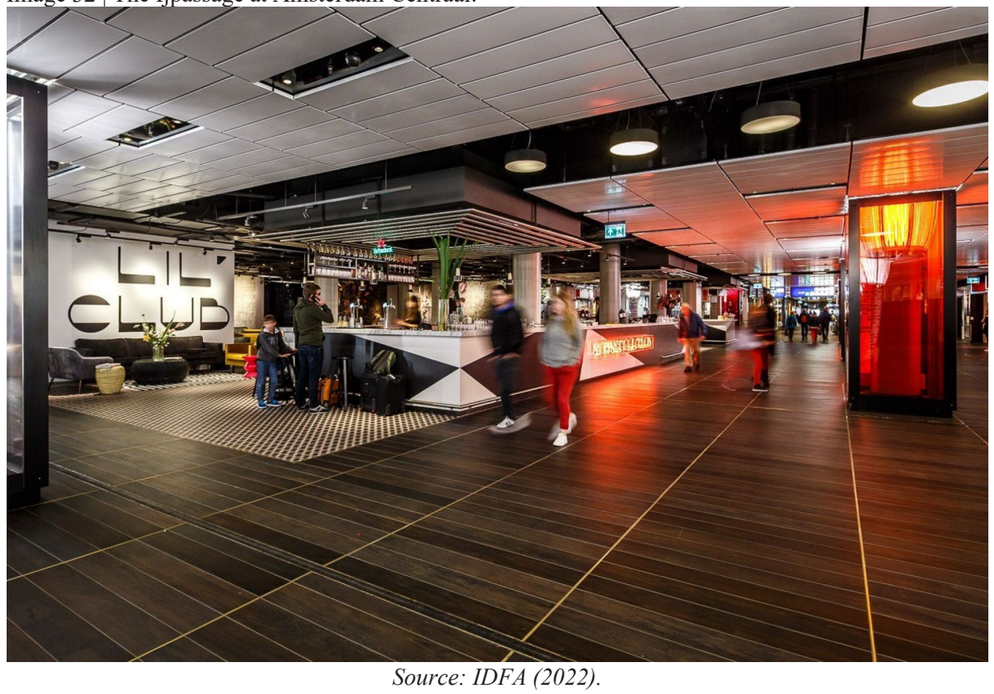
Image 31 shows one of these concourses: the Middenpassage, this is the central white concourse in image 30. The intention behind the concourse's design is not ambiguous: it has been designed for transfer flows. There is no seating available, lighting is bright to make travellers more alert and bright white walls further improve visibility. The functions operate on quick encounters with travellers during their transfer between different connecting lines.

Image 31 | The Middenpassage at Amsterdam Centraal:



Source: Hegeman (2022).

Image 32 | The Ijpassage at Amsterdam Centraal:



Source: IDFA (2022).

For the Ijpassage in image 32, a different purpose is visible. The concourse has no stairs to the platforms on top of it, so this concourse is not for transfers to and from the trains. Travellers transferring through the station between other modalities than the train may use this concourse in order to skip OV-gates. However, this concourse has primarily been constructed in order to be a public place within the heart of the station and a connection from the city centre towards the water front.

The Ijhal in image 33 has been designed to be both a public space and a transfer space. It connects the bus terminal on top of it and the ferries next to it to the rest of the station. Tram 26 and the kiss and ride are located on each far end of the Ijhal, see image 34. Therefore, a lot of transfers take place in this spacious and light hall. On the other hand, a lot of restaurants such as the Schnitzelhaus and the Wagamama are located facing the Ijhal on one side and the Ij on the other side. Also, the Ijhal links all other concourses, including both public concourses. This way, the Ijhal is both part of the public realm and the transfer network of Amsterdam Centraal.

Image 33 | The Ijhal at Amsterdam Centraal:

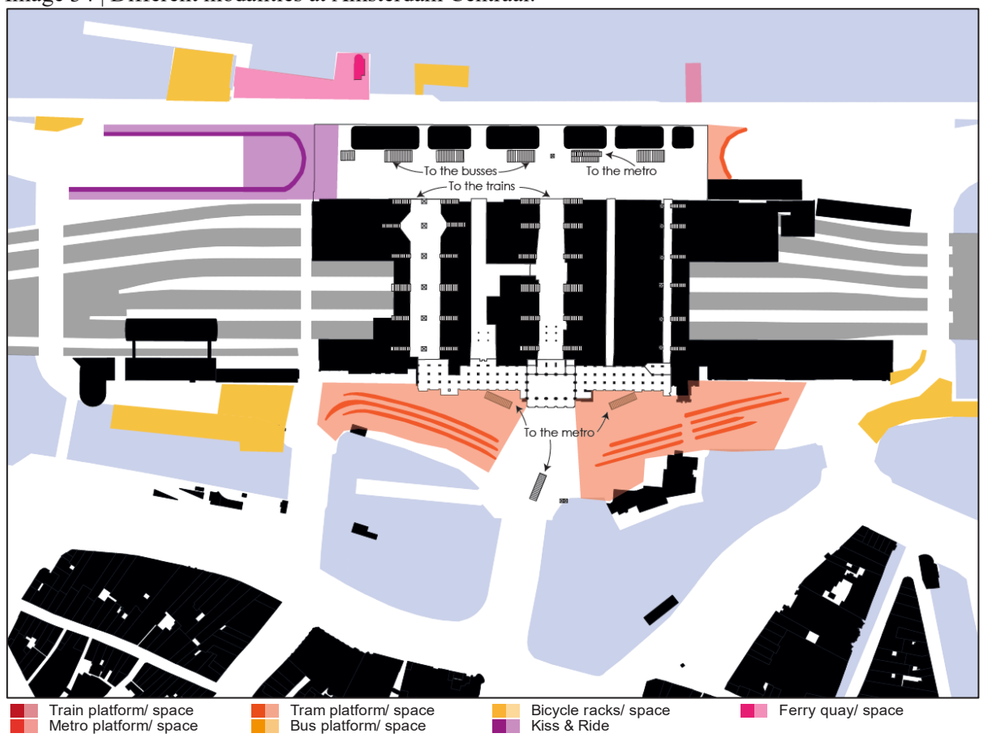
Source: Verwol (2022).

Although both the public concourse and the Ijhal have appealing public functions, it must be noted that the Ijhal scores higher on occupation rate. Because the Ijhal combines the nodal and the public function, it creates both a necessity to cross the space and an opportunity to stay. This is something that the concourses lack. The transfer-concourses do not offer the option to stay, they are rushed instead. Whereas the public concourses possess no necessity for people to enter it.

In that sense, the Ijhal really is an eye-opener, as it thanks a big part of its success to the combination of the nodal and the public function in one space. Apparently, both the combination of the public and the nodal can bring successful public places towards the station. It is crucial to design these places to be as public as possible, so that many different groups are invited to use these space.

Appealing as the public functions in the concourses may be, there will always be highly attractive public spaces around the corner in the inner city of Amsterdam. For shopping, the Kalverstraat and the Rokin offer a much bigger variety of boutiques. So in order for the public functions within the station to be a success, they have to relate to the surrounding city by either being unique in the functions offered or easily accessible by their location.

Image 34 | Different modalities at Amsterdam Centraal:



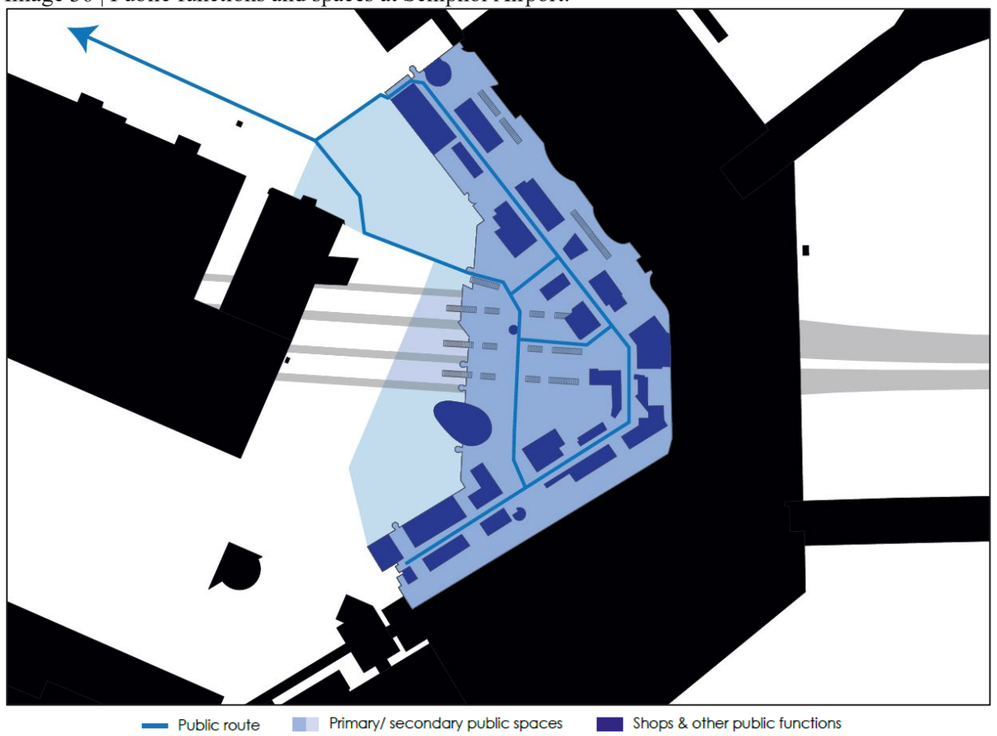
Own illustration.

In a similar way as the Ijhal, Schiphol Airport's central hall (Schiphol Plaza) has a combined functionality to it. Centrally located in the hall are the different stairs and elevators to the three train platforms underneath, see image 36. Surrounding the hall on three sides is a complex of spacious internal streets featuring 38 shops and eighteen restaurants and cafés, forming the buffer zone between the central hall and the terminal, see image 35.

Image 35 | One of the streets at Schiphol Plaza:

Retrieved from Travelpro, 2021.

Image 36 | Public functions and spaces at Schiphol Airport:



Own illustration.

Image 37 | Schiphol Plaza's main hall:

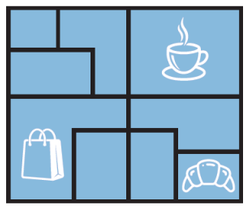
Retrieved from: Wikipedia, 2020.

At Schiphol Airport the platforms of the station are situated underground entirely whereas the main hall, Schiphol Plaza (image 17), connects the station to the airport at ground level. Schiphol Plaza has a large variety of urban facilities, ranging from restaurants to fashion boutiques to even a supermarket and a branch of the Rijksmuseum.

Schiphol Plaza features a total of 37 shops and eighteen bars and restaurants (Luchthaven, 2020) of which most feature opening hours till 22:00h in the evening. Schiphol Plaza has a total area of 22.000m^2 (Benthem Crouwel Architects, 2020). Unlike most of the airport, Schiphol Plaza is accessible to the public. No OV-card or passport is needed.

At Schiphol Airport, it seems that the implementation of the Airport City concept has led to the formation of an urban station. 'City life' stretches over the ground floor through Schiphol Plaza with an abundance of shops and if one takes the stairs downward, the train platforms are reached. This is just an example of how mobility and public life can exist together.

Similarly, if one would walk into one of the public streets surrounding the central square, the terminal can be reached. Hence these streets do not just offer leisure to travellers and visitors, they also facilitate passenger flows from the station to the terminal and vice versa. This way the shops can benefit from a large flow of pedestrians, giving them exposure and many potential customers. Whereas the travellers benefit from the scenery on their walk and the high level of amenities and services, providing them with anything they might need on their journey. This mutualistic relation between the nodal and the public function of the station should be put to good use, hence the following definition of public places:



"Public places: The programme of the location is as public as possible, offers a wide range of functions and amenities that attract citizens 24/7 and coexists harmoniously with the nodal function."

In order to make the programme as public as possible, a wide range of different shops, cafés and other functions is not enough. Cafés and restaurants for example, do impose certain rules or requirements on their customers. In general, in order to sit on a terrace, one should buy at least a drink or a snack. Luckily, in a well-designed station there are plenty public spaces where people can sit without restrictions. However, usually these spaces are located outside and for example only feature secondary seating.

In order to really make a unique space, a station living room could be implemented in the station, see image 35 on the following page. A station living room is a public space within the station, offering a comfortable place to stay. Luxury seating, free wifi, a place to charge your phone, a restroom and some newspapers on the table. The station living room is a traveller's home away from home. Currently, there are already some initiatives featuring station living rooms in The Netherlands, such as at Arnhem Centraal, Den Haag Centraal and Rotterdam Centraal (Stationshuiskamer, 2022). I would argue that the station living room is crucial when creating urban stations.

"The station living room: a comfortable, freely accessible public place at the station in which travellers can feel at home, they can meet up, grab a bite, read a paper or just recharge."

Image 38 | A station living room:

This is the station living room at Rotterdam Centraal, notice the wooden slats in the ceiling of the station hall in the back. This particular station living room features comfortable seating, a library, different 3D-models of Rotterdam and a bar where one can order beverages and snacks. See also appendix 1 for a photo rapportage.
Retrieved from Stationshuiskamer, 2022.

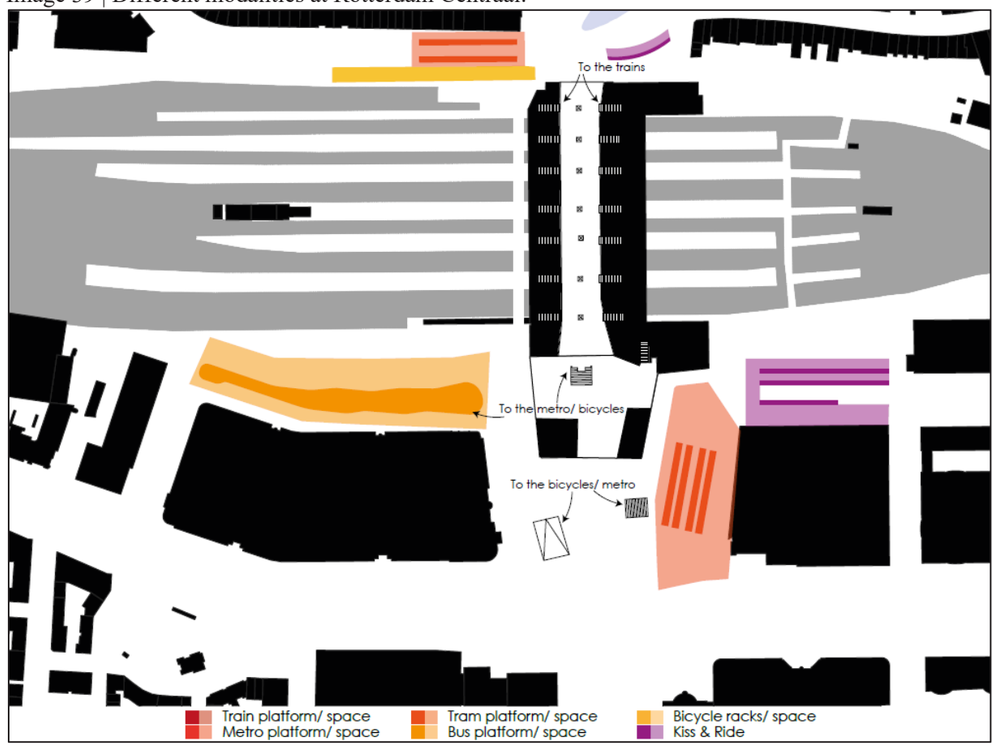
3.3. Connectivity.

In recent years, station design in The Netherlands shows a clear tendency in restoring connections between both sides of the tracks, especially in the new designs known as the 'Nieuwe Sleutelprojecten'. As is visible in image 27-29, the station hall of Utrecht Centraal is placed over the tracks, connecting both the platforms and each side of the city altogether. This greatly benefits the connectivity for pedestrians around in and around the station area.

As described in the introduction, the pedestrian zone is the area that links the station. This connection runs within the station on one hand, but also between station and city on the other hand. A well designed pedestrian zone within the station ensures smooth and pleasant transfers for travellers, whereas a well-designed pedestrian zone around the station complex ensures a good connection between different parts of the city and between station and city.

This is in addition to the functional relation that has been described in the previous paragraph. Looking at the examples of Rotterdam Centraal, Arnhem Centraal and Antwerpen Centraal, the pedestrian zone will be analysed hereunder to see how connectivity plays a part here.

Image 39 | Different modalities at Rotterdam Centraal:



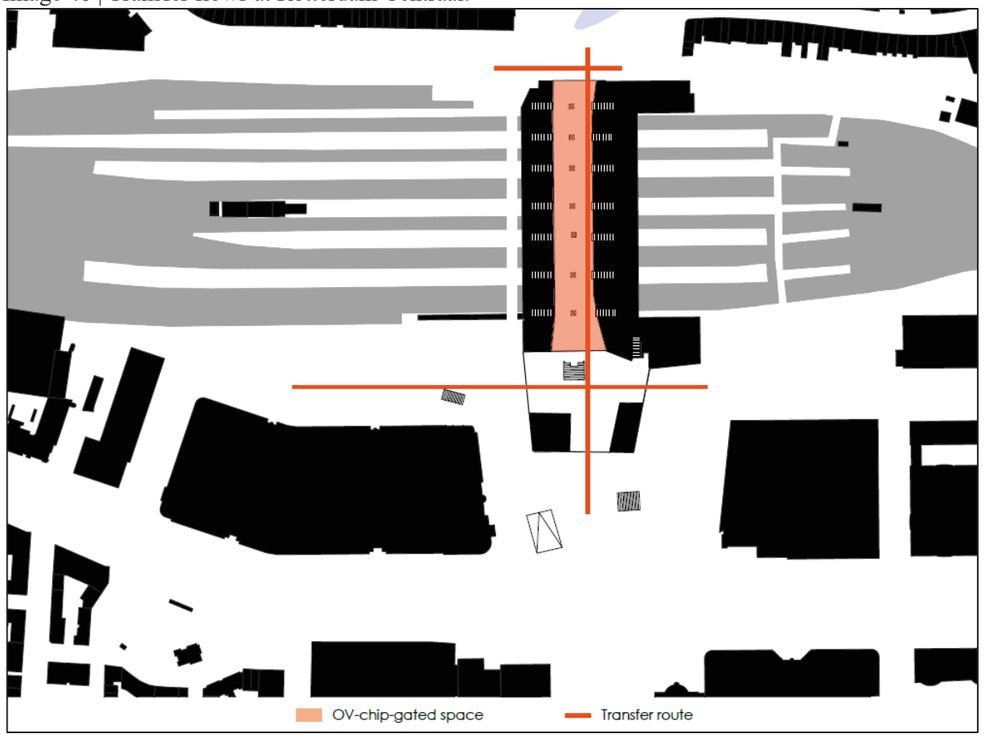
Own illustration.

Rotterdam Centraal is a station that characterizes itself by a very clear setup, see image 39. One central concourse runs under the tracks and connects the train platforms with the station hall, that is surrounded by all other modalities. On the Northside of the station, there is a taxi stop, some bicycle racks and the remnants of a former tram stop. The lines that used to stop there, now stop at the Southside of the station, together with all other tram lines. As a result, all busses, trams and metros stop on one side of this station, accompanied by an extensive bicycle parking facility, car park and a kiss and ride.

The result of this setup is that transfers between different modalities other than the train, can happen via the more spacious station hall and accompanying square, see image 40 and 41. These transfers do not need to cross the concourse, which can be dedicated to travellers departing or arriving by train or passers-by just crossing the station.

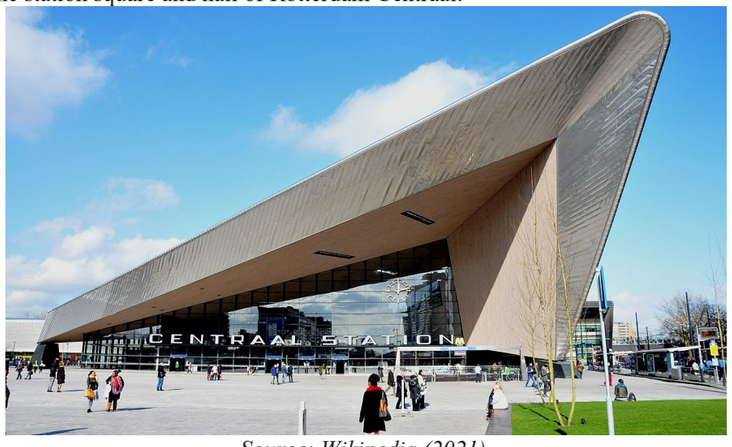
The minimalistic setup in Rotterdam and the fact that all modalities (other than the train) are situated on one side of the station, create short and simple transfers. It also alleviates pressure on the concourse. By keeping an eye on a clear configuration of the station and by designing the internal pedestrian zone in a clear and comfortable way, designers can ensure smooth connectivity within the station.

Image 40 | Transfer flows at Rotterdam Centraal:



Own illustration.

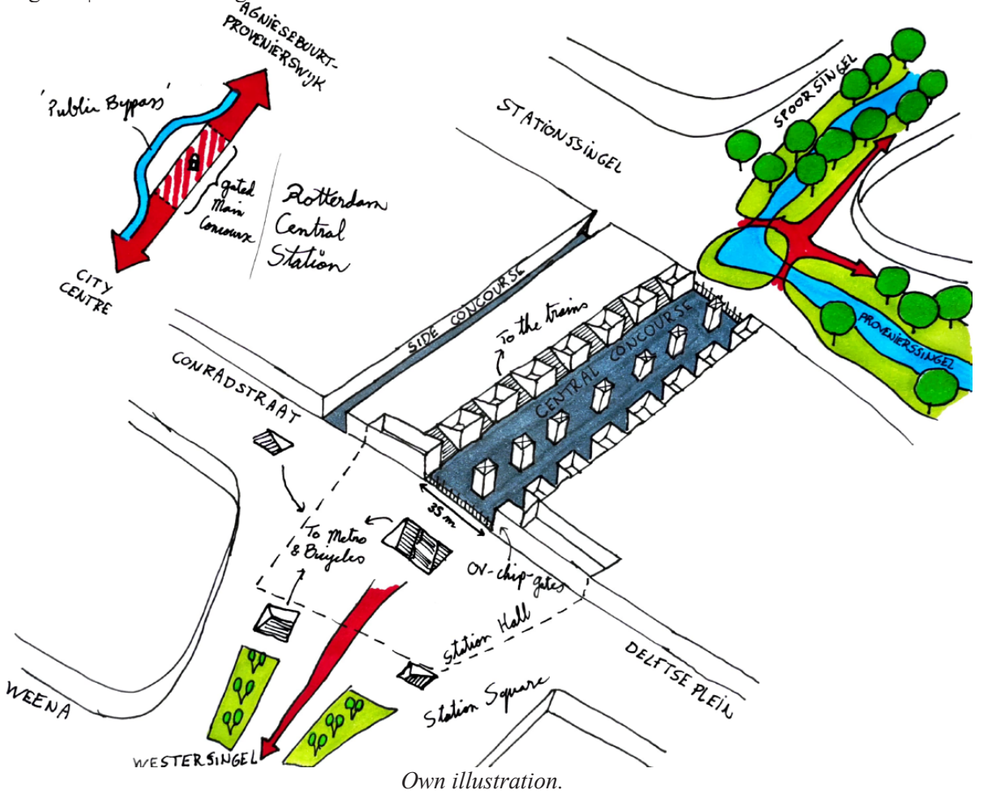
Image 41 | The station square and hall of Rotterdam Centraal:



Source: Wikipedia (2021).

Looking at Rotterdam Centraal (image 40 & 41), it becomes clear that not just the internal connectivity has been thought of. A clear and well connected axis (image 42) runs through the spacious station hall and concourse, connecting subsequently the Westersingel, the station square, the station hall, the concourse, Provenierssplein and the Spoorsingel and Provenierssingel. From the inner city, the station is easily accessible. The central axis from Westersingel to Spoorsingel is located at ground floor level. Other modalities make way for active transportation: most cars pass under ground level through the Weena tunnel, whereas trams and busses have been moved to the sides of the axis, see image 41. Even the bicycle lanes move to the side, giving free reign to pedestrians.

Image 42 | The axis through Rotterdam Centraal:



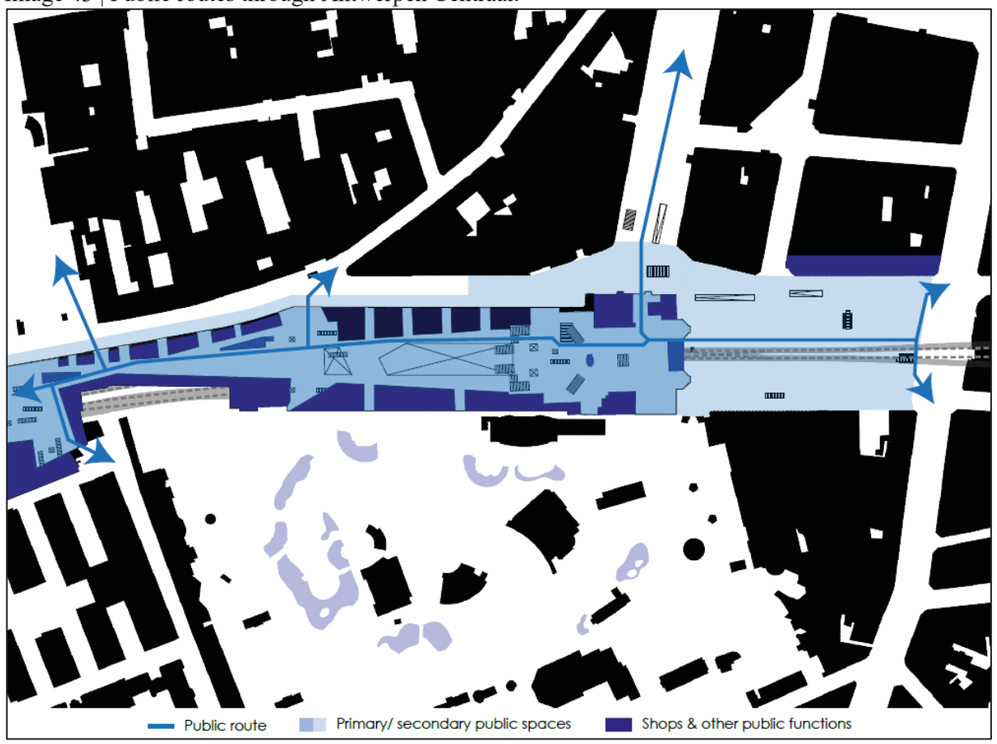
Own illustration.

Although the Central Concourse has a very good spatial connection with the surrounding grid, there is one major disadvantage to it. The concourse is not a public space because it is closed off by OV-chip gates. Therefore, only citizens with a valid OV-chip card or train ticket may enter the concourse. Although a very pleasant and spacious concourse, well-connected to the city, it is not accessible for all.

In order to facilitate a connection for the public, a side concourse has been created for both pedestrians without the proper card or ticket to enter the Central Concourse and cyclists. This way, Rotterdam Centraal enables a smooth connection between both sides of the city, although the side concourse has a much lower spatial quality. If one where to choose, the Central Concourse would be the preferred route due to its much better spatial quality and visibility.

Another station that stands out in creating a strong physical connection between station and city is Antwerpen Centraal. Earlier on in the paper it has been mentioned that stations can play a pivotal role in connecting different parts of cities for pedestrians. Antwerpen Centraal is a great example of a station with a fine-grained network of routes, providing plenty connections between the station building and the surrounding city streets, see image 43.

Image 43 | Public routes through Antwerpen Centraal:



Own illustration.

In image 43, the ground floor of Antwerpen Centraal is shown. Looking at this floor, a lot of connections between the central concourse and the surrounding streets are visible. Especially between the concourse and the Pelikaanstraat that is situated on the upper side, parallel to the station. This is also visible in image 44 on the next page, as a lot of openings in the façade provide either visual and/or physical connections between the interior and the exterior. Also note the amount of public functions at the ground floor: it is really a continuance of the city and similar to Amsterdam Centraal and Schiphol Plaza in size.

There is however one exception, on the South side of the station, the Antwerpen Zoo is located. Therefore, towards this side there are no connections. Imagine if it was another residential area, how would Antwerpen Centraal's ground floor be used by pedestrians then?

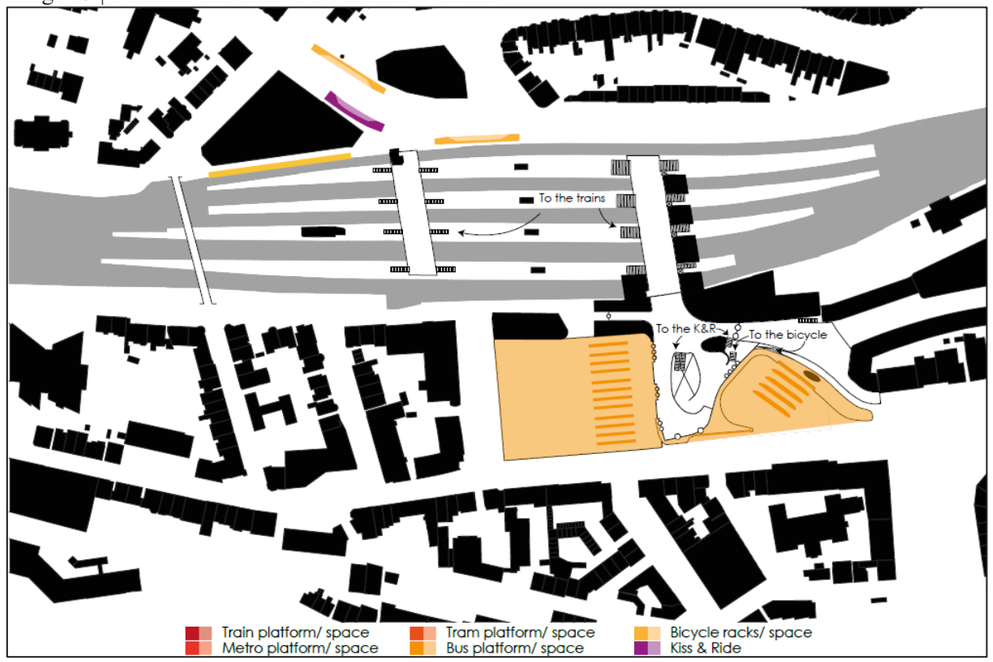
An important reason for Antwerpen Centraal's openness is the lack of ticket gates. Because the tracks are partly elevated and partly subterranean, the ground floor is free of obstacles and everyone is free to enter and walk through the station. In that sense the ground floor of Antwerpen Centraal really is a public space and a continuation of the city.

Image 44 | The Pelikaanstraat next to Antwerpen Centraal:

Source: Antwerpen Morgen (2022).

Arnhem Centraal is another great example of a station that really created comfortable and high quality walking connections. In image 45, the different modalities at Arnhem Centraal have been depicted. In image 46, the resulting transfer flows are shown, connecting these different modalities. It shows that within Arnhem Centraal's station hall, a lot of different flows come together. Around the hall, the concourse towards the train and multiple bus platforms are located. Underneath the hall are parking facilities for both bicycles and cars. On top of the hall, a kiss and ride is situated on an elevated landscape. Also multiple offices can be reached from there, including the two office towers.

Image 45 | Different modalities at Arnhem Centraal:

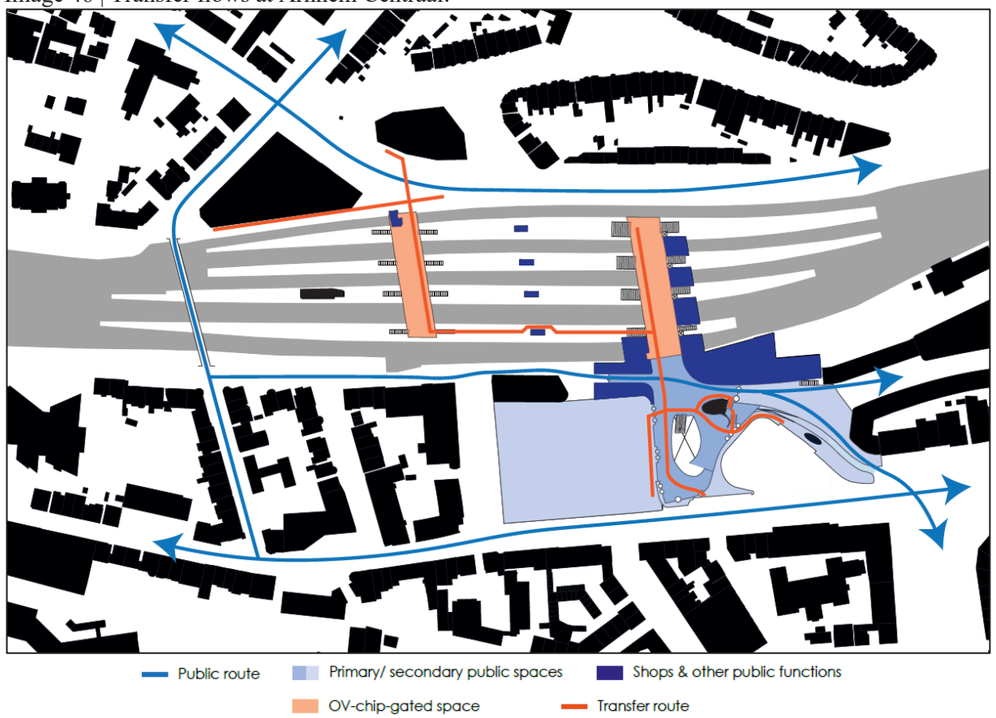


Own illustration.

Station halls often take in a central position within a station and because so many flows cross in the hall, it can be a problematic situation. People can lose their orientation, forcing them to stop. Which in turn leads to congestion. Therefore, natural wayfinding is a key factor. At Arnhem Centraal, the different routes can organically move through the hall, see image 47. Curves create natural routes without the loss of orientation and daylight guides travellers towards their destination. The lack of stairs removes the need to watch ones feet, improving the ability to navigate through the space.

The station hall of Arnhem really is an original because of its novel way of connecting flows through ramps and elevated landscapes, see image 48. From the city centre, pedestrians can walk straight into the station and cross it via multiple routes, each on a different level. Travellers hurrying for their train take the ramp to the concourse at -1, whereas business(wo)men working in the office towers, choose the ramp that leads to the elevated cityscape on top of the station hall.

Image 46 | Transfer flows at Arnhem Centraal:



Own illustration.

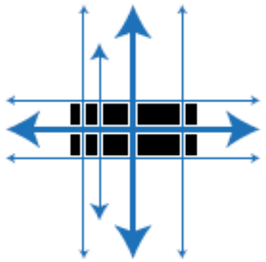
Image 47 | The station hall of Arnhem Centraal:

Own image.

Image 48 | Smooth transitions between multiple floors at Arnhem Centraal:

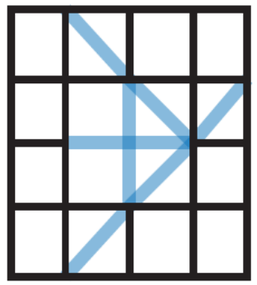
Retrieved from Architectuur, 2016.

Enabling a comfortable and smooth pedestrian zone that connects both the station internally as the station and the city to one another is crucial when aiming to integrate the station within the city, hence the following definition:



"(Inter)connectivity: Minimize the barrier effect of the station and strengthen connectivity between both sides of the city and station and city by creating plenty passages and cross-unders."

The case of Antwerpen Centraal's ground floor with its permeability all around and the case of Amsterdam Zuid with the Minerva concourse (this will be analysed more thoroughly in the next paragraph) both show the importance of connections between both the city and the station and both sides of the city. When designing a station area, it is highly advisable to aim to create a smooth continuance of the city's grid throughout the station area such as in Antwerpen Centraal. The way to do this is by adding streets and making sure these streets are designed for the right target groups. As described earlier, pedestrians and cyclists should have priority in the station area, hence the formulation of a new public place follows:



"Connecting streets: provide both extra connections within the station and between city and station, aiming to create continuous routes prioritizing pedestrians and stimulating cycling."

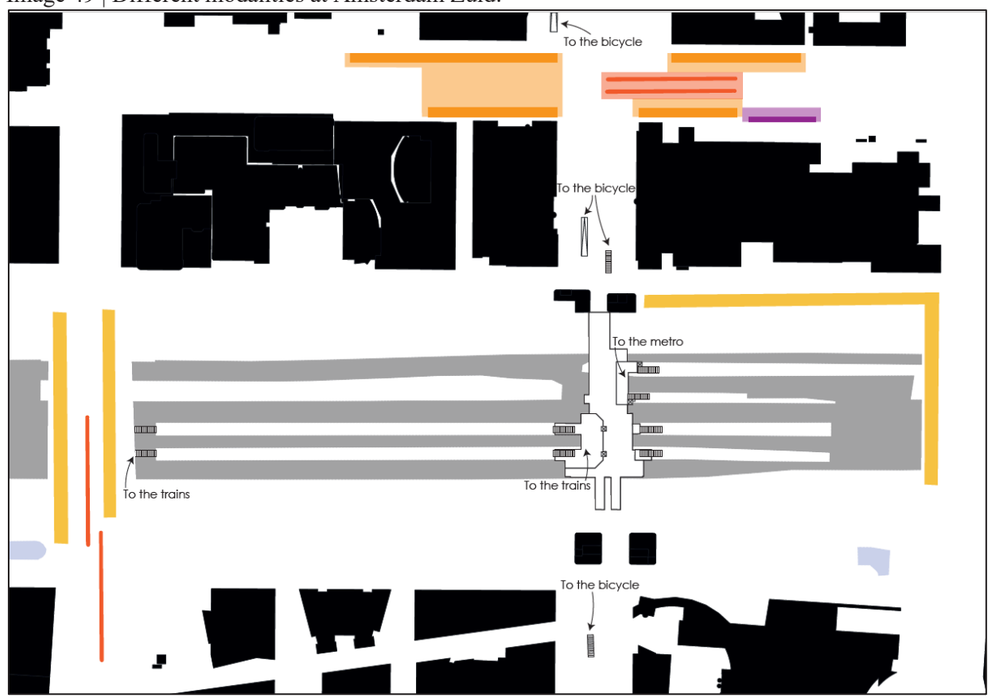
3.4. Spatial Quality.

After people have a reason to enter the station and a route that leads them there, it is up to the atmosphere of the space whether they decide to stay longer or not. As described in the introduction: the use of high quality materials, plentiful daylight and greenery and a variety of options to sit, invite people to stay. This is crucial when creating a high quality public place.

In order for the station to be integrated within the city, the station can copy urban features. The functional mix and good pedestrian zone have already been mentioned, in this section the role of spatial quality will be further analysed through the example of Amsterdam Zuid.

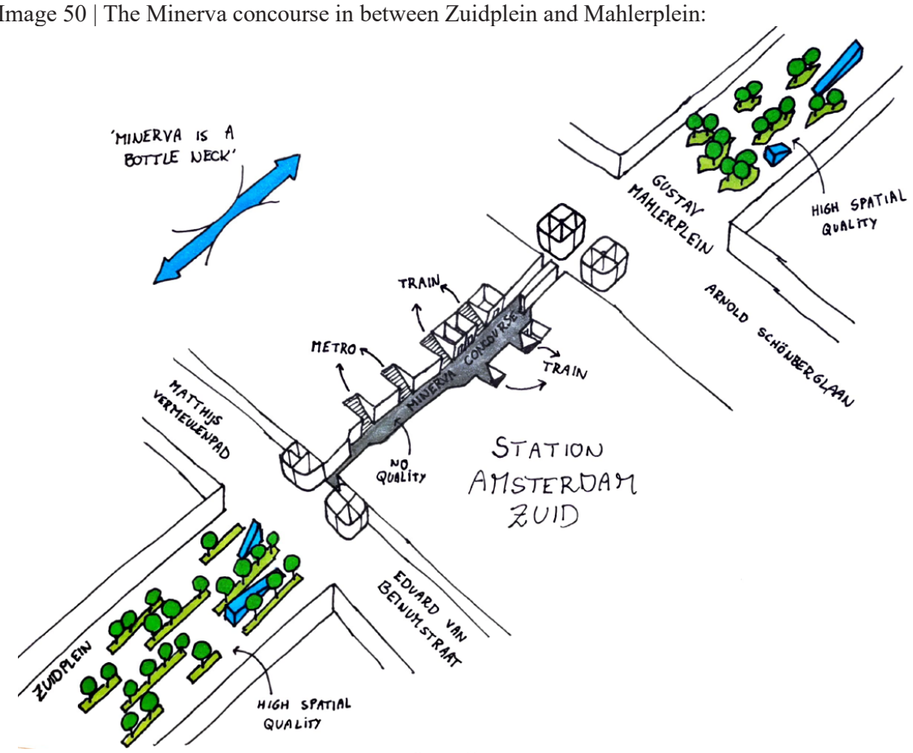
Amsterdam Zuid is an example with a questionable spatial quality in the public space surrounding the station. In its current shape, the station is quite distinct from the other stations in this paper. The station is rather small, counting only four train tracks and two island platforms. It also lacks a station hall, or at least, a covered one. In fact, Zuidplein functions as the station's main hall, connecting train and metro to bus, tram, bicycle, kiss & ride and taxi, see image 49. Zuidplein is located on the North side of the Minervapassage, see image 49-51. The Minervapassage is the main concourse running through the station, connecting both the train and metro platforms and both neighbourhoods on each side of the station.

Image 49 | Different modalities at Amsterdam Zuid:



Own illustration.

Image 50 | The Minerva concourse in between Zuidplein and Mahlerplein:

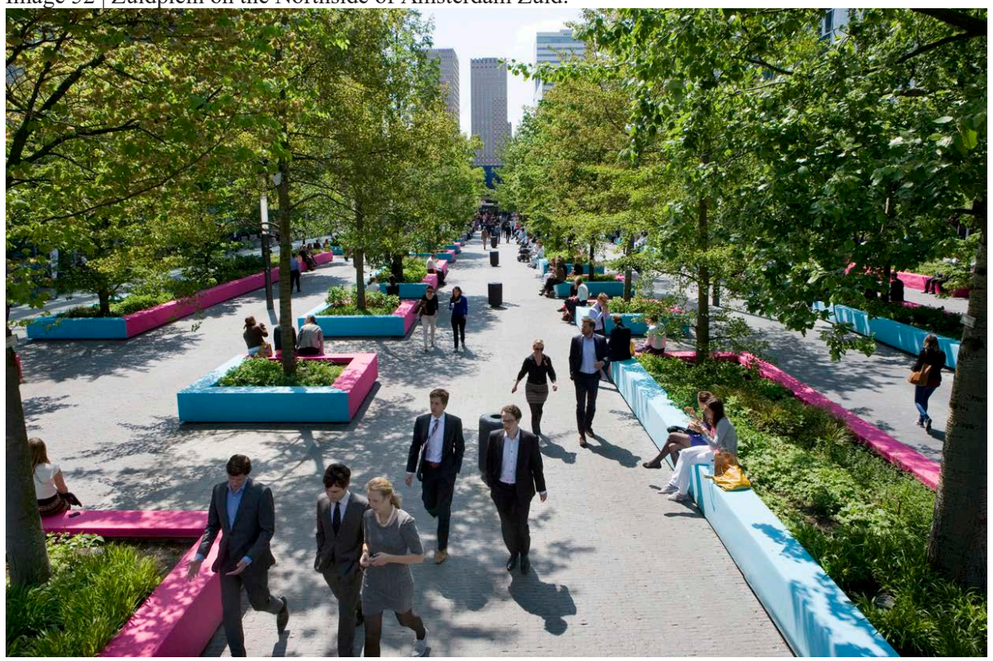


Own illustration.

Image 51 | The Minerva concourse at Amsterdam Zuid:

Retrieved from Zuidas, 2019.

Image 52 | Zuidplein on the Northside of Amsterdam Zuid:



Retrieved from: Service Studievereniging, 2015.

Image 53 | Gustav Mahlerplein on the Southside of Amsterdam Zuid:

Retrieved from Zuidas, 2018.

Looking at image 52, the Zuidplein is well-used by citizens, mostly business men and women that work in nearby offices. There is a high spatial quality at the square, with lots of greenery and secondary seating so that people can have a nice lunchbreak for example.

In that sense, Zuidplein is similar to Amsterdam Centraal's Ijhal. Both the nodal function (most modalities are situated around Zuidplein) and the public function (people that work in the area relax at the square during lunchbreaks, enjoying the cafés and restaurants in the plinths) are present. A difference however, is that Zuidplein really is a part of the city instead of the station. Where the Ijhal is located within the station of Amsterdam Centraal, it is the other way around at Amsterdam Zuid, where the station is located within the public realm. An important factor contributing to this, is the lack of a dedicated station building and station hall.

In fact, the Minervapassage is the only part that really feels as a 'station', and not as a part of the city. It is a rather dark and small concourse that runs underneath the tracks. Due to the bad spatial quality, see image 51, the Minervapassage has no public meaning. It is a non-place connecting the station and both the North and South side of Amsterdam Zuid. The nodal function clearly dominates the space. The few functions that are present in this concourse, are focused on the traveller in a similar fashion as Amsterdam Centraal's Middenpassage. The concourse does not attract a wide range of citizens, it facilitates travellers with some basic amenities and nothing more. The concourse is not a place where people like to stay voluntarily, nor is this being facilitated (for example by the lack of seating).

Characteristic for Zuidplein and Mahlerplein is their relatively green infill. The squares feature many trees, surrounded by integrated secondary seating. These two squares stand in contrast to the other station squares at Amsterdam Centraal and Arnhem Centraal for example, where greenery is virtually absent.

But what is most striking, is the contrast between these bustling and liveable city squares and the Minerva concourse and the viaducts that run between them (see image 50-53). Due to the infrastructural bundle that divides both parts of the Zuidas and the lack of design vision for the concourse and the viaducts, that emerged mainly as utilitarian infrastructure, the differences in spatial quality are enormous.

Although the concourse and the viaducts aim at mitigating the station's barrier effect by providing routes to cross the railway, the lack of spatial quality results in a social barrier. At night, the concourse and the viaducts are shady parts of the city where personal safety can become an issue.

In the new design for Amsterdam Zuid, that is currently being constructed, the architects aim at improving the spatial quality of the Minerva concourse in order to create a continuous comfortable experience when walking from one side to the other, see image 54. In order to do so, the concourse will be widened up to a width of over 40 meter, even wider than the concourse at Rotterdam Centraal that has a width of 35 meter. Also, the plinths of the station will be entirely filled with shops and services. Large glass facades create an open atmosphere providing passers-by and travellers with interesting views in the functions behind the façade.

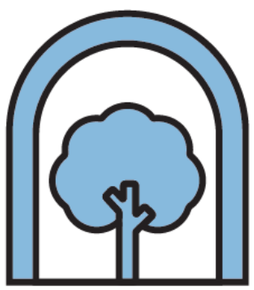
The case of Amsterdam Zuid shows the consequences that emerge when a station area has poor spatial quality and inhibits city life. In order to remove the social barrier of the railway infrastructure, spatial quality in crossings is crucial, hence the following definition of spatial quality:

"Spatial quality: the public space in and around the station is diverse, of high quality and is inviting to all. It induces a feeling of safety and acts as a connector of the urban fabric"

Image 54 | The new design for Amsterdam Zuid and it's Minerva concourse:

The new design for Amsterdam Zuid station and it's Minerva concourse bij Zwart Jansma Architects, Team V and Arcadis. The small columns and high roof create a welcoming entrance for the Minerva concourse and the wide and bright concourse facilitates a comfortable connection between both parts of the Zuidas.
Retrieved from: ZJA, 2022.

Within cities, both squares and parks have an important place within the network of public spaces. Squares and parks provide the city with valuable and diverse outdoor places for both locals and visitors. Although most stations feature a station square, none of the analysed stations features a park (with the exception of the new Amsterdam Zuid). Nevertheless, a park could give a very nice addition to the range of available places. If stations aim at integrating within the city and take over characteristics of the city in order to form a continuance of the urban fabric, a park is part of the architect's/ urbanist's toolbox here. Especially given the current climate crisis and the positive influence of parks on wellbeing and city climate in combination with the sustainable nature of public transportation, parks can convey a message in the station area. Hence the following public space has been formulated:



"Welcoming park: a green space that provides a comfortable experience for both travellers and citizens and that helps in improving the local climate."

3.5. Visibility.

Although the aim of this paper is to define how a station can be seamlessly integrated within the cityscape, this is by no means a way to disguise the station in any way. In fact it has been stated in the introduction that it is rather important that the station remains recognizable as such in order to guide travellers towards their goal.

Whereas traditional grand station buildings such as Amsterdam Centraal, consisting of a front building (made out of brick, facing the city) and a train shed on the backside (usually glass and steel, covering the platforms and the tracks), is easily recognizable. A modern integrated urban hub might be less so, especially if the train tracks and platforms are not in plain sight but underground for example as is the case in image 16 in the introduction.

Image 55 | The roof of Rotterdam Centraal clearly distinguishes the station from its surroundings:

Retrieved from Schlijper, 2017.

Thanks to its iconic roof, Rotterdam Centraal is easily recognized, see image 55. Although Rotterdam Centraal has been recently constructed being one of the 'Nieuwe Sleutelprojecten', it still consists partly of the traditional notion of the separate station building, but the building does make an attempt at continuing city life within it by creating strong visual and physical connections between its interior and exterior.

If a station is really going to be part of the city, the station building will no longer be a separate structure. In the case of Amsterdam Zuid, due to the lack of a dedicated station building, the station is unintentionally already exploring this new typology. All that the station consists of is a concourse which provides access to the platforms and two squares that actually belong to the city. Because the station is located in between the highway, on a dike, the station would be hardly visible from the street.

Instead of a large roof, a clock tower or an arrival hall, the station uses a bright blue screen to display itself towards the city, see image 56. This way, it provides clarity to travellers on where to head when trying to catch a train. Apart from the comfortability offered by the station, or the availability of services, the station makes an interesting example of a station with a large potential to be further embedded within the surrounding cityscape.

Image 56 | The bright blue screen at Amsterdam Zuid:

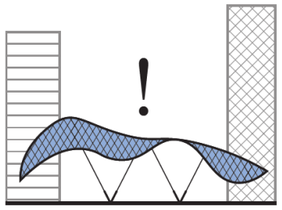
Retrieved from NRC, 2019.

Image 57 | Berlin Hauptbahnhof:

Retrieved from gmp, 2022.

Berlin Hauptbahnhof (image 57) is another interesting example. In fact, the station is nothing more than a cross-shaped glass roof spanned in between two n-shaped office buildings. The office buildings where built as being part of one integrated design, completed as early as 2006. Just like Rotterdam Centraal and Amsterdam Centraal, the station features a large roof covering the station and sheltering its travellers. However, at Berlin Hauptbahnhof the city actually continues through the station. Important walkways to and from the centre are not hindered by the railway infrastructure, which is put both above and underground.

The large integrated roof gives the station a clear visibility from the surrounding city, but the roof creates much more than just a station. It creates a new part of the city, which is essential for an integrated urban station. Hence the following definition of visibility:



"Visibility: the station is distinctive and clearly visible from its surrounding city scape, it provides good orientation towards both travellers and passers-by."

In order to create the aspired visibility, a monumental element is required to distinguish the station from its surroundings. On top of this, the monumental aspect should create new valuable spaces for the city and or the station. It may provide space for large public gatherings in order to act as an urban catalyst:

"Monumental aspect: a monumental element that creates recognizability and provides a space for public activities and acts as an urban catalyst."

3.6. Flexibility.

On one hand, stations are usually built to last for multiple decades to a century, whereas on the other hand society and technology change continuously (Spoorbeeld, 2016). As a result, many stations undergo numerous renovations and changes over time, see once more image 22. Think of platform extensions, widenings of concourses, additions of new modalities or putting tracks underground. In order to create a more flexible station design, three possible strategies have been described: over-dimensioning, flexible structure and 'Plug-&-Play-concept'.

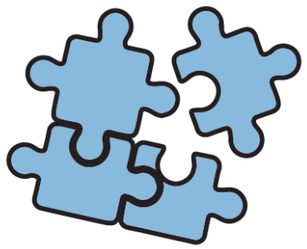
An example of over-dimensioning can be found at Rotterdam Centraal, where the roof covering the platform and the tracks is broader than the current station requires. Instead, the roof extends in Northern direction beyond the seventh platform, see image 58 hereunder. Note that there is no track on this side of the platform. In the future, the seventh platform could well be widened and an extra track could be placed adjacent to it, increasing the station's capacity.

Image 58 | The North side of Rotterdam Centraal:

Retrieved from 3Develop, 2022.

In contrast to Rotterdam Centraal, the underground station at Schiphol Airport faces difficulties pertaining to its capacity. The Schipholtunnel currently features four tracks, at the station these tracks split to six tracks accompanying three island platforms. Because of the described increase in train travels in the introduction, the station needs to expand. However, because the station is surrounded by the airport's underground infrastructure, this proves to be impossible. Next to the station are located Schiphol Airport's underground luggage handling facilities, therefore, the Schipholtunnel cannot be widened and capacity will be limited.

Would the station for example have been over-dimensioned, by keeping space for an extra island platform with two tracks, only realised in casco, this could have eliminated future problems. Especially when designing an integrated station such as Schiphol Airport, it proves crucial to keep in mind necessary future alterations. In combination with the importance of minimizing construction hindrance, flexibility will be defined as follows:



“Flexibility: Over-dimensioning and structural flexibility enable the station to adapt to ever-changing circumstances and minimize construction hindrance for the surrounding city.”

At Rotterdam Centraal, the excess space under the roof is not used for any particular reason other than sheltering the far end of the concourse. Seen from the platforms at the first floor, gravel is visible on the roofs of the retail units underneath. In this particular case it might be odd to think of any other scenario, but this currently unused space could perhaps be of more means if it was given a flexible infill for the time being.

A public plays might be difficult to prove feasible due to the remote position within the station complex. However, a vertical farming installation could be a useful infill, as it could take years before this part of the station would be put to good use otherwise. This is just a suggestion, but it is actually an important aspect.

Because of the high construction costs of large public buildings, it is important that they are used efficiently. Over-dimensioning a station could be crucial for a station’s future, but it is hard to pitch to a developer if the space remains unused or creates no profit for years. Especially when spaces are located near flows of people, it is important that all space has a meaningful infill in order to prevent shady corners and an uncomfortable atmosphere.

Over-dimensioning can also be the result of temporary vacancy of a retail unit or it can be the result of creating a landmark, see the previous paragraph. However, this does not change the excess space. Both for smaller and larger spaces that are meaningless for long enough periods, temporary infill should be arranged, just like the symphonic orchestra performance or the art studio at Rotterdam Centraal in image 23 in the introduction. In that sense, NS Stations and municipalities could act as a curator for stations in order to give meaning to excess space and provide a place for cultural manifestations in the urban station. This enhances the integration of the station within the city and provides a nice surprise for travellers and passers-by, leading to the formulation of the last public space:

“Temporary infill: the excess space in the station is put to good use by enabling temporary (public) functions and cultural manifestations. This enhances the urban character of the station.”

4. Conclusion

In summary, public transportation is on the rise. More and more people will choose public transportation over more pollutant modes as a result of an increasing climatological concern, an improved city planning and the emergence of new modalities. As a result, new modalities such as hyperloop will further complexify the station if implemented. This increased complexity reinstates a focus on the nodal function of the station within the design process.

It has also been described that stations are increasingly seen as a place to stay, rather than just a space to pass through. Besides the traditional way of designing stations as efficient transfer hubs, stations are now being designed as a public place as well. They are intersected by public routes, they house public functions and they offer places to stay for their users. A similar tendency can be seen at airports, where airport cities and aerotropolises redefine and enrich airport development.

The integration of urban features within stations is important as stations are often situated in central parts of the city. By integrating the station in its urban surroundings, a continuous cityscape can be achieved. One in which station and city are connected seamlessly. This mitigates the barrier-effect that stations generally impose on their urban surroundings. In order to achieve this, a proposition for six design principles has been described in the introduction.

The central question within this research paper is:

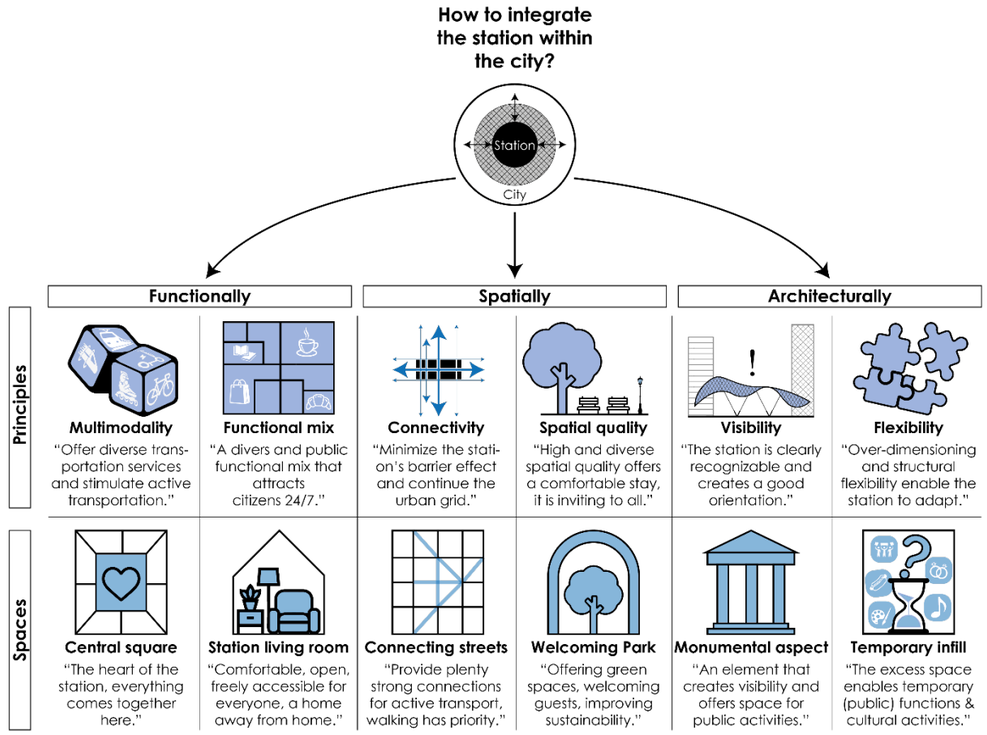
"Are the six design principles: multimodality, functional mix, connectivity, spatial quality, visibility & flexibility apt contributors to the integration of an urban multimodal station within its surrounding cityscape?"

In order to provide an answer to the research question, seven existing multimodal stations have been thoroughly analysed (using Nolli maps) on the basis of their relation with the surrounding city and their internal functionality in order to see whether the formulated design principles can be identified in their designs. The results have shown that in most case studies, the formulated design principles were recognizable in the designs.

This can be partly attributed to the fact the sources as Bureau Spoorbouwmeester and NS Stations have formulated clear visions for station design that have informed this research. Both parties often act as important advisors for station design projects in The Netherlands as well, so the same vision is already being applied in the work field. From what I have seen during my research, there is a clear tendency in the field of station design. Different parties, from policy makers to designers, are actively and passionately improving and redesigning station areas and reinstating the grandeur that stations once had.

The results have shown many examples where, albeit implicitly, the six formulated design principles led to successful station designs. Hence, I believe that the defined design principles form an apt contributor to the integration of urban multimodal stations within their surrounding cityscape. However, the results have also shown that there can be achieved more by adding explicit design spaces to accompany these design principles. This can in fact act as an extra programme of requirements for station designers and alike in addition to the programme of requirements as provided by the client or the commissioner.

On the next page, the six design principles and their accompanying spaces are being visualized in the graph. The **central square** acts as the focal point for transfers and is the heart of the **multimodal** hub, both the nodal and the public functions come together here. The **station living room** acts as the most public space by providing a living room for all in addition to the diverse and public **functional mix** that the urban station should offer in general. **Connecting streets** form the embodiment of a **connected** station, enabling the continuance of the urban grid and prioritizing active transportation for a comfortable and liveable station quarter. The **welcoming park** is a novelty in the station quarter, it embodies the sustainable character of the public transportation hub and forms an addition to the wide range of available public spaces with a high **spatial quality** within and around the station. The **monumental aspect** creates **visibility** for the station, improves orientation and should enable cultural manifestations in the highly accessible station area. Lastly, a **temporary infill** gives meaning to temporary excess spaces in and around the station and creates a more **flexible** station.



Each design principles has more to offer than just its accompanying space, however, these spaces form focal points in station design for expressing the design principles. Together with the six design principles, the six urban spaces can help architects and designers when designing an urban integrated station complex. Hopefully the design principles and urban spaces prove to be helpful to you as well, regardless of your relation to the work field of station design.

5. Limitations & recommendations

Within this research, seven stations within The Netherlands and Belgium have been analysed. These analyses provided interesting conclusions, mainly with regards to contemporary Dutch station design. However, further research would be advisable. In order to widen the scope of the research, more international stations could be analysed. Interesting cases could include larger stations from France, England and Germany such as Berlin Hauptbahnhof, which has been briefly described shortly in the analysis.

In general, these stations are situated in bigger cities, they are more complex due to a larger number of connecting train and metro lines and they have a more vertical configuration. These stations could provide useful information for the future situation within The Netherlands, if train travel keeps increasing and urbanisation and population growth continue.

Apart from the selection of stations, the six design principles could be researched more specifically. However, setting up nodal configurations and redesigning station areas to fit the needs of cyclists and pedestrians could entail entire researches on their own for example. Unfortunately, within the scope of this research these design principles cannot be studied more in-depth.

Also it has been mentioned that the implementation of public functions within the station and the creation of a high spatial quality would improve the public character of a station. However, both the functional mix and the design of the spaces could lead to an entire research in its own right as well. Hence, it would also be advisable to study and test these six principles more in-depth. Preferably by carrying out more plan analyses accompanied by research-by-design in order to test the principles in a more practical way.

In order to further research the relation between the station and the city, especially with regards to the future, it could be interesting to research whether and to what extent the two will merge. Will stations in their current form as separate buildings cease to exist in order to make room for a fully integrated hubs within the cityscape? Obviously this is a hard one to answer, but perhaps answers can be found in airports. Airports already have a longer tradition of attracting public functions in order to improve user experience, especially because travellers often wait at the airport for hours. Comparing stations to airports might reveal future scenarios. A small step towards this approach has been already undertaken within this paper, but further research would be highly advisable.

Finally, an important cause for this research has been my graduation project in which the goal is to implement a hyperloop terminal within the station of Amsterdam Zuid. If a hyperloop were to emerge, it would make most sense to place it within or near an existing station, in order to profit from the already existing accessibility of this location. This specifically leads to a more complex configuration for the station, not just because of the extra modality, but also because this will drastically increase passenger flows and the need for special facilities.

As trains will not be competitive on distances of over 600 to 700 kilometres, demand for air traffic will persist. Unless a new modality, such as hyperloop, is to be realized, this will not change. A scenario where hyperloop is the main connector for Europe is not unthinkable, but in order for hyperloop to substitute air traffic, a highly comfortable and efficient user experience is crucial.

Currently, a lot of research is being done into the technical functionality of hyperloop by different teams all over the world such as Hardt and Virgin. However, generally the physics outweigh the actual user. Further research into user experience would be essential. For one as the new modality of hyperloop can only succeed if travellers actually choose to use it as their preferred mode of transportation and therefore it should be perceived as a comfortable way of transport.

6. Sources

6.1.Visual sources.

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A courtesy of Benthem Crouwel Architects.

Image 3: A render of a potential hyperloop system from Delft Hyperloop:
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Image 26: Graph of Dutch and Belgian HSL-connections.
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Image 31: The Middenpassage at Amsterdam Centraal.
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Image 40: Transfer flows at Rotterdam Centraal.
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Image 42: The axis through Rotterdam Centraal
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Image 47: The station hall of Arnhem Centraal.
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Image 50: The Minerva concourse in between Zuidplein and Gustav Mahlerplein.
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Image 51: The Minerva concourse at Amsterdam Zuid.
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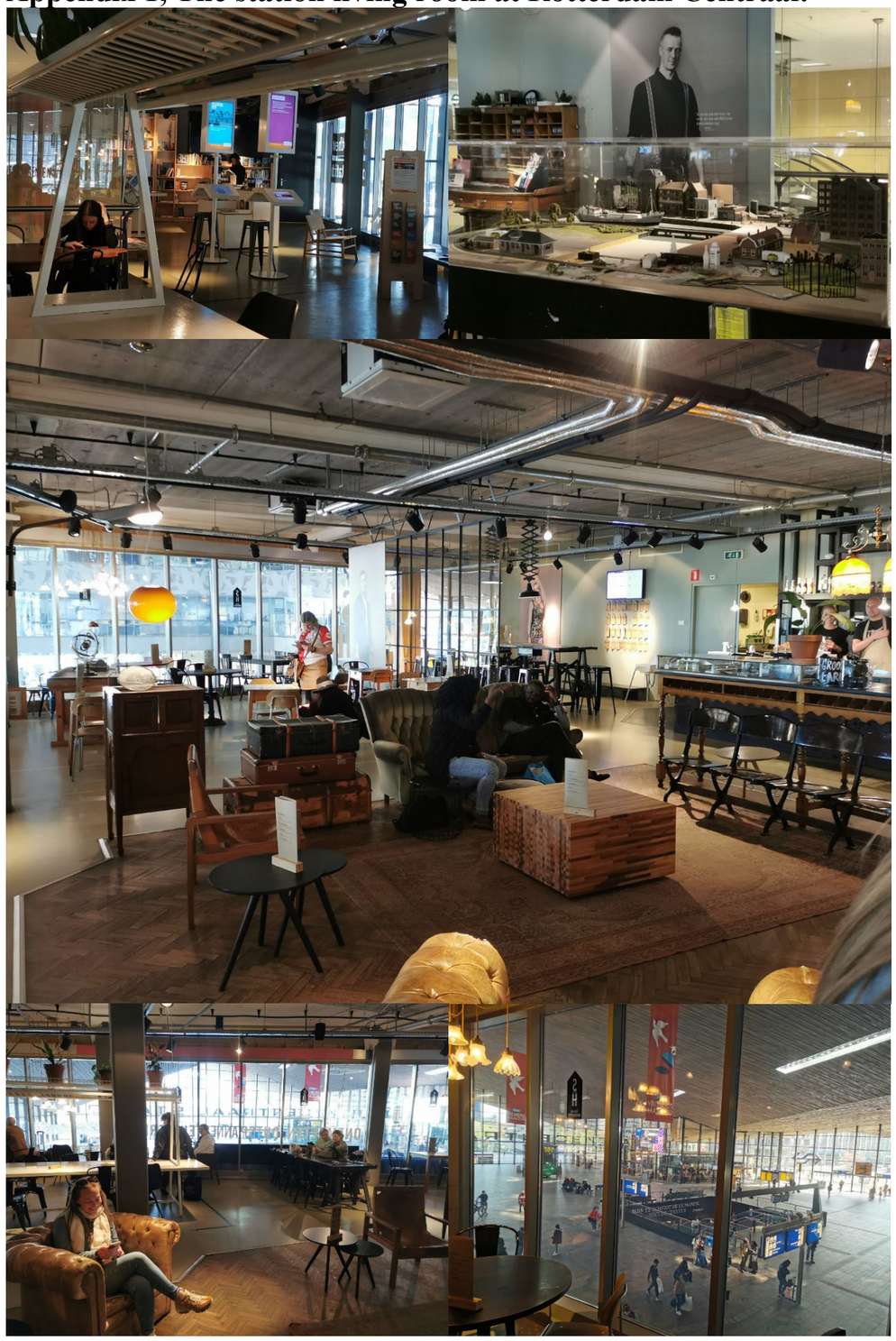
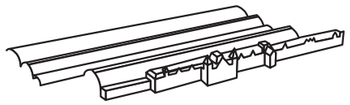
Appendix 1, The station living room at Rotterdam Centraal:

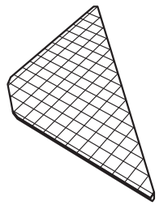


Appendix 2, Nolli map analyses.

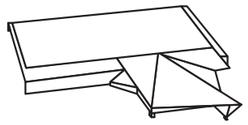
The analyses have been added separately on the following pages.



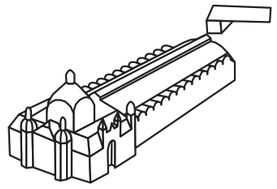
Amsterdam Centraal



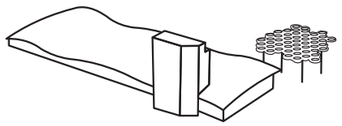
Schiphol Airport



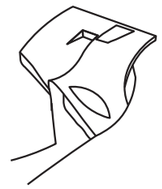
Rotterdam Centraal



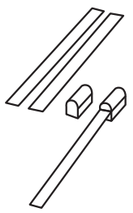
Antwerpen Centraal



Utrecht Centraal



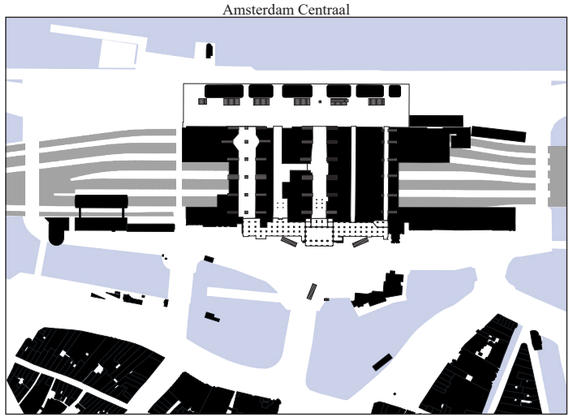
Arnhem Centraal



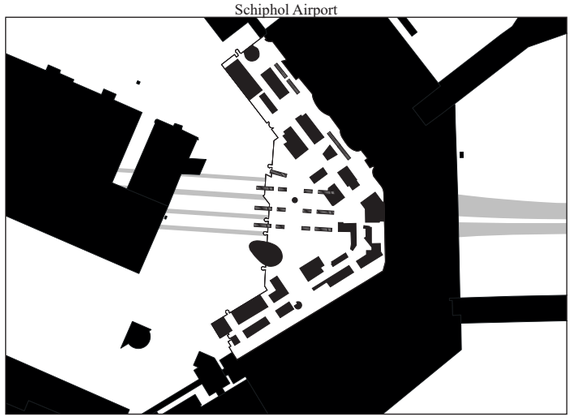
Amsterdam Zuid

Nolli maps

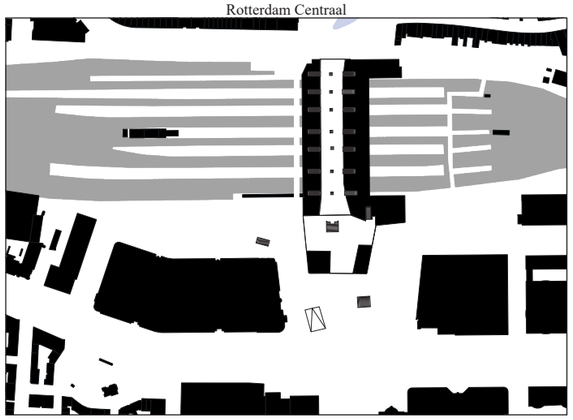
Amsterdam Centraal



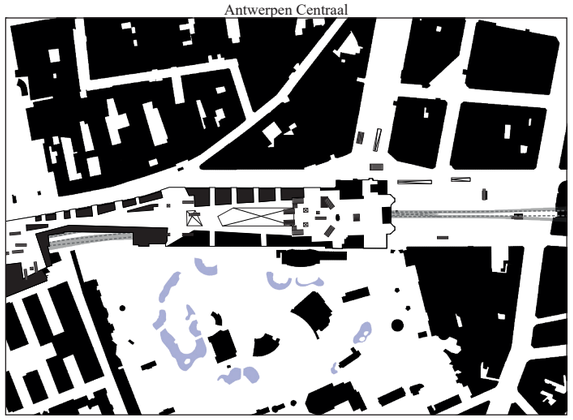
Schiphol Airport



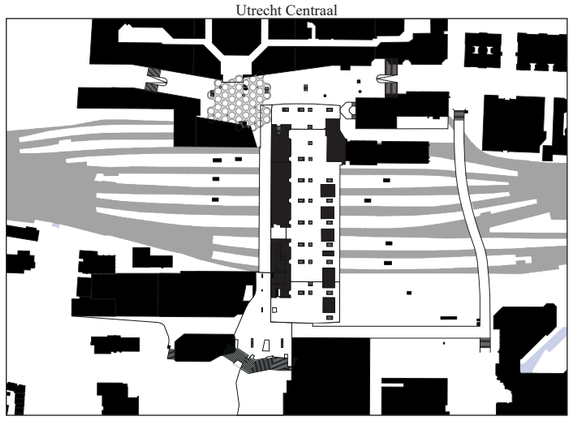
Rotterdam Centraal



Antwerpen Centraal



Utrecht Centraal

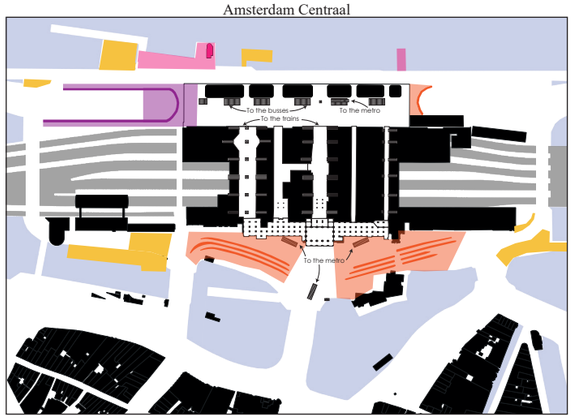


Arnhem Centraal

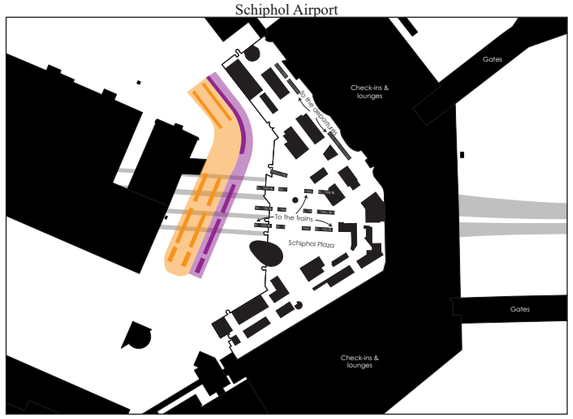
Amsterdam Zuid

Different modalities

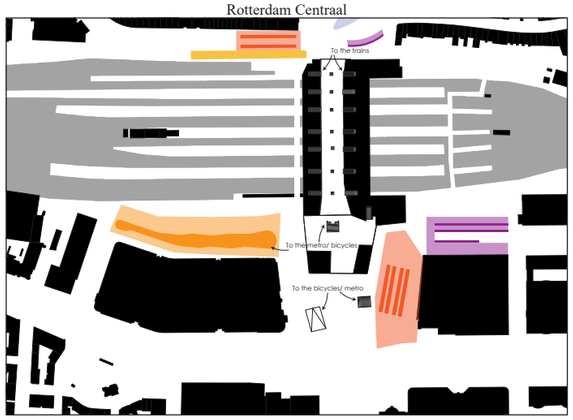
Amsterdam Centraal



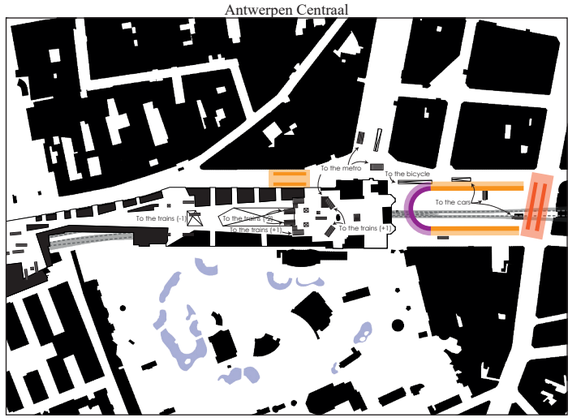
Schiphol Airport



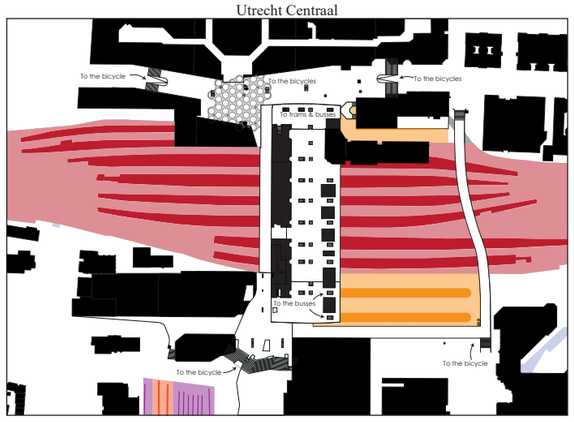
Rotterdam Centraal



Antwerpen Centraal

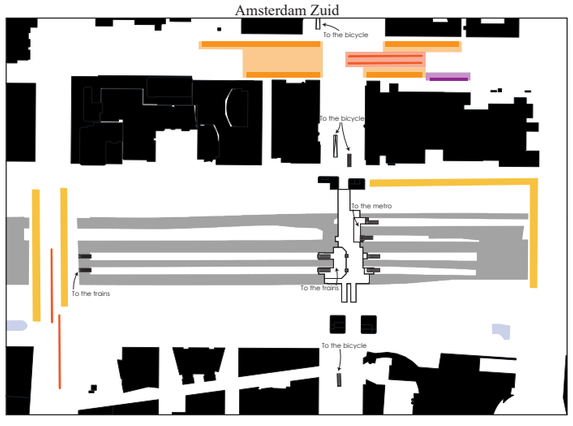


Utrecht Centraal



Arnhem Centraal

Amsterdam Zuid



Legend

- Buildings
- Emplacement (+1/ -1)
- Water
- Public space
- Vertical circulation
- Train platform/ space
- Metro platform/ space
- Tram platform/ space
- Bus platform/ space
- Bicycle racks/ space
- Ferry quay/ space
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

Legend

- Buildings
- Emplacement (+1/ -1)
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- Public space
- Vertical circulation
- Train platform/ space
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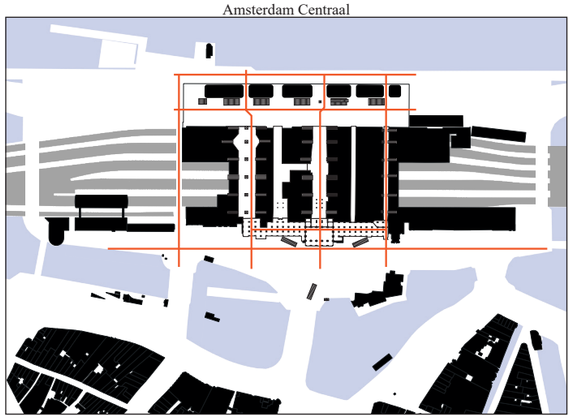
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

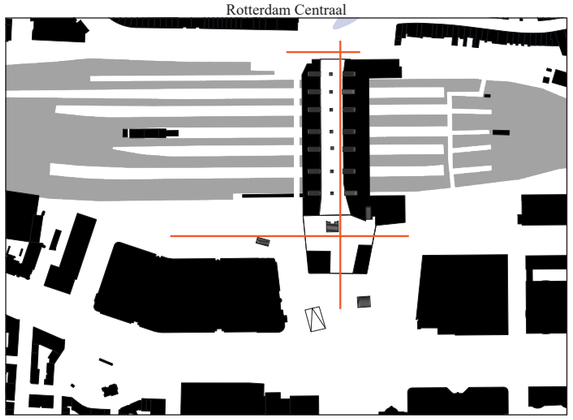
Transfer routes

Amsterdam Centraal

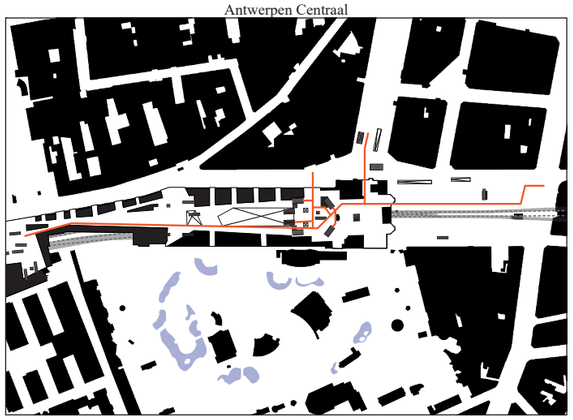


Schiphol Airport

Rotterdam Centraal



Antwerpen Centraal



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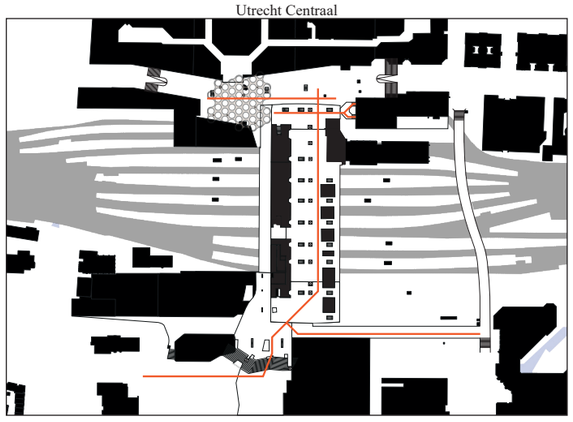
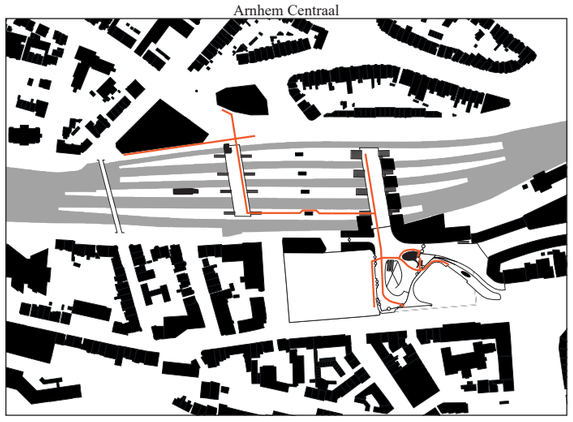
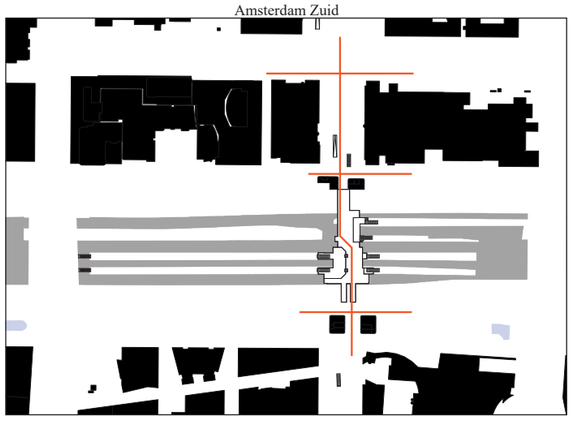


Arnhem Centraal



Amsterdam Zuid



Legend

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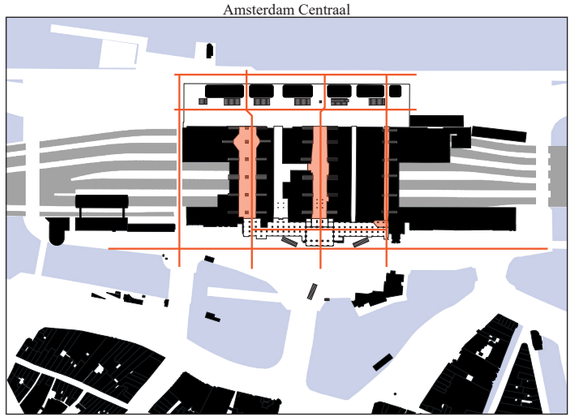
- Bus platform/ space
- Bicycle racks/ space
- Ferry quay/ space
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

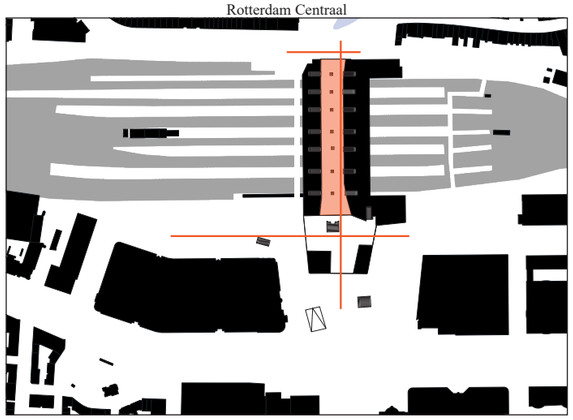
OV-chip-gated areas

Amsterdam Centraal



Schiphol Airport

Rotterdam Centraal



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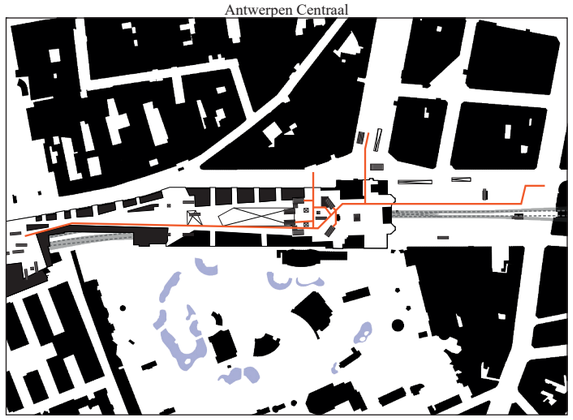
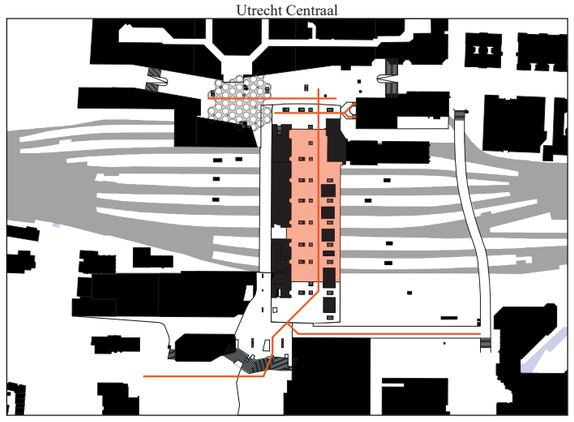
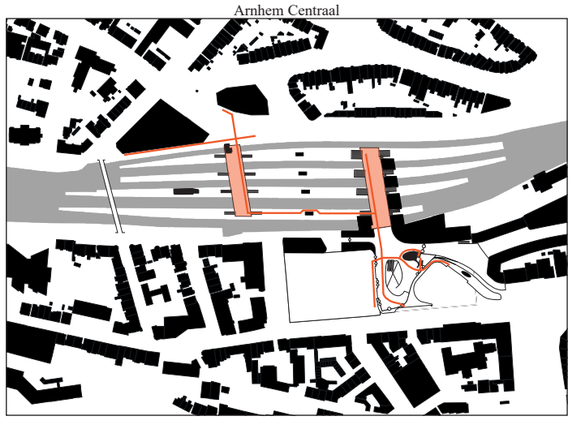


Utrecht Centraal



Arnhem Centraal



Amsterdam Zuid

Legend

- Buildings
- Emplacement (+1/ -1)
- Water
- Public space
- Vertical circulation
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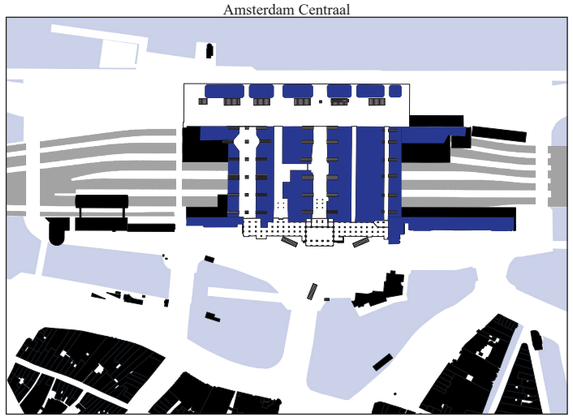
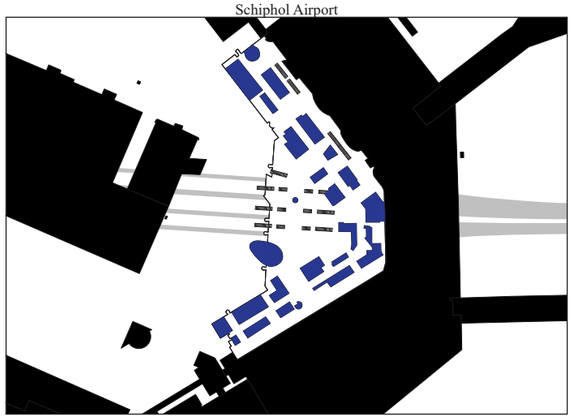
- Bicycle racks/ space
- Ferry quay/ space
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

Public functions

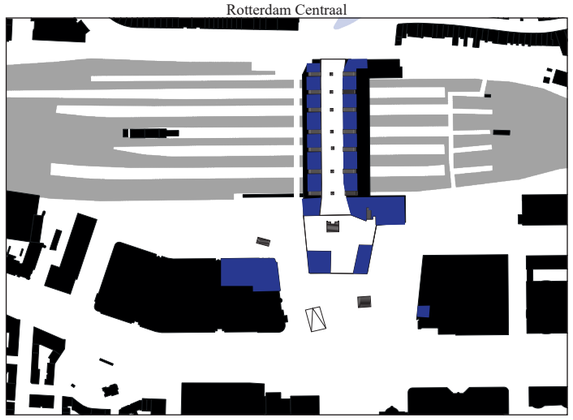
Amsterdam Centraal



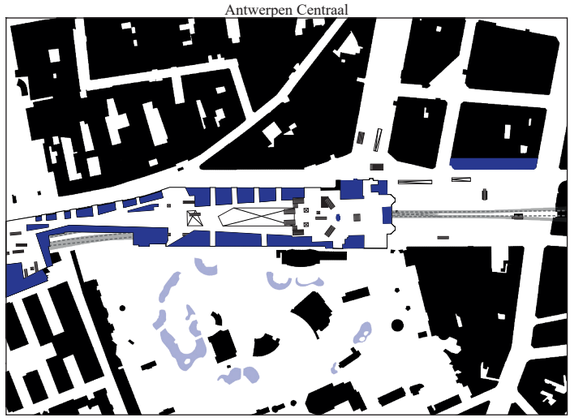
Schiphol Airport



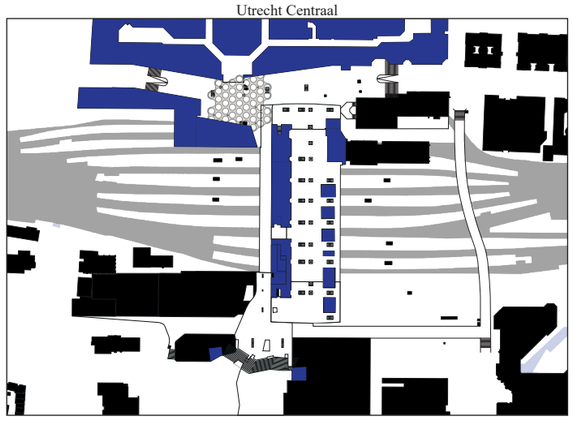
Rotterdam Centraal



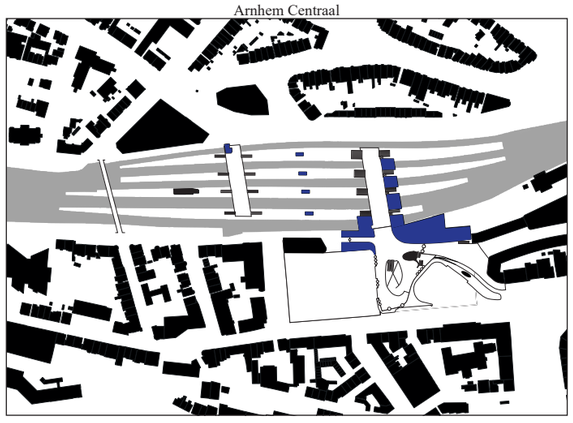
Antwerpen Centraal



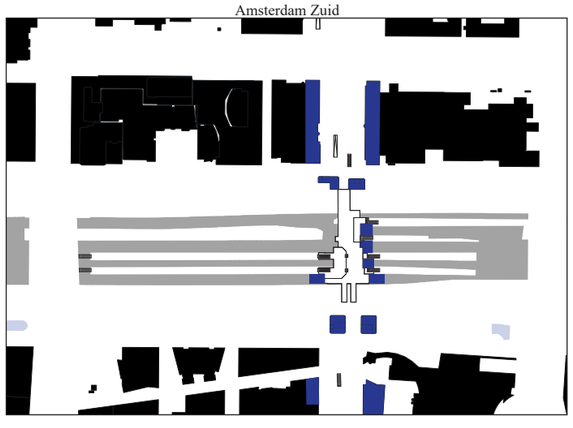
Utrecht Centraal



Arnhem Centraal



Amsterdam Zuid



Legend

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- Vertical circulation
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- Bus platform/ space
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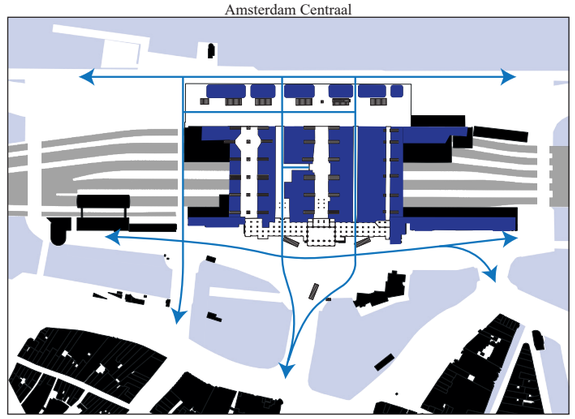
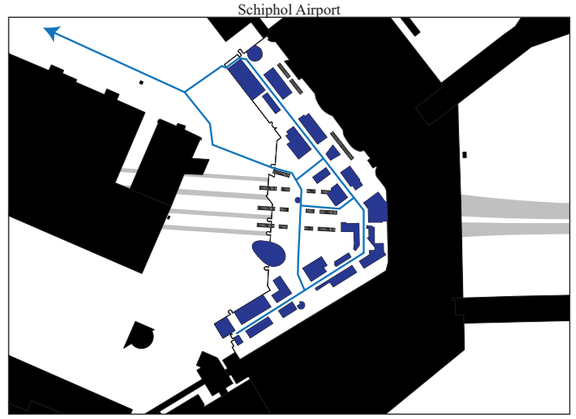
- Ferry quay/ space
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

Pedestrian routes

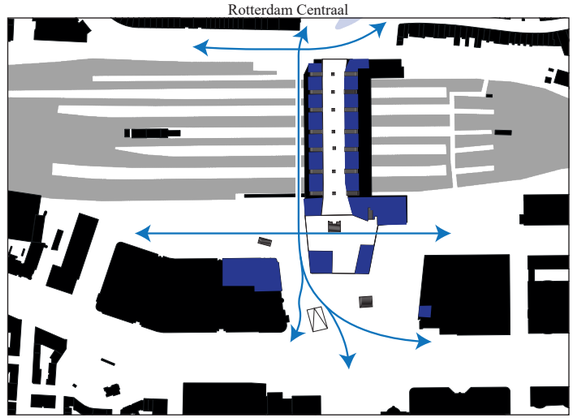
Amsterdam Centraal



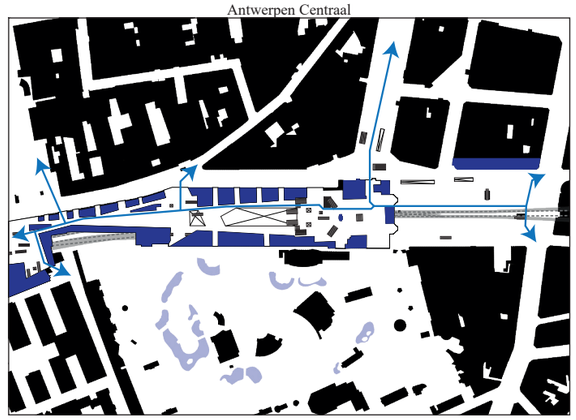
Schiphol Airport



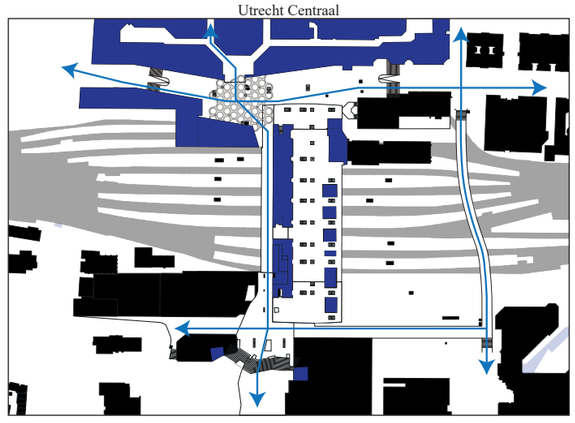
Rotterdam Centraal



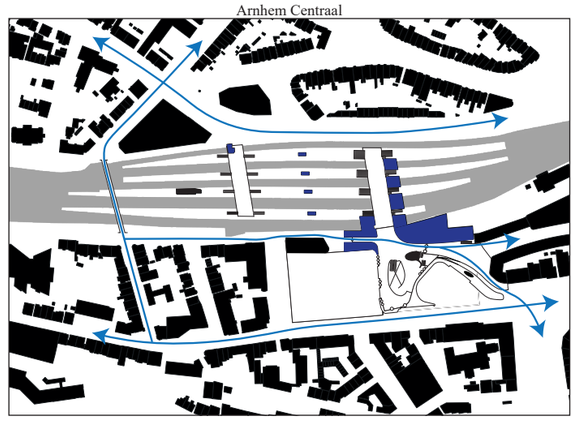
Antwerpen Centraal



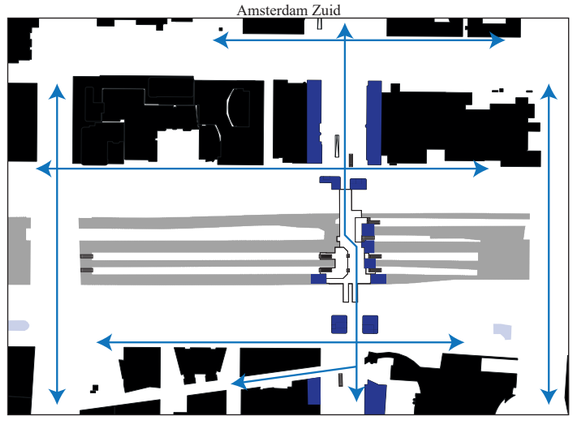
Utrecht Centraal



Arnhem Centraal



Amsterdam Zuid

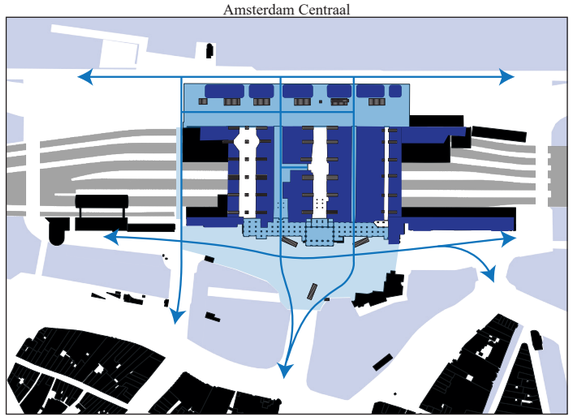


Legend

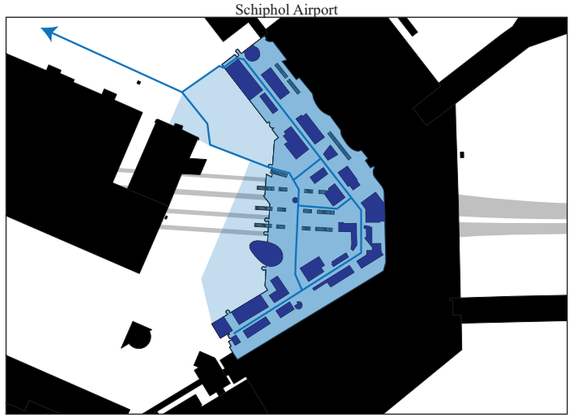
- Buildings
- Emplacement (+1/ -1)
- Water
- Public space
- Vertical circulation
- Train platform/ space
- Metro platform/ space
- Tram platform/ space
- Bus platform/ space
- Bicycle racks/ space
- Ferry quay/ space
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

Public places

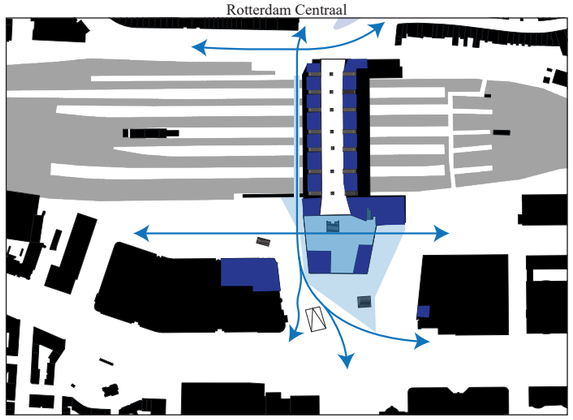
Amsterdam Centraal



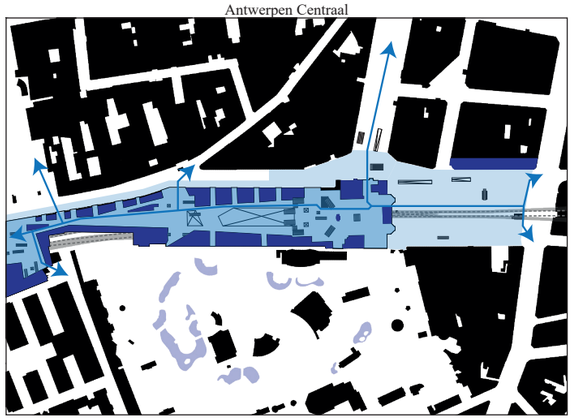
Schiphol Airport



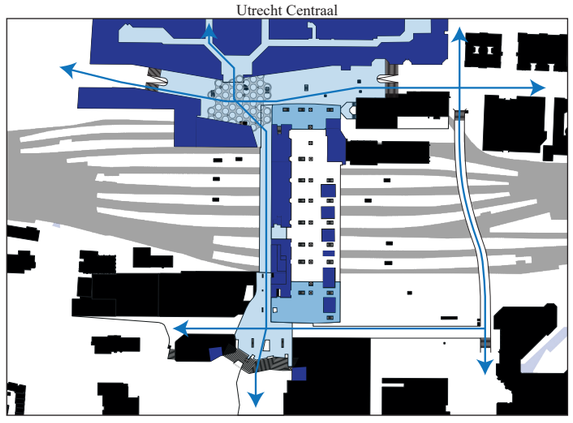
Rotterdam Centraal



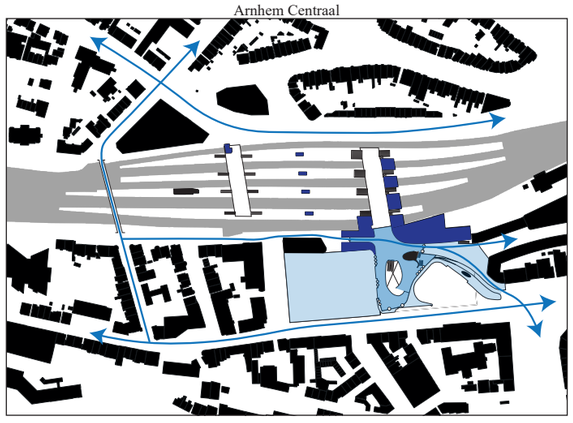
Antwerpen Centraal



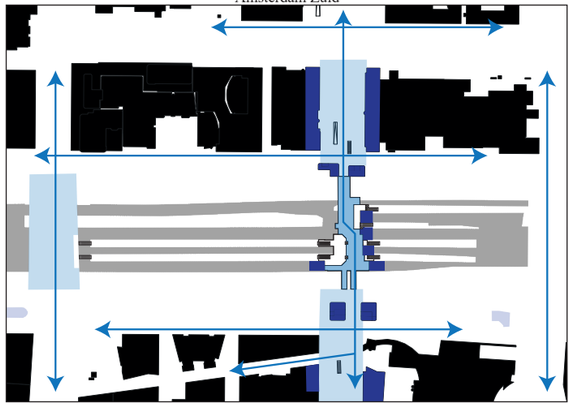
Utrecht Centraal



Arnhem Centraal



Amsterdam Zuid

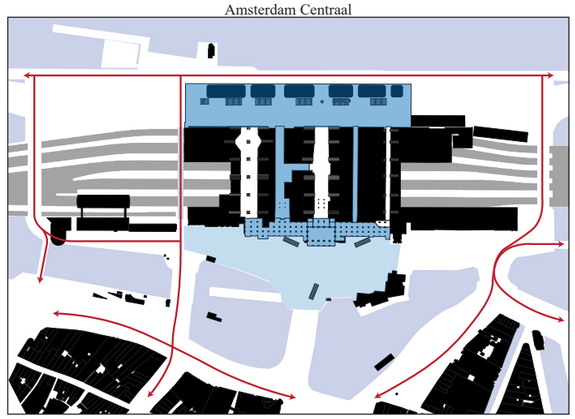


Legend

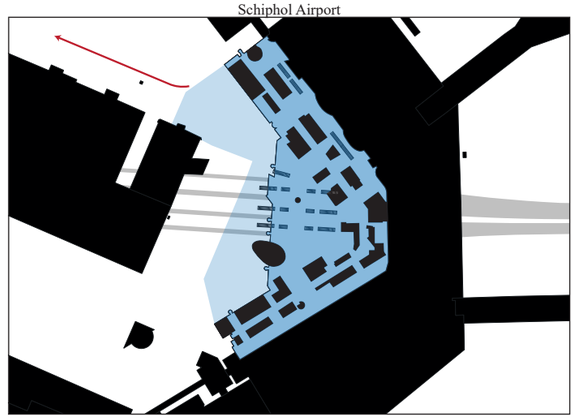
- Buildings
- Emplacement (+1/ -1)
- Water
- Public space
- Vertical circulation
- Train platform/ space
- Metro platform/ space
- Tram platform/ space
- Bus platform/ space
- Bicycle racks/ space
- Ferry quay/ space
- Kiss & Ride
- Transfer route
- OV-chip-gated space
- Public route
- Primary/ secondary public spaces
- Shops & other public functions
- Cycling route to station

Bicycle routes

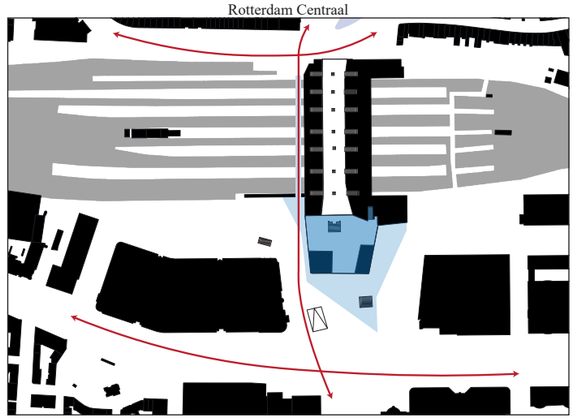
Amsterdam Centraal



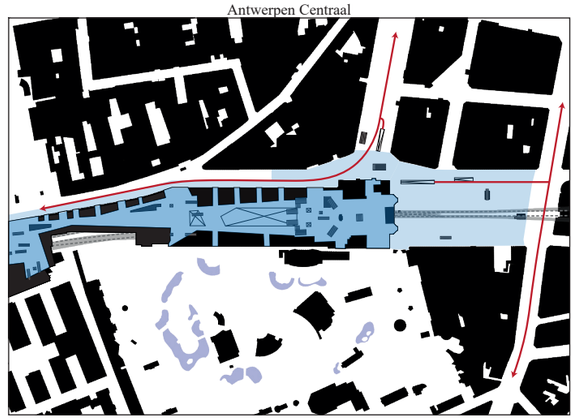
Schiphol Airport



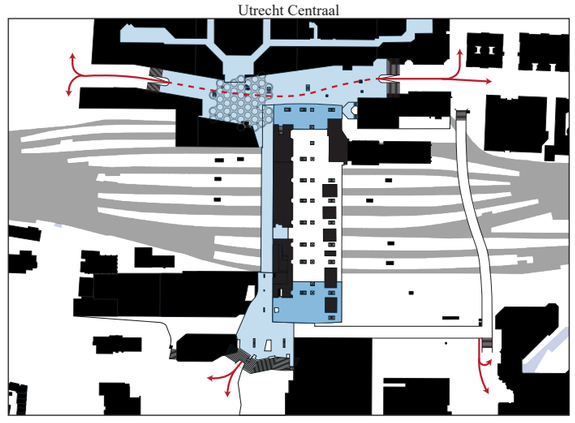
Rotterdam Centraal



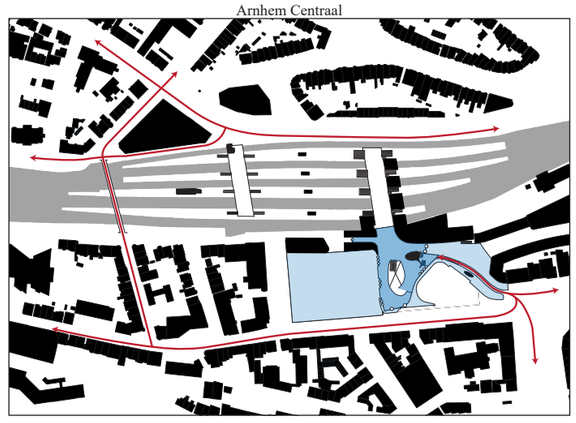
Antwerpen Centraal



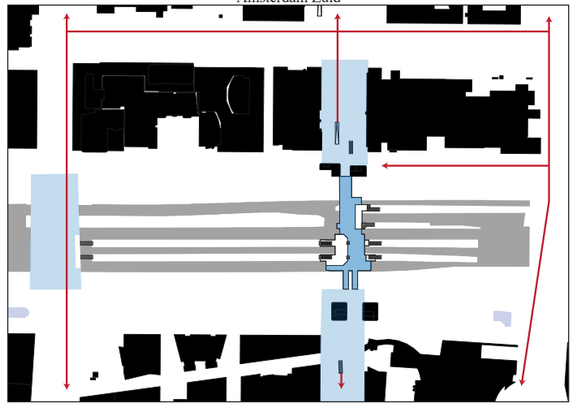
Utrecht Centraal



Arnhem Centraal



Amsterdam Zuid



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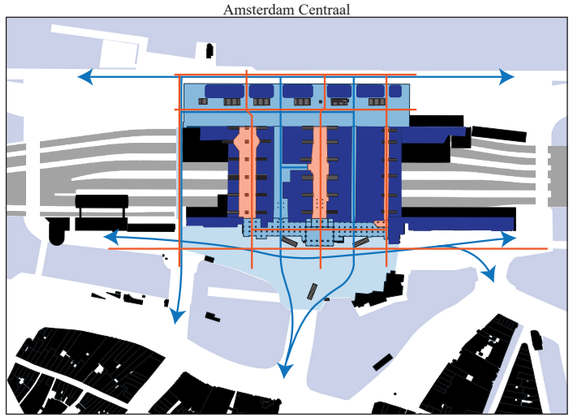
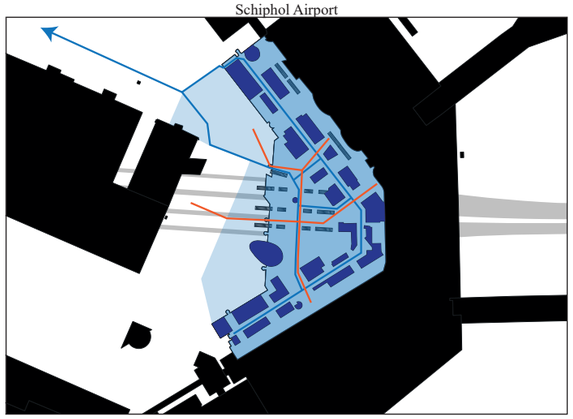
- Cycling route to station

Node versus place

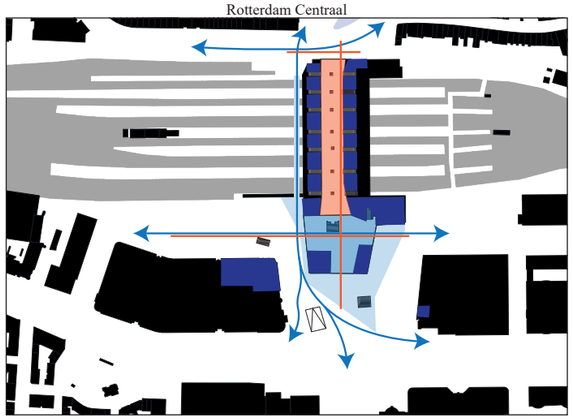
Amsterdam Centraal



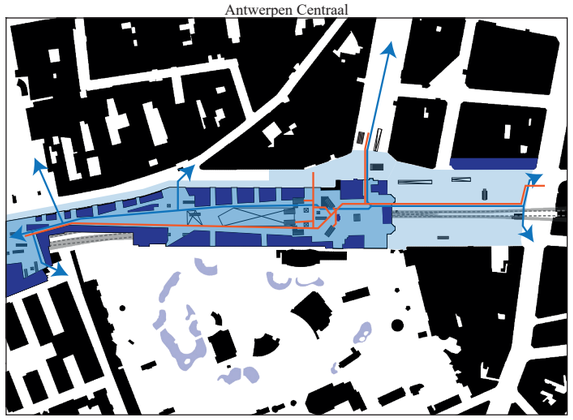
Schiphol Airport



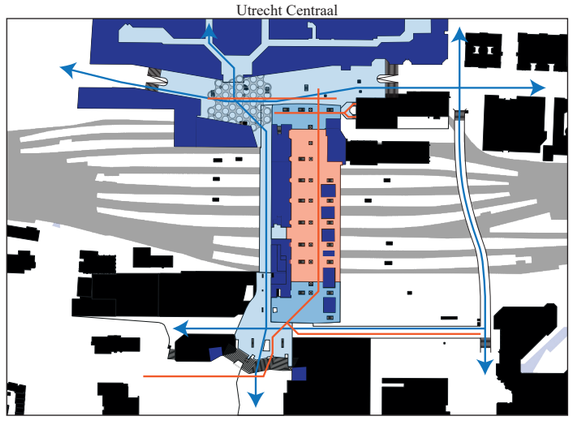
Rotterdam Centraal



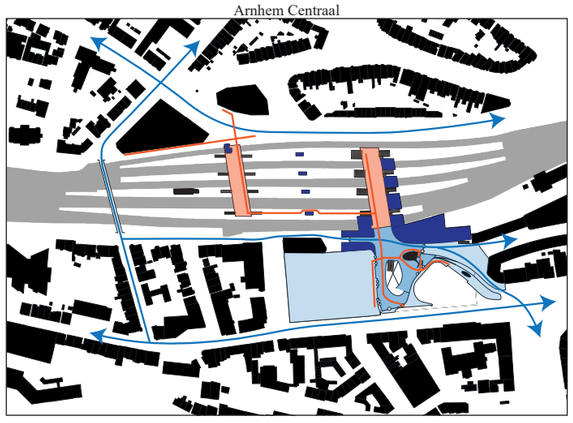
Antwerpen Centraal



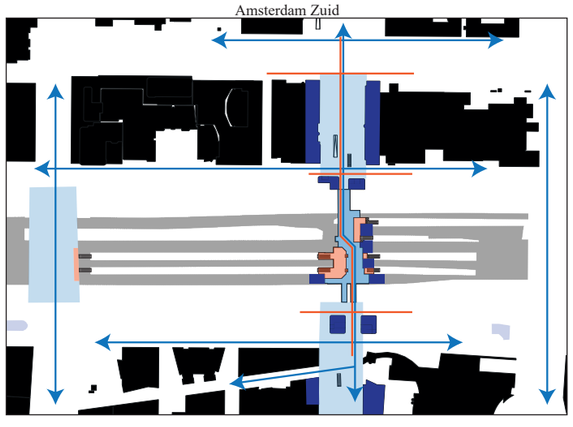
Utrecht Centraal



Arnhem Centraal



Amsterdam Zuid



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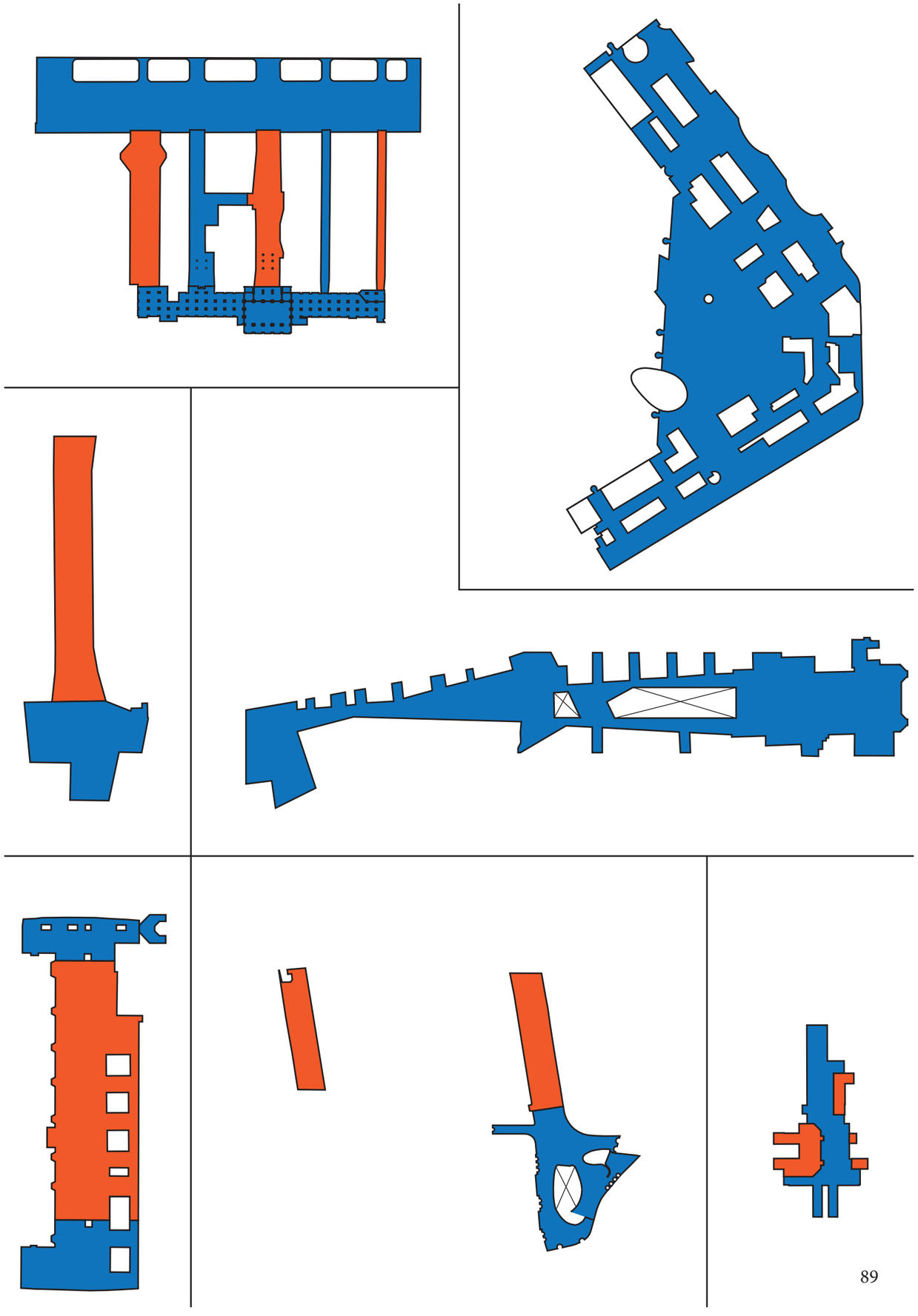
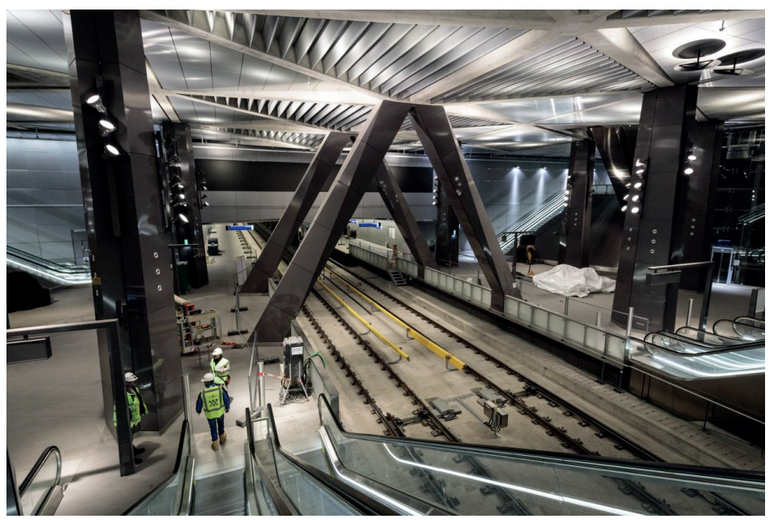


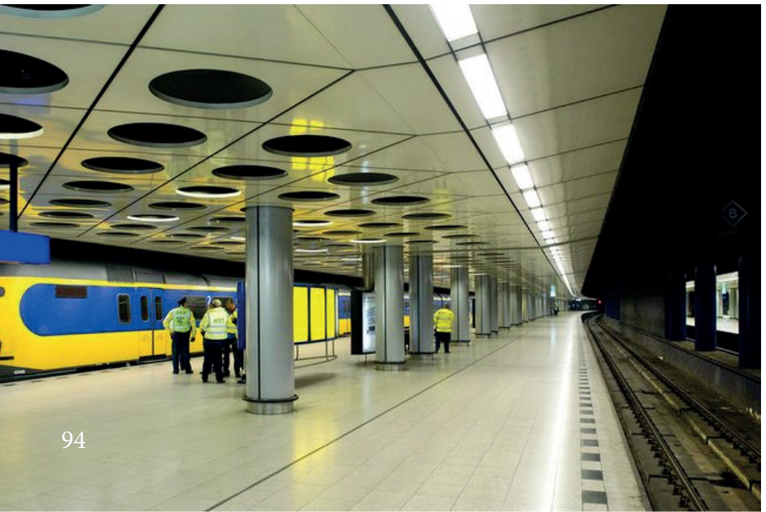
Appendix 3, Photo collage per station.

The photo collages have been added separately on the following pages.

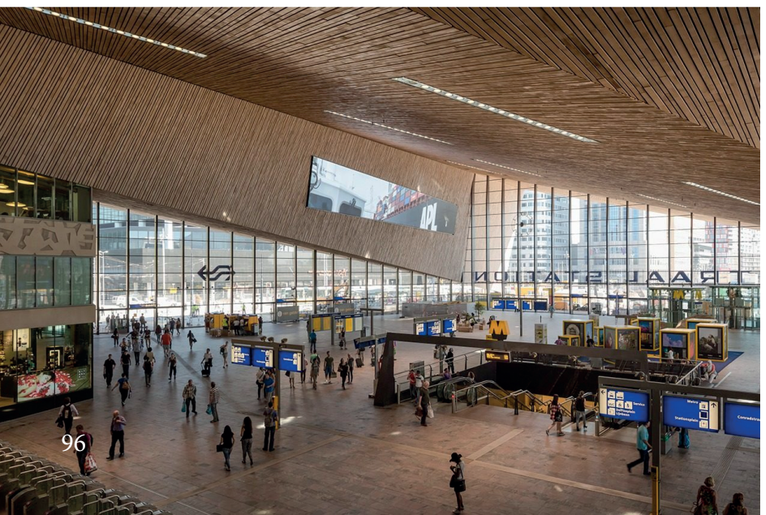
Amsterdam Centraal

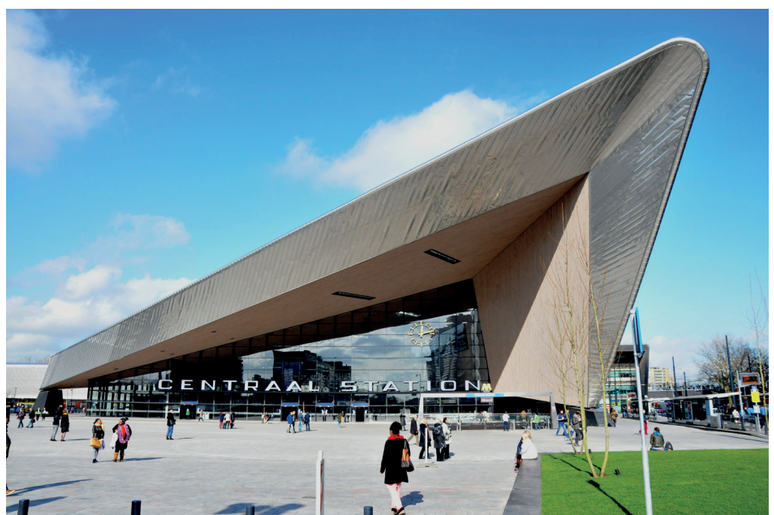


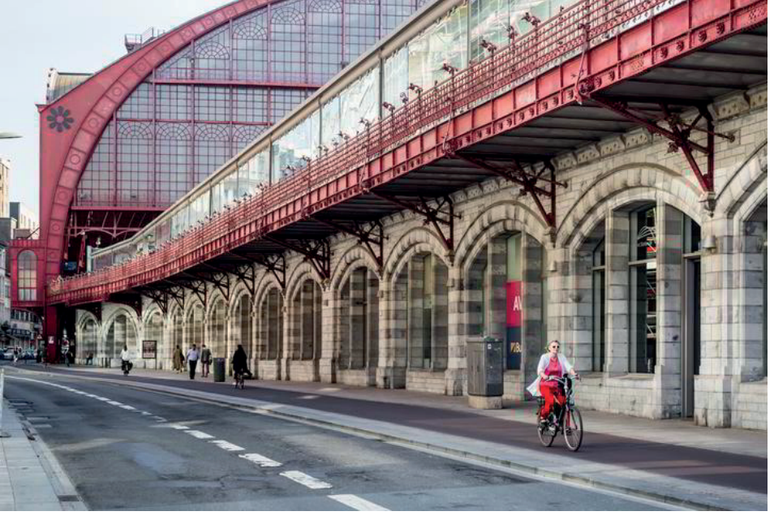
Schiphol Airport



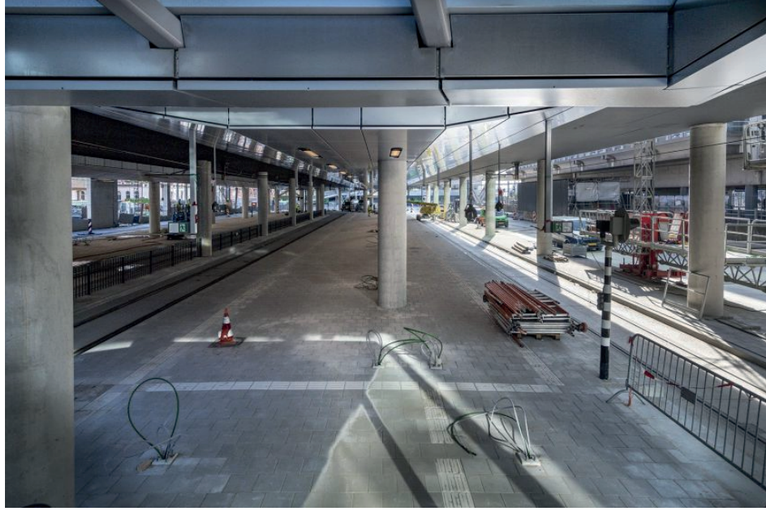
Rotterdam Centraal



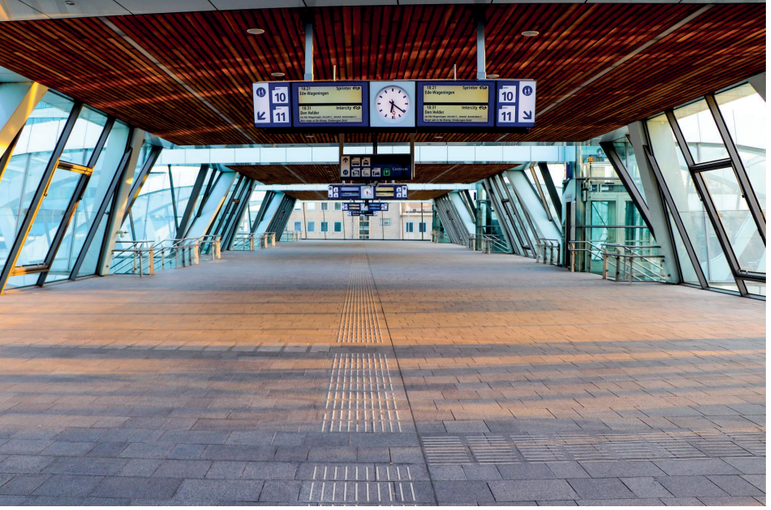




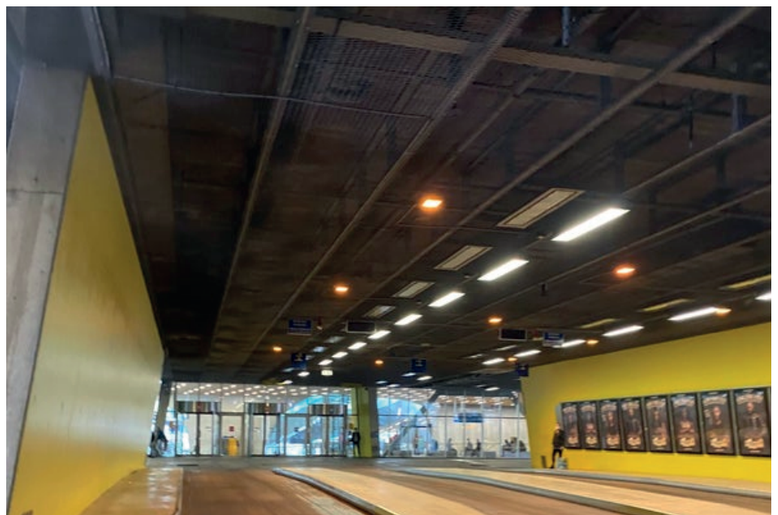
Antwerpen Centraal

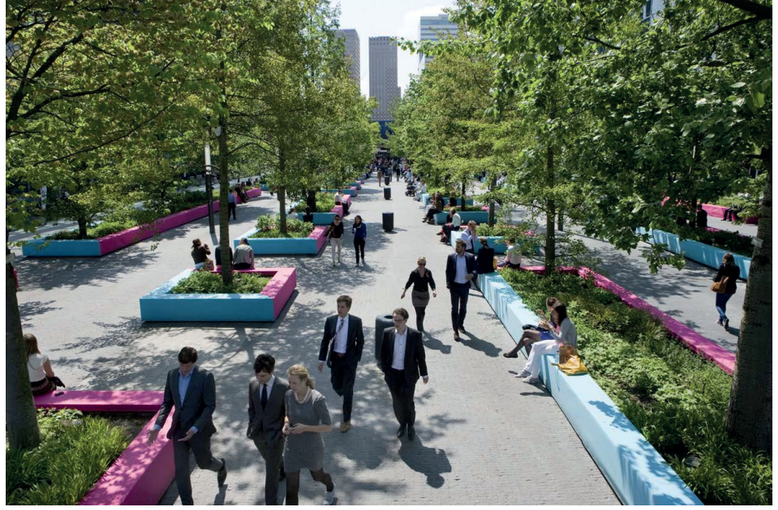


Utrecht Centraal

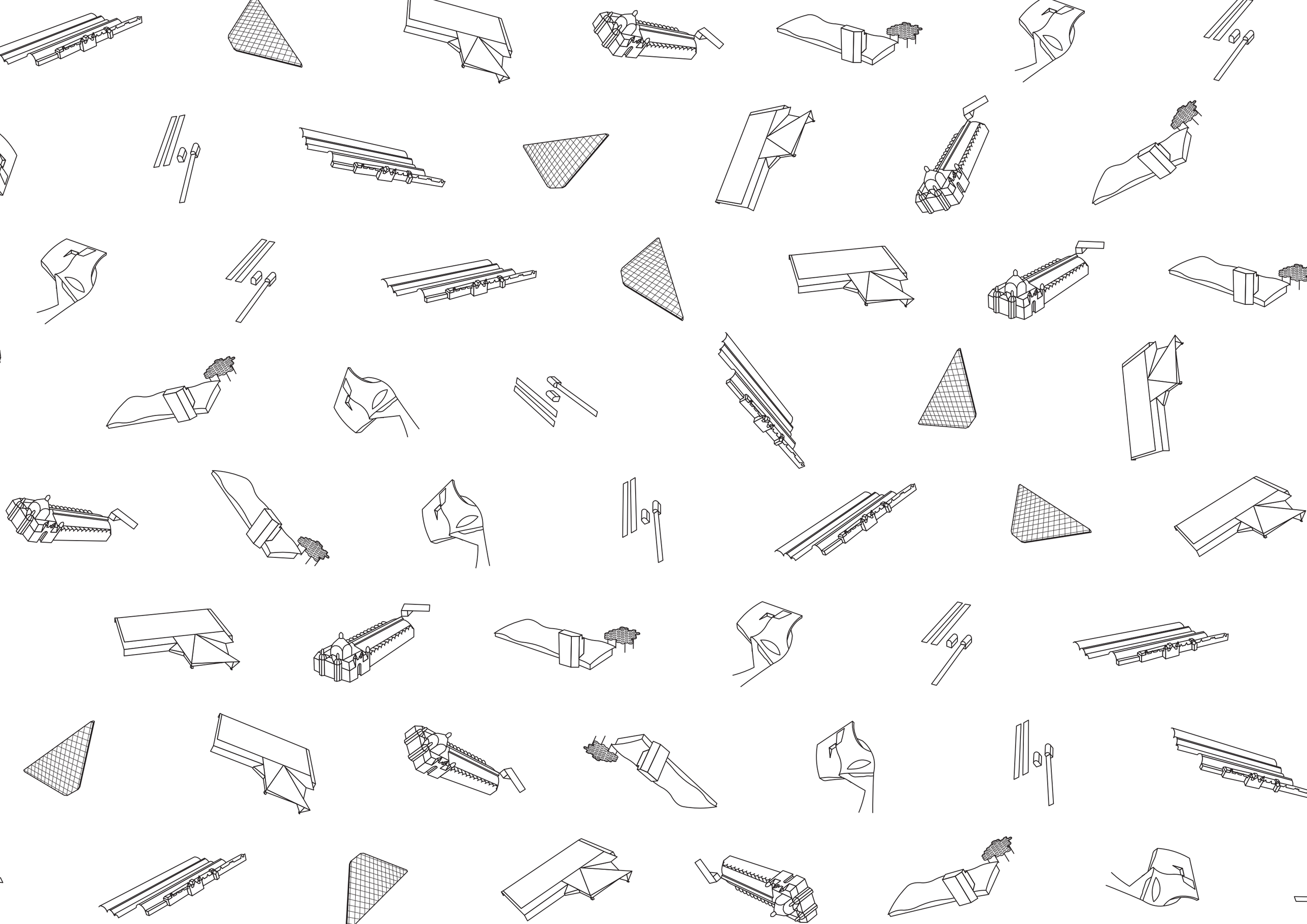


Arnhem Centraal





Amsterdam Zuid



PUBLIC | TRANSPORT

"A research into the double role of the station. How can stations become an integral part of the city?"

Dear reader,

Thank you for reading my graduation paper :)

Kind regards,
Robin