Literature research on best practice elements of bicycle infrastructure

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Declaration of Authorship

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Abstract

Good cycling infrastructure can positively impact the number cyclists and the bicycle mode share as Hull and O'Holleran found out in 2014. This research therefore concludes selected best practice examples in the context of bicycle infrastructure. It highlights and defines infrastructural elements which improve the overall safety or the comfort of the cyclists, as well as enhance the directness and the interconnectivity of a bicycle network. The findings were collected through the method of scientific literature review. For a more convenient structure of the paper, the findings have been grouped in the categories of *Bicycle Paths & Lanes*, *Intersection Design*, *Bicycle Storage* and *Urban Design*. Each item contains a brief description, the preceding issue and location examples of where the corresponding infrastructure has been applied to. The main findings of the research are 1) that there is a wide catalogue of best practice examples for bicycle infrastructure to almost every commonly known issue, 2) that best practice is the key to good bicycle infrastructure and, 3) that Denmark and the Netherlands are the pioneers and benchmark countries when it comes to practically proved bicycle infrastructure. This research forms the foundation of a consecutive master thesis that focuses on the implementation of the aggregated elements in the City of Munich.

Table of Content

1. Introduction

1.1. Why should one cycle

Climate change was once called "the biggest threat to security that modern humans have ever faced" by the British broadcaster David Attenborough (Attenborough, 2021, as cited in United Nations, 2021). While the increasing temperatures are a consequence that should most probably be tackled on a global level by politicians and businesses, there are little steps that can be done by everyone – one of them is to change the personal mean of transport. In 2019, the traffic sector was accountable for a fifth of Germany's total greenhouse gas emissions. 95% of those originate from the road sector (Umweltbundesamt, 2021). A possible, emission-free option is the bicycle. In the context of fighting climate change, cycling does not necessarily intend the recreational cycling rather than the use of the bicycle as a daily mode of transport. Especially in cities, where cycling trips are usually faster than by car, it is a serious alternative to the space consuming and (mostly; electric cars excluded) polluting automobile (Reid, 2018; Walker, 2012).

The United Nations initiated a resolution follows a strategy that increase s everyday cycling shares in cities across the globe (Amaral, 2022). While cycling is probably not going to solve the climate crisis on its own, it can definitely be part of the solution process (Bondam, 2019). Besides that, cycling comes with various advantages other than inner city trip times and its emission free operation. Frequent cyclists benefit from a lower chance of cardiovascular diseases, diabetes and obesity as well as better cognitive functioning and improved mental health (Garrad et al., 2012). Besides that it is an almost free mode of transport and provides the feeling of independency and mobility (Rérat, 2020). Yet, bicycles do not only favor the cyclists themselves but also its surroundings. In addition to lower health risks and therefore lower societal costs, bicycles do not emit pollutants nor noise and take up a fraction of the space of a car (Rérat, 2020).

Despite the list of advantages, it seems that many urban planners, politicians and residents have not fully understood the improvement they could achieve - for the city and its inhabitants (Canzler, 2017). In fact, some might see the bicycle purely as the bogeyman of the car that slows down traffic and only has the purpose of annoying cars drivers. Others might not see the necessity of costly bicycle infrastructure if just a few people cycle. Or in the words of Colville-Andersen: "If, while surveying a river or a harbor, you don't see anyone swimming, does that mean you don't need a bridge? No, of course not." (Colville-Andersen, 2018). So, the question, why bicycles are not on same planning and societal level as cars are, is probably better answered by a psychologist, rather than an urban planner (Monbiot, 2019).

1.2. The effect of good cycling infrastructure

Even though the saying "If you build it, they will come" is a misquote from the 1989 movie Field of Dreams ("If you build it, he will come"), it is an often and diversely used quote. In the multi-disciplinary online database Scopus alone, searching for the quote delivers more than 300 scientific documents. While in the movie it was referring to constructing a baseball field and the arrival of a deceased baseball player, the quote is often used for supplying infrastructure and gaining potential clients (Phil Alden, 1989; Powell, 2021).

Powell expresses the example of the Isle of Weight which became the "Tech Island" and home to large technology companies, simply by providing the required infrastructure in the form of broadband internet to most parts of the island (Powell, 2021). Investing great financial means into a project as in the case of the Isle of Weight does however not necessarily have to go in the right way. Prior and during the Summer Olympics in Rio 2016, large financial means were allocated to the games by the Brazilian government. Yet, after the Olympics had ended the specifically constructure infrastructure was abandoned in no time. The golf course, worth $16 Million, was shut down only six months after the Olympic Games (Powell, 2021). It proves the point, that simply lavishing a project with money yet without a plan can go wrong. Nevertheless, some cities are putting great financial effort in cycling infrastructure. The City of Oslo is investing more than $2 Billion in their cycling strategy to increase the mode share to 16 % by 2025 (Sutton, 2016).

As found out in a 2014 case study, providing good cycling infrastructure can have a large impact on mode choice (Hull & O'Holleran, 2014). According to that study, it is necessary to implement a governmental plan, that prioritizes cyclists, provides the required financial means as well as the legal rights and promotes cycling by more than physical infrastructure.

With this as a foundation, cycling infrastructure can improve cyclability of cities – especially in the fields of safety, comfort, and continuity. The study of Hull and O'Holleran also provides an excerpt of infrastructural elements and requirements for such a shift. Inter alia these are wide cycle paths, high quality lighting and good pavement asphalt. It is therefore essential to provide sufficient infrastructure, not only to increase the attractiveness but also the comfort and the safety of urban cycling.

The aim of this research document is to provide a catalogue of best practice infrastructure for bicycle infrastructure that underlines the findings of Hull and O'Holleran (2014). This research is not an encompassing library of all available infrastructural elements rather than a collection of successful and practically proven components of a bicycle network. Besides those, the research also contains selected individual solutions of cities and regions. By covering the fields of bicycle paths and storage as well intersection and urban design, the research provides a wide view on the topic.

This paper is designed to work as a foundation for city planners and people generally interested in bicycle infrastructure or facing a problem with it. An easy comparison of a local issue to the best practice solution is made possible through a summary of the initial issue prior to the introduction of the relevant infrastructural element. A brief description of the solution gives the reader a first idea of it. Most of the elements have three applicable locations that allow the reader to look up local solutions in greater detail – either through the annotated sources, individual research or by contacting the corresponding city.

2. Methodology

2.1 Literature Research

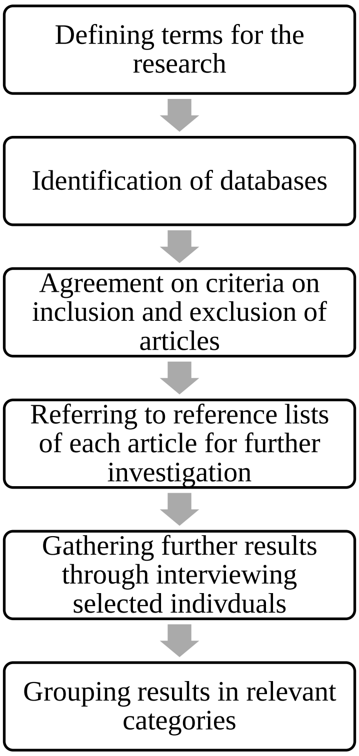

Figure 1: Methodology flow chart

The literature research about best practice bicycle infrastructural elements was elaborated through the method of a literature review. A comprehensive approach was not chosen due to size of the topic and the aspired extent of the research paper.
The current state of the art of infrastructural and urban design elements were obtained from scientific papers, newspaper articles and online information databases. Additionally, case studies were used to locate the literature findings to corresponding countries, regions, or cities.
The literature review followed the four steps defined by Fink in 2020: Planning, Selection, Extraction, Execution (Fink, 2020). The outcome – the developed methodology steps for this research - is illustrated on the left (Figure 1). Because infrastructural elements in cycling are an encompassing topic, all types of publications were considered during the research. Most resources were journals and newspaper articles, selected books, and open publications from relevant companies as well as publicly available statistical data (e.g., Statista). For the purpose of this research topic company websites and blogs were also considered as a trusty-worthy source if they are published by officially recognized entities and the provided content was available at a second source as well.

2.2 Interviews

To improve the findings gathered through the literature research informal interviews have been conducted. The interviewees were selected representatives of the City of Munich and the Green City e.V. All three interviews were held as an informal discussion meaning they did not follow a preformulated questionnaire nor a were they recorded. The overall aim of the interviews was to get insights on frequently mentioned, unknown or recent infrastructural elements. The interviews were held during the literature review process and did not create new mention worthy results and will further not be mentioned in the findings. Yet, while the interviews did not provide further findings, it supported the comprehensive view on the topic.

2.3 Selection Criteria

To keep this research document to a sensible extent the number of featured elements was limited to a total of 50 solutions during the beginning of the literature research. This number contained both physical elements as well as planning methods and approaches. The capacity limit of 50 elements was chosen in reconciliation with literature like this research paper.
After the literature reviewing process, it was decided by the author to exclude planning principles to focus the paper more on the topic of physical bicycle infrastructure. Therefore, this research document contains 45 entries. Overall, elements were only chosen if they were mentioned in at least two different sources to remain a scientific claim. Yet, most of the sources were found in more than two sources. The selection of elements aimed to highlight solutions that frequently used, nationally or globally, as well as elements that are unique to certain locations. The idea of best practice was interpreted in such a way that a best practice element can be the most practically proven solution to a unique problem as well. As can be seen in the

findings section, the elements were grouped in the four categories of paths and lanes, intersection design, bicycle storage and urban design. During the selection process it was aimed to contain the same number of solutions per category. As can be seen in the subsequent section, the category of bicycle storage contains eight and urban design 14 elements. It must be mentioned, that is not due to differences in the extensiveness of literature findings rather than the overall selection process. Afterall, the selection of elements was rather difficult because the elements lack subjective scientific criteria other than citations in research documents.

3. Findings

The literature reviewing process created various results which are summarized in the following section. Each selected element has a description that either explains its advantage and/or its functionality, a brief analysis of the initial issue and location examples where the corresponding solution has been applied. As described in the previous section, the selected elements were grouped in the categories of Paths & Lanes, Intersection Design, Bicycle Storage and Urban Design. Not only does this improve the overall structure of the research document and makes it more comprehensible but also allows a more systematic coverage of the field of bicycle infrastructure.

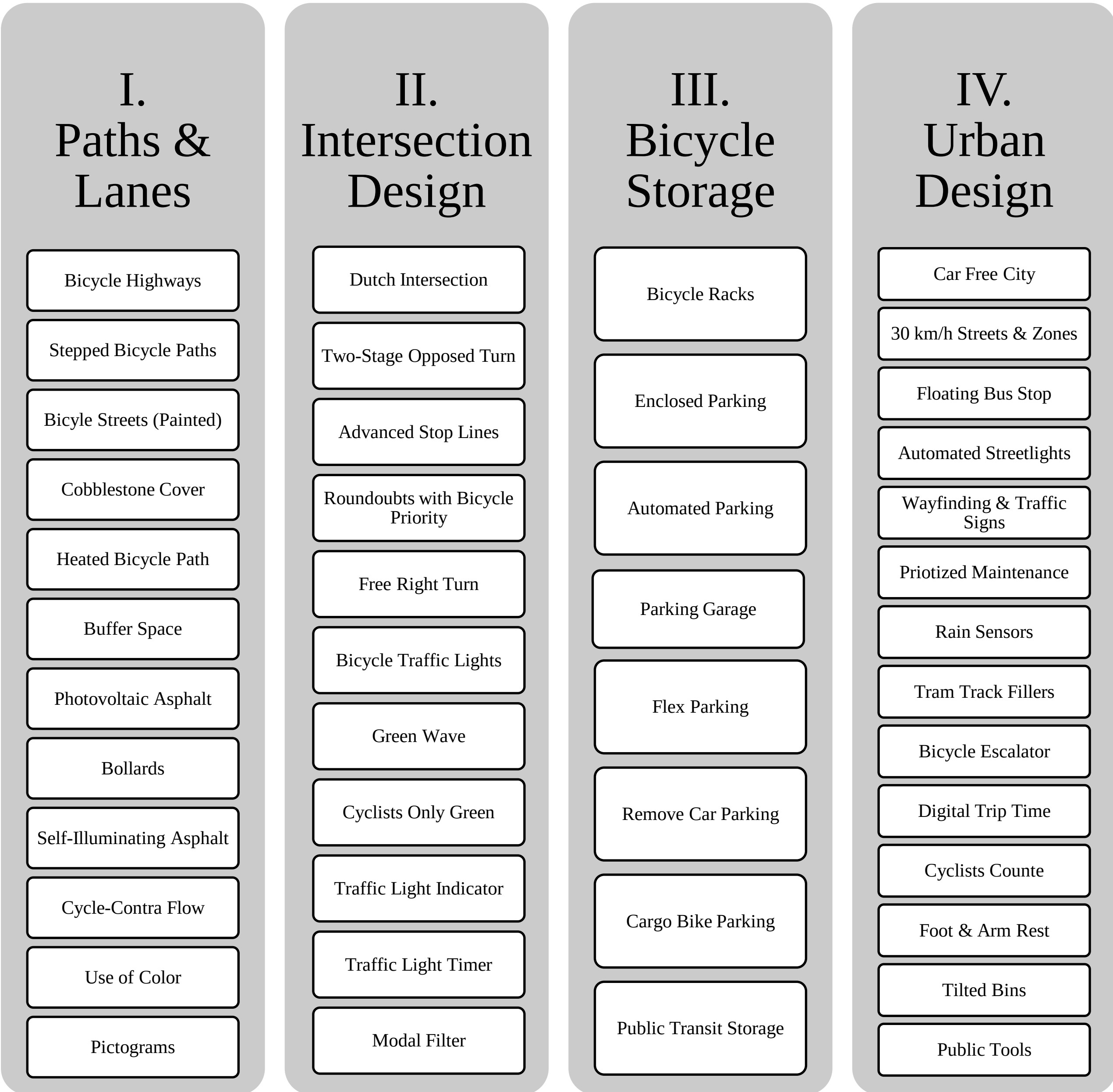

Figure 2: Overview of the best practice elements per category

3.1 Bicycle Paths & Lanes

In the following bicycle paths (separated bicycle lanes) and lanes (on-street bicycle lanes) can be understood as the connecting piece between intersections, bicycle parking and storage and all other types of destinations for cyclists. In this section all elements that are related to bicycle paths and lanes are listed and further explained. Throughout the research various design standards for bicycle paths and lanes have been identified. These range from no designated cycling infrastructure at all to separated, 4-meter-wide one-way paths in the Netherlands (Schröter et al., 2021). Design standards for bicycle paths differ not only from country to country but also from national regions and cities (Schröter et al., 2021). The comparison of design standards is not part of this research document rather than the accentuation of best practice examples. An overview on European standards has been put together by Schröter et al. (2021). More extensive descriptions about each infrastructural element as well as a larger image can be found in the appendix.

Table 1: Overview of Bicycle Path & Lane elements

Infrastructural Element	Description	Initial Issue	Example	
Highway	Long distance, continuous and wide bicycle paths that connect cities and urban regions	Conflict between cyclists and embarking/disembarking passengers	Leuven-Brussels, Mulheim an der Ruhr-Essen, Arnhem-Nijmegen	
Stepped Bicycle Path	Bicycle paths that are physically elevated from streets	Insufficient physical separation between motorized road users and cyclists	Copenhagen, Utrecht, Stockholm	
Bike Street	Streets in which bicycles are prioritized and have additional rights	Insufficient space for bicycle infrastructure	Utrecht, Amersfoort, Bremen	

Cobblestone Cover	Coverup of cobblestone streets/street sections	Unsafe road surface	Seville, Copenhagen	
Heated Bicycle Path	Bicycle paths that are heated from below	Elaborate winter service	Krommenie, Wageningen	
Buffer Space	Safety space between parking lots and bicycle lanes and paths	Risk of dooring (cyclists colliding with opening car doors)	Cleveland, Berlin	
Photovoltaic Bicycle Path	Photovoltaic modules that embedded in bicycle paths	Environmental interference for PV plants	Maartensdijk	
Bollards	Physical barrier (e.g., concrete or plastic) between bicycle paths and streets	Insufficient physical separation between motorized road users and cyclists	Stockholm, Seville, Nantes	
Self-Illuminating Bicycle Path	Fluorescent elements embedded in bicycle paths making the asphalt glow in the dark	Easy to overlook bicycle infrastructure	Lidzbark Warminski, Eindhoven	
Cycle Contra Flow	Cyclists own the right to ride against the direction of one-way roads	Reduced interconnectivity through one-way roads	Munich, Utrecht, Oslo	

Use of color	Use of paint or colored asphalt to mark entire bicycle paths or sections	No in color separation between streets and bicycle lanes/paths	Netherlands, Berlin, New York	
Pictograms	Use of symbols to mark bicycle infrastructure or directions	Misuse of bicycle infrastructure by pedestrians and motorized road users	Copenhagen, Berlin, Utrecht	

3.2 Intersection Design

As mentioned in the introduction section, creating a cycling network is the key for improving the cyclability of a city. Intersections play a cruel role in a cycling network. Their main purpose is to efficiently coordinate the crossing of streets and bicycle paths. The design of crossings crucial because intersections are the main site for incidents with bicycles participating (Statistische Ämter des Bundes und der Länder, 2022). Therefore, it is key to not only design intersections to their maximum efficiency but also to increase their safety levels. This section contains all infrastructural elements that support the purpose of good intersection design. More extensive descriptions about each infrastructural element as well as a larger image can be found in the appendix.

Table 2: Overview of Intersection Design elements

Infrastructural Element	Description	Initial Issue	Example	**Image**
Dutch Intersections	Bicycle paths are distanced from the street in the intersection area	Conflict between turning motorized road users and continuing cyclists	Utrecht, Antwerp	
Two-stage opposed turn	Cyclists turn left in two stages. They cross the intersecting street, turn their bicycle by 90° and go ahead on the subsequent green phase of the intersecting street	Potential risk by turning left in busy intersections	Berlin, Stockholm, Munich	

Advanced Stop Lines	Cyclists move ahead of waiting motorized road users to make themselves more visible	Motorized road users that oversee cyclists at intersections	Utrecht, Berlin, Copenhagen	
Roundabout with Bicycle Priority	Roundabout in which the street and bicycle paths are separated, and bicycles have right of way at the exits	Cyclists and motorized road users having to mix in roundabouts	Copenhagen, Utrecht, The Hague	
Free Right Turn	Cyclists can turn right on intersections regardless of traffic lights	Redundant waiting times at intersections	Brussels, Copenhagen, Paris	
Bicycle Traffic Lights	Traffic lights that are designed to meet the requirements of cyclists (height, position, etc.)	Traffic lights solely designed for motorized road users and inflexible intersection coordination	Amsterdam, Berlin, Cambridge	
Green Wave	Traffic lights on main artilleries are coordinated to speed of cyclists change in time to enable a green traffic light wave	Uncoordinated traffic lights prolonging bicycle trips	Copenhagen, San Francisco, Amsterdam	n.a.
Cyclists Only Green	Traffic lights for cyclists turn green earlier and/or longer than the lights for other road users	Missing intersection priority for cyclists	Cambridge, Assen, Copenhagen	
Traffic Light Indicator	Small LEDs on the pavement indicate if cyclists can make an upcoming green light in time	Inability to adjust cycling speed to traffic light cycles	Odense, Rotterdam, Copenhagen	

Traffic Light Timer	A timer installed next to the traffic light counts down the seconds of a green or red-light phase	Temptation of running red lights	Frederiksberg, Copenhagen, Amsterdam	
Modal Filter	Cyclists can pass through modal filters while cars or trucks can't. Can be used to stop through traffic in a bicycle street	Lack of separation and traffic flow control possibilities for bicycles and motorized road users	Houten, Stockholm, Cambridge	

3.3 Bicycle Storage

Bicycle storage and bicycle parking is an often neglected, overseen or ignored topic of city planners and architects (Colville-Andersen, 2018). Yet, it is of great importance and can crucially impact the attractiveness of a destination ridden to by bicycle. With various solutions for bicycle parking racks, this section concentrates on the concept of bicycles storage on a larger scale. More extensive descriptions about each infrastructural element as well as a larger image can be found in the appendix.

Table 3: Overview of Bicycle Storage elements

Infrastructural Element	Description	Initial Issue	Example	**Images**
Bicycle Friendly Parking Racks	Parking racks that enable a safe stand while making locking the bicycle secure and simple	Bicycle racks are often poorly designed and do not offer a safe stand	Helsinki, Munich, Copenhagen	
Parking Lockers	Enclosed compounds or boxes that can only be accessed with a key, pin code, access card etc.	Regular parking racks are not inviting to park expensive bicycles there	Oberhausen-Sterkrade, Hamburg, London	
Automated Parking	Parking towers aboveground or underground that automatically store bicycles in them	Bicycle parking is space intensive	Tokyo, Halle/Saale, Třinec	

Parking Garage	Large scale bicycle parking comparable to car parking garages. Often with secure access and other services	Public transit stations are required to provide large parking supplies	Utrecht, Houten, Münster	
Flex Parking	Parking space is used in dependency of time by cars, bicycles or no one	Urban space is spatially limited and temporally different in demand	Amsterdam, Copenhagen	
Remove Car Parking	Car parking is removed to provide more space to cyclists or pedestrians	Car parking require large urban spaces	Oslo, Paris, Barcelona	
Cargo-Bike Parking	Bicycle parking that meets the requirements of cargo bikes	Bicycle parking is often not designed to serve cargo bicycles	Malmo, Dublin, Strasbourg	
Bicycle Storage on Public Transit	Storing facilities that enable simple and sufficient storing possibilities on public transit	Transporting bicycles on public transit is often difficult	NS International, Swiss Railway, Belgium Railway	

3.4 Urban Design

Urban design is a broad field and can contain basically everything that is related to urban public space. In the context of this research paper, it includes all infrastructural elements that can either not be grouped in bicycle paths and lanes, intersection design and bicycle storage, or can be classified as bicycle furniture and legal redesign of street purposes. More extensive descriptions about each infrastructural element as well as a larger image can be found in the appendix.

Table 4: Overview of Urban Design elements

Infrastructural Element	Description	Initial Issue	Example	**Image**
Car-Free Cities	Cars are (partly) banned from cities, providing more space for cyclists and pedestrians	Cars take up large amounts of urban space either through roads or parking facilities	Bogota, Oslo, Ghent	
30 km/h Streets	30 km/h streets are shared by cyclists and motorized road users	Speeds above 30 km/h are particularly harmful to cyclists and pedestrians	Paris, Brussels, Madrid	
Floating Bus Stops	Bicycle paths are passed behind the bus stop, so cyclists do not have to stop for passengers that embar and disembark the bus. Passengers can wait for transit on an "island" between bicycle path and street	Conflict between embarking and disembarking passengers and cyclists	Berlin, Stockholm, Houten	
Automated Streetlights	When cyclists pass a street or intersection surrounding streetlights are turned on automatically	Streetlights are essential yet require energy and cause light pollution	Port of Moerdijk, Gera, Mechelen	n.a.
Wayfinding & Traffic Signs	Coherent and easy to follow wayfinding shows the directions and lengths to selected destinations. Signs are designed to meet requirements of cyclists	Insufficient wayfinding can make bicycle trips more complicated than necessary	Utrecht, Stockholm, Amsterdam	

Prioritized Maintenance	Bicycle infrastructure is prioritized for maintenance	Cycling commuters must often subordinate to car commuters e.g., for winter service	Copenhagen, Oulu, The Hague	
Rain-Sensors	Weather sensors detect rain and enable green waves on main artilleries to speed up travel times of cyclists	Cyclists are particularly exposed to weather	Rotterdam, Groningen, Odense	
Tram Track Fillers	Spring-loaded mechanism or foam is inserted in tram tracks so cyclists cannot catch their wheel in the tracks	Tram tracks are a potential risk to cyclists	Not available	n.a.
Bicycle Escalator	Located at steep hills, bicycle escalators help cyclists to overcome the hill	Steep hills are a physical barrier to certain cyclists	Trondheim	
Digital Trip Time Display	Displays show current travel times to certain locations for cyclists. They can also be used for announcing detours or other information	Communication of notifications on a short notice is not possible	Copenhagen	
Cyclist Counter	Cyclist counter help officials to analyze traffic flow. They can also work on a motivational level for cyclist	Gathering data is essential to analyze traffic and demand flows	Munich, Oslo, Copenhagen	
Foot & Arm Rests	Cyclists do not have to step off their bicycle at intersections and thereby keep a bit of their momentum	Stopping and stepping off at intersections makes cyclists lose their momentum	Copenhagen, Montreal, Berlin	

Tilted Bins	Bins are tilted so garbage can be disposed more easily while cycling	Cyclists must slow down or stop to throw away their garbage	Copenhagen	
Tools & Pumps	Tools and pumps are provided for free so cyclists can do little maintenance work themselves	Cyclists either need tools to do their own repairs or must head to bicycle shops	Munich, Dublin, Utrecht	

4. Discussion

As the purpose of this paper is to identify and to assess the best practice examples of bicycle infrastructure, the findings section featured and assessed various solutions including their initial issue and cities or countries of application. The findings led to the following three key statements.

1. There is a wide catalogue of best practice examples for bicycle infrastructure to almost every commonly known issue.

This research document highlights 45 different best practice examples for the general topics of bicycle paths and lanes, intersection design, bicycle storage and urban design. More than 50 cities are listed in the findings section and almost every infrastructural element has three applicable examples named. As mentioned in the methodology section, the list of infrastructural elements had to be limited to keep this research paper to an appropriate length. It shows that there are certainly various other solutions across the globe, that aim to improve cycling and its infrastructure. While not all of them fall under the concept of best practice, some do. Yet it also shows that there are various issues and problems that need solving. While wide bicycle paths and bollards are long known solution to unprotected and small bicycle paths, rain sensors and smart lighting are solutions to problems that could have not been dealt with, without the required technology.

These technical features though, display the minority of best practice solutions. Most of them concentrate on physical features such as asphalt colors or metal posts to stop through traffic. They have been around for quite a while and symbolize the core of the best practice catalogue. Technical inventions such as the LED strips ahead of traffic lights are an extra that improves the comfort of cyclists but do not necessarily impact the overall safety of cyclists or interconnectivity of a network. Yet, with those new inventions the catalogue gets extended slowly and problems that were not able be dealt with in the past, will be in the future.

The great number of solutions shows that to almost every known issue someone has somewhere already identified a workaround to overcome the problem. As many cities use the same concept or approach to overcome the same issue, the selected idea can be seen as a working and practically proved solution.

Countries like the Netherlands, which have great cycling history, gathered their best practice elements and created their own national design standard – the CROW Design Manual for Bicycle Traffic (Cathcart-Keays, 2016; de Groot & CROW kenniscentrum voor verkeer, 2016). The Dutch bicycle infrastructure is seen as the benchmark blueprint for other countries as the Bruntlett and Bruntlett prove by their book Building the Cycling City: The Dutch Blueprint for Urban Vitality from 2018. The literature investigates to which extent those Dutch blueprints and templates can be and have been transferred to North American cities (Bruntlett & Bruntlett, 2018).

That once again proves the point of the importance yet also the easement that can be achieved with best practice infrastructure. There are solutions to almost every issue, so the need to reinvent the wheel is redundant. It does however not necessarily mean, to stop thinking. Cities, cyclists, bicycles, and technologies change. Cargo bicycles demand other parking facilities than regular bicycles. The internet offers new possibilities for the interconnectivity of infrastructure. But the core solutions for a bicycle network are already there. The bicycle and its operating principle have been the same for decades, yet bicycles got lighter, faster, or more practical.

2. *Best practice solutions are the key to good bicycle infrastructure*

Through the work of cities like Utrecht or Copenhagen, the need for iterative planning processes and reinventions of the wheel were made almost redundant for other cities. The concept of best practice comes with the great advantages that the thinking, planning, and designing processes do not have to be gone through again. An established solution can be copied from one city and pasted to another one.

Cities like Ljubljana made use of this concept more than 50 years ago. Slovenian architect Edvard Ravnikar initiated the process by writing an article about the bicycle infrastructure in Copenhagen, after which a team of urban planners from Slovenia travelled to the Danish capital. They analyzed the cities infrastructure and took a copy of it to Ljubljana. They implemented 40 kilometers of bicycle tracks, which led to a bicycle mode share rise from two percent to ten percent in one year. After that, mode shares stagnated for four decades, as the city stopped the implementation process of further cycling infrastructure (Colville-Andersen, 2018).

The City of Almetyevsk, located in the southwest of Russia, followed a similar strategy in 2015. They decided to implement 200 kilometers of bicycle tracks across the city based on the model of Dutch bicycle infrastructure with the help of Dutch urban planners. In the first year after the resolution, approximately 50 kilometers worth of cycling paths have been built. Though, due to the challenging climate conditions, different types of asphalt had to be tested in advance and because of the lack of suppliers, own signs were produced. Other than that, the Dutch example has been followed through (Colville-Andersen, 2018).

With success stories like the ones from Ljubljana or Almetyevsk, the functionality of best practice models can be proven. While the example of asphalt adaption in Russia shows that a solution cannot always be transferred from A to B directly, the findings offer a solid framework which can be adapted to local conditions.

Authors like Colville-Andersen, who was part of the design team in the Almetyevsk project, gathered planning concepts and design principles, while the CROW Design Manual for Bicycle Traffic Design or the London Cycling Design Standards describe requirements and dimensions of bicycle infrastructure in detail (Colville-Andersen, 2018; de Groot & CROW kenniscentrum voor verkeer, 2016; Transport for London, 2014).

The literature findings in this paper underline the fact, that best practice is a practically applicable concept for bicycle infrastructure. Originating from the same issue, different cities applied the same solution. Most probably time-delayed and based on the fact, that one city stepped ahead and implemented the respective solution successfully.

Bicycle streets, “Sheffield Stands’ and bicycle traffic lights are just a few examples from the findings that must have been initiated by one city and then made their way all over the world.

3. Denmark and the Netherlands are the pioneers and benchmark countries when it comes to practically proved bicycle infrastructure.

Denmark and the Netherlands are often quoted to be the best cycling countries in the world (Cathcart-Keays, 2016). Further, since 2013 the Cities of Utrecht, Amsterdam and Copenhagen were the highest rated cities in the Copenhagenize Index (Copenhagenize Design, 2019a). These statements are underlined by the findings of this research document. Most of the infrastructural elements are found in a Dutch or Danish city. In fact, more than 15 cities listed in the findings section are in the Netherlands or Denmark. Ljubljana and Almetyevsk are just two cities that made use of the existing infrastructure that is available in Copenhagen.

And in fact, the Dutch and Danish cyclists of today benefit from smart decision making in the past. “What started in the 1970s with the oil crises and accelerated through the 1980s and 1990s in Denmark, the Netherlands, and scattered individual cities was a steady, pragmatic process” as described by Colville-Andersen (2018).

While almost five decades of cycling infrastructure planning offer plenty of time for iterative try and error, Colville-Andersen also stresses the fact, that both Denmark and the Netherlands were simply not in a hurry (Colville-Andersen, 2018).
Today both are among a very limited number of countries that have their very own national cycling embassy. Those provide a public-private platform, which aim it is to further improve cycling (Bundesministerium für Digitales und Verkehr, 2022). The ADFC, the General German Bicycle Club, also frequently mentions how Germany could benefit from the solutions provided by the Netherlands and Denmark (ADFC, 2019).

While this research paper concentrates on the bicycle infrastructure rather than planning processes, marketing, or political will power, it quickly becomes clear that cities like Utrecht, Copenhagen and Amsterdam are doing it right – in many ways. But they are not only doing it but did it right. They have already found out, what makes good practical infrastructure and have together created an unwritten catalogue of best practice solutions. Those solutions are not only functionable in Dutch and Danish cities, but also work or can be adapted to work in other places of the world as well. That leaves one concluding finding: Someone who wants to design and provide good cycling infrastructure should in the first-place look, what others did – preferably the Dutch and the Danish – and cannot be too proud to copy something from someone else.

5. Conclusion

The infrastructure catalogue of best practice elements offers a solution to almost every issue. With that in mind it is astonishing that cities still try figuring out how to overcome a certain problem. Cities like Munich implemented a bicycle lane in the middle of a busy street, with cars passing left and right of the cyclists in 2021. While that was only due to a construction site, the lane had to be used for almost a year (Krattiger, 2022). Colville-Andersen commented on a similar issue in Washington: "Why, then, do we see crap like this showing up on city streets? Who, in their right mind, would actually choose to put cycling citizens in the middle of a street with speeding cars on either side? Certainly not anyone with an understanding of the bicycle's role in urban life as transport, or with a sincere desire to encourage cycling and keep people safe." (Colville-Andersen, 2018).

While this subjective comment might not be ideal to scientifically describe the approach of the city planners of Munich for their solution, it shows, that there is a clear misunderstanding of what is a good and a bad solution. Colville-Andersen further states, that a mid-lane bicycle lane can be found in other cities as well, yet it can't be found in cities of the cycling nations Netherlands or Denmark (2018).

Another example for (not) using best practice infrastructure are bicycle stands. The "Sheffield Stand" has proved itself one of the best parking solutions for bicycles, yet there are still cities and companies that use simple parking stands in which the front wheel is pushed in between two metal frames that offer little to no support (Allgemeiner Deutscher Automobil Club, 2018). Coming back to the City of Munich, they recently announced a pilot test for protective bollards on bicycle lanes. A total number of five small bicycle lane sections will be equipped with different types of bollards to find out how effective and practical they are. For at least a year the city will test the bollards and evaluate the findings (Neff, 2022). At the same time Forester wrote about the importance and design criteria of physical barriers between cars and bicycles already in 1994 (Forester, 1994). In 2018, the ADFC (General German Bicycle Club) published a position paper for protected bicycle lanes, including a bollard type comparison (Allgemeiner Deutscher Fahrrad Club e. V., 2018). The CROW Design Manual for Bicycle Traffic also gives design guides on bollards and curbs including their dimensioning (de Groot & CROW kenniscentrum voor verkeer, 2016). This creates the scientific opportunity to identify the motives and reasons why cities like Munich do not refer to best practice examples and rather try to reinvent the wheel.

This offers the opportunity for further research. It is intended to refer to this issue in a consecutive master thesis which not only tries to answer the question from above, but also which infrastructural elements are in the interest of the citizens (cyclists and not-cyclists) of Munich and to what extent those can be implemented in the city.

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Appendix

Appendix 1

Bicycle Highways

<u>Description</u>

Bicycle highways are long-distance bicycle paths that connect cities or urban centers. They are wider than regular bicycle paths and should contain as little stops as possible. Through their directness and the omission of stops they allow fast travel from A to B (Bundesministerium für Digitales und Verkehr, 2022; de Groot & CROW kenniscentrum voor verkeer, 2016).

Figure 3: Woman cycling on a wide bicycle highway (Evenäs, 2019)

<u>Initial Issue</u>

Connections between cities and urban centers sometimes only exist in the form of regular roads with often high-speed limits, creating a non-inviting and dangerous surrounding for cyclists.

<u>Example</u>

Mulheim an der Ruhr to Essen (Germany)
Leuven to Brussels (Belgium)
Arnhem to Nijmegen (Netherlands)

Stepped Bicycle Paths

<u>Description</u>

Stepped bicycles paths are physically elevated from neighboring roads and thereby physically separate cyclists from motorized traffic users. When running parallel to a walkway there should be another (smaller) step between pedestrians and cyclists (Black, 2014).

Figure 4: Stepped bicycle path on Hills Road in Cambridge (Cycling Embassy of Great Britain, 2016)

<u>Initial Issue</u>

Non-apparent bicycle lanes could on-purpose or accidentality be used by motorized road users for parking or as an additional lane, resulting in an uncomfortable and hazardous situation for cyclists.

<u>Example</u>

Copenhagen (Denmark)
Utrecht, Netherlands
Stockholm (Sweden)

Bicycle Streets (Highlighted)

Description
Bicycle streets are a special legal and urban planning element that grants cyclists additional rights compared with motorized road users. For better recognition by motorized road users and cyclists, roads can be fully painted leaving a gap left and right to prevent dooring (Colville-Andersen, 2018; Dutch Cycling Embassy, 2021). In the Netherlands usually dyed asphalt is used to generate the red appearance (de Groot & CROW kenniscentrum voor verkeer, 2016).

Figure 5: Group of people cycling on a highlighted bicycle street (Pinder, 2020)

Initial Issue
Bicycle streets are often just marked by a sign at the beginning and the end of the street and do not differ enough from any other road.

Example
Utrecht (Netherlands)
Amersfoort (Netherlands)
Bremen (Germany)

Cobblestone Cover

Description
Cobblestones are covered by a layer of asphalt, wood or a completely reconstruct with a different type of paving stones to create an even and grippy bicycle strip (Black 2014, Colville-Andersen 2014). Existing cobblestones do not have to be removed entirely and can be conserved.

Figure 6: Rebuilt cobblestone street with an even bicycle strip (Colville-

Initial Issue
Cobblestones are uncomfortable to ride can create a slippery surface when wet.

Example
Seville (Spain)
Copenhagen (Denmark)

Heated Bicycle Paths

<u>Description</u>
By running (waste) heat of local industries through pipes underneath the bicycle paths, they can be heated and cleared from snow and ice (Boffey 2018).

<u>Initial Issue</u>
Winter service is a cost and time-consuming effort to provide a safe and working bicycle infrastructure.

Figure 7: Woman on heated bicycle path in Wageningen Schiffer 2015)

<u>Example</u>
Krommenie (Netherlands)
Wageningen (Netherlands)

Buffer Space

<u>Description</u>
Implementing a save space between bicycle paths and motorized road users, signposts, and other infrastructural elements, helps to reduce collisions and dooring accidents. An often used distance is 0.50m (Schröter et al., 2021).

<u>Initial Issue</u>
Cyclists are exposed to the risk of dooring or collision with lamp posts etc. if bicycle paths pass them close by.

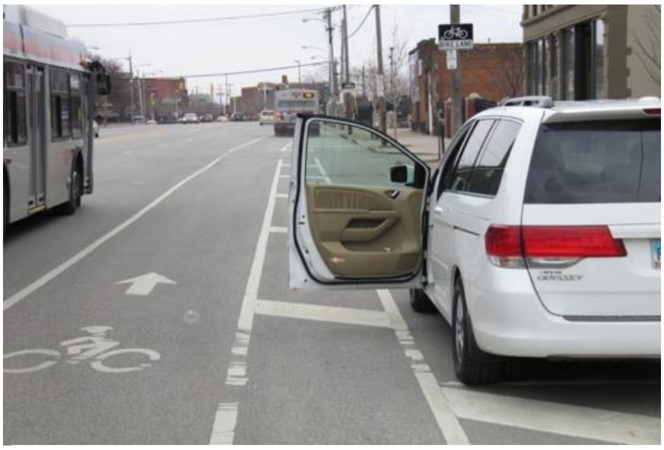

Figure 8: Buffer space protects cyclists from dooring (Schimek, 2018)

<u>Example</u>
Cleveland (USA)
Berlin (Germany)

PV Bicycle Path

<u>Description</u>
Instead of asphalt, special photovoltaic panels are used to pave bicycle paths. This allows the harvest of solar energy without large additional environmental interventions (Furtula 2021).


Figure 9: Cyclists on PV bicycle path in Noord-Holland (Furtula 2021)

<u>Initial Issue</u>
Photovoltaic and solar parks often require a large scale to be efficient and thereby portray a large interference in the environment.

<u>Example</u>
Maartensdijk (Netherlands)

Bollards

<u>Description</u>
Vertical bollards are used to physically and visually separate bicycle lanes from other modes of transport. They can be designed in different heights and out of materials as plastic, steel, or concrete. They are a cheaper solution than stepped bicycle lanes and can be used as a temporary measure. Depending on the solution they can function as a strict barrier or leave the possibility of being overrun by a car (Black 2014, de Groot and CROW kenniscentrum voor verkeer 2016).


Figure 10: Small bollard design in Groningen (Hembrow, 2013)


Figure 11: Green bollard design in Vancouver (Engel 2019)

<u>Initial Issue</u>
Physically not separated bicycle lanes can easily be used by motorized road users for parking or (accidentally) used as an additional drive lane.

<u>Example</u>
Stockholm (Sweden)
Seville (Spain)
Nantes (France)

Self-Illuminating Bicycle Paths

Description
Self-illuminating bicycle paths use an asphalt mixture that contains phosphors. Because of their physical properties, they absorb sun light and emit it throughout the night in form of a blue light. This makes bicycle paths not only more visible to all road users however also creates a safer psychological feeling to cyclists. The idea is based on an art installation by Daan Roosegaarde from 2014 (Metcalfe, 2014, 2016).

Figure 12: Self-illuminating bicycle path and walkway in Lidzbark Warminski (Strabag, 2016)

Initial Issue
Poor lighting of bicycle paths and lanes can lead to overseeing obstacles that block the path for cyclists.

Example
Lidzbark Warminski (Poland)
Eindhoven (Netherlands)

Cycle-Contra Flow

Description
Cycle-contra flow lets cyclists travel against the direction of a one-way road. This allows cyclists to travel on a more extensive network than motorized road users and makes travel times shorter by improving the connectivity (Black, 2014; Dutch Cycling Embassy, 2021). Standards for the opening of one-way roads to cyclists differ from country to country (Halpern, 2020).

Figure 13: Entrance to one-way road in a residential area (European Transport Safety Council, 2018)

Initial Issue
One-way roads are often used to direct motorized road users through a city in a controlled way. Yet, it impairs the bicycle network to the same extent.

Example
Munich (Germany)
Utrecht (Netherlands)
Oslo (Norway)

Use of color

<u>Description</u>

Separating bicycle paths and lanes from walkways and streets by color can have a large impact on safety and comfort of cyclists. Different colors clearly mark bicycle lanes as such and thereby minimize the misuse of other road users. Colors additionally work as a guide for directions. The color type is depended on the aspired effect and/or the overall color scheme used in the city/country (Autelitano & Giuliani, 2021; Black, 2014). Example for color effects: Creating awareness and improving safety in intersections is usually achieved with blue or red bicycle lanes (Autelitano & Giuliani, 2021).

Figure 14: Red-dyed asphalt for bicycle lane (Asphalt Industry Alliance, n.a.)

<u>Initial Issue</u>

Bicycle paths and lanes often blend in with regular streets and walkways. This can lead to serious incidents when pedestrians or motorized road users use the bicycle infrastructure.

<u>Example</u>

Netherlands (national level)
Berlin (Germany)
New York (USA)

Pictograms

<u>Description</u>

Pictograms are mostly used when physically separated bicycles paths are not applicable, and a mixed traffic must be adapted. With the right use of pictograms cycling can not only be made more convenient but also create a objectively and subjectively safer surrounding for cyclists (Koppers, 2021).

Figure 15: Bicycle pictogram on a protective bicycle lane (Herbst, 2020)

<u>Initial Issue</u>

Because of spatial limitations cyclists must often share traffic space with other road users. Mixed traffic can lead to confusing and dangerous situations if the rights of each road users are not clear.

<u>Example</u>

Copenhagen (Denmark)
Berlin (Germany)
Utrecht (Netherlands)

Appendix 2

Dutch Intersections (Separated Intersection)

Description

Dutch intersections separate motorized road users and cyclists in the intersection area, making crossings for cyclists safer. Motorized road users have more time to look out for cyclists, the safety curb provides additional protection and by keeping an appropriate curve radius, cyclists do not have to slow down drastically (de Groot & CROW kenniscentrum voor verkeer, 2016; Holeywell, 2016; Wagenbuur, 2014).

Figure 16: Rendering of a Dutch Intersection (Wagenbuur, 2011)

Initial Issue

Regular intersections do not provide enough time for cyclists to be seen by right-turning motorized road users and have little to no physical separation at the crossings.

Example

Loevenhoutsedijk – Brailledreef in Utrecht (Netherlands)
Kardinaal de Jongweg – Meester Tripkade in Utrecht (Netherlands)
Justitiestraat – Mechelsesteenweg in Antwerp (Belgium)

Two-stage opposed turn

Description

Two-stage opposed turn improve the safety of left turning cyclists for the cost of trip time on larger intersections. In the first stage cyclists that want to turn left follow the road ahead and cross the intersecting road. After the crossing cyclists come to a hold on the right and turn their bicycle 90 degrees. They are now ahead of the waiting line of the intersecting road. In the second stage they wait for the green signal of the intersecting road and go ahead. For a successful two-stage opposed turn it is required that enough and save waiting space for cyclists is provided and that all necessary traffic lights can be seen by cyclists (Allgemeiner Deutscher Fahrrad-Club e.V., 2019; Black, 2014).

Figure 17: Two-stage opposed turn with painted waiting box (National Association of City Transportation Officials, 2014)

Initial Issue

Cyclists must cross one or multiple lanes to make their way to the left-turn-lane ahead of an intersection. With busy intersections they must wait in the exposed center of the crossing in between the passing motorized road users until they can fully turn left.

Example

Berlin (Germany)
Stockholm (Sweden)
Munich (Germany)

Advanced Stop Lines (ASL)

Description
When cyclists and motorized road users approach a stop signal at a traffic light the stop line for cars or trucks is set further back than for cyclists. This allows cyclists to move ahead of the cars and make themselves visible for car drivers. Though, ASL only create a benefit during red light phases or if early start phases for cyclists are implemented (ADFC Hamburg, 2019; Black, 2014; Britain, 2014; de Groot & CROW kenniscentrum voor verkeer, 2016).

Figure 18: Filled advanced stop lines (Cycling Embassy of Great Britain, n.a.-a)

Initial Issue
Cyclists can be easily overseen by motorized road users. Especially right turning traffic is a risk to ongoing cyclists.

Example
Utrecht (Netherlands)
Berlin (Germany)
Copenhagen (Denmark)

Roundabouts with Bicycle Priority

Description
Roundabouts with external paths work like Dutch intersections because cyclists are separated from other road users in the crossing area. At the exits of the intersection, at which cars or trucks must cross the continuing bicycle path, cyclists are prioritized. This allows a comfortable and continues cycle flow (Black, 2014; de Groot & CROW kenniscentrum voor verkeer, 2016). If well planned, roundabouts take up as much space as regular intersections, provide more greenery and have less operational costs due to the fact that no traffic lights must be serviced and operated (Dutch Cycling Embassy, 2021).

Figure 19: "Dutch style" roundabout in Cambridge (Campaign, 2020)

Initial Issue
Roundabouts, especially multi-laned, represent a vast safety problem for cyclists. Motorized road users usually go at greater speeds than cyclists and visibility is limited. This is an essential issue when cars or trucks exit the roundabout because they could easily oversee cyclists.

Example
Jægersborg Alle – Bernstorffsvej in Copenhagen (Denmark),
Hindersteinlaan – De Tol in Utrecht (Netherlands),
Plesmanweg – Nieuwe Parklaan in The Hague (Netherlands)

Free Right Turn

Description
The free right turn signage – in use for motorized road users already – allows cyclists to turn right independently of the traffic light signal (Black, 2014; Bundesanstalt für Straßenwesen, 2019; Christian, 2016).

Initial Issue
Despite availability of bicycle paths and the lack of cross traffic, right-turning cyclists must wait at intersections, prolonging trip times.

Example
Brussels (Belgium)
Copenhagen (Denmark)
Paris (France)

Figure 20: Turn on red sign in Belgium (@Qr189 via Wikimedia Commons, 2013)

Traffic Lights for Cyclists
Description
Installing traffic lights for cyclists improves comfort (not having to contort to see car traffic lights) and can be used to prioritize or control cycling flows separately of other road users (Black, 2014; de Groot & CROW kenniscentrum voor verkeer, 2016).

Initial Issue
Traffic lights are usually designed to meet the need for motorized road users (height, orientation) and can thereby be hard to see by cyclists (e.g., in two-stage opposed left turn). Additionally, unseparated traffic lights do not allow to separately control car and bicycle flows.


Figure 21: Traffic lights at superhighway in Copenhagen (Marianne Weinreich, 2019)

Example
Amsterdam (Netherlands)
Berlin (Germany)
Cambridge (United Kingdom)

Green Wave

Description
The green wave – already standard for motorized road users – improves traffic flow across main artilleries for cyclists by turning traffic lights at intersections to green according to speeds of cyclists (e.g. 20 km/h in Copenhagen) (Colville-Andersen, 2018; Schiller, 2016). Trip durations can be reduced by up to 30 % through green waves (Buczynski, 2018).

Initial Issue
Stop-and-go traffic for cyclists is prolonging trip times and is energy intensive because the bicycle must be continuously accelerated by the cyclists.

Example
Nørrebrogade in Copenhagen (Denmark)
Valencia Street in San Francisco (USA)
Raadhuisstraat in Amsterdam (Netherlands)

Cyclists Only Green

Description
Longer and/or earlier green light periods for cyclists allow for shorter travel times and lead to a more save intersection crossing. Cyclists can start ahead and make themselves more visible to motorized road users. At the same time travel times for cars are enlarged because longer stops are required, making cycling more attractive and showing a mode favor through officials (Barth, 2013; Ridler, 2020).

Figure 22: Green light for cyclists while cars have to wait (Andersen, 2019)

Initial Issue
Intersections are the main site for accidents with the participation of cyclists.

Example
Hills Road in Cambridge (United Kingdom)
City of Assen (Netherlands)
Gyldenløvesgade in Copenhagen (Denmark)

Traffic Light Indicator

Description
Located approximately a hundred meters ahead of an intersection with traffic lights, LEDs embedded in the bicycle path indicate if a cyclist can make the green light phase according to a reference speed. Depending on the color of the light the cyclist can either speed up to make the green phase or slow down if the traffic lights are already red.

Initial Issue
When approaching a traffic signal, cyclists can usually not tell if they make a green phase or not. Often a little acceleration could lead to making a green light.

Example
Odense (Denmark)
Rotterdam (Netherlands)
Copenhagen (Denmark)

Figure 23: LED lights embedded in asphalt (City of Copenhagen, 2011)

Traffic Light Timer

<u>Description</u>
A timer installed at the traffic light indicates cyclists how long a green or red traffic light signal will last. Cyclists can adapt their speed in advance depending on the countdown time and patiently wait at a red light (M. Colville-Andersen, 2013; Colville-Andersen, 2018; de Groot & CROW kenniscentrum voor verkeer, 2016).

Figure 24: Traffic light countdown for cyclists (Colville-Andersen, 2013)

<u>Initial Issue</u>
Without knowing how long a red traffic light will last, the temptation of running the red light will grow. Ahead of the intersection a speed adaption in dependency of the light phase is difficult.

<u>Example</u>
Frederiksberg (Denmark)
Copenhagen (Denmark)
Amsterdam (Netherlands)

Modal Filter

<u>Description</u>
Modal filters represent a barrier that only allows pedestrians and cyclists to continue their travels on a street. A modal filter can be used to hinder motorized road users from reaching pedestrian zones, make streets unattractive for cars or to limit through traffic in bicycle streets (Allgemeiner Deutscher Fahrrad Club e. V., 2020; Black, 2014; Cycling Embassy of Great Britain, n.a.-b).

Figure 25: Modal filter, location unknown (Cycling Embassy of Great Britain, n.a.-c)

<u>Initial Issue</u>
Without modal filters streets are open to all road users without prioritizing certain modes.

<u>Example</u>
Houten (Netherlands)
Stockholm (Sweden)
Cambridge (United Kingdom)

Appendix 3

Bicycle Racks

Description

Bicycle racks are versatile in their design. One design that proved itself space and cost efficient, provides secure locking possibilities and does not necessarily damage the bicycle if it falls over, is the "Sheffield Stand" or "Inverted-U" (Bunt & Associates Engineering, 2021; Great Britain Department for Transport, 2020). It is a simple, sometimes tubular, u-shaped, or rectangular metal stand. Two bicycles can be lent against the parking rack and locked to the stand. Additionally, some of the parking racks are equipped with a chain which allows bicycles with an integrated frame lock to be fixed to the stand (Seppälä, 2017).

Figure 26: Inverted-U with a frame lock chain (Seppäla, 2017)

Initial Issue

Some bicycle parking racks are designed in such a way, that they do not provide enough stand or possibilities to lock the bicycle. Some bicycle stands damage the bicycle if they fall over (e.g., "wheel bender").

Example

Helsinki (Finland)
Munich (Germany)
Copenhagen (Denmark)

Secure parking & parking lockers

Description

With the rise of costly electrical bicycles the need for secure bicycle parking facilities increases (Zweirad-Industrie-Verband e.V., 2022). There are various solutions for secure parking of bicycles which mainly differ in their size. While there are small boxes in which only one individual bicycle can be parked, there are other solutions with which multiple bicycles can be stored in an enclosed encounter. Parking spots can either be booked in advance or the at locker. Access can be granted through a pin code, a member card or through the smartphone (Bezema, n.a.; Blume, 2019; Bunt & Associates Engineering, 2021).

Figure 27: PIN-code accessible locker for 20 bicycles (Kienzler Stadtmobiliar GmbH, n.a.)

Initial Issue

Bicycles, especially electric bicycles, are often very costly and therefore not suitable for taking it for daily travels to public transport stations or other public destinations.

Example

Oberhausen-Sterkrade – Single parking boxes (Germany)
Hoheluftbrücke in Hamburg – Two-story parking racks (Germany)
Hockney in London – Residential parking boxes (United Kingdom)

Automated Parking

Description

Automated parking garages are either underground or aboveground. Cyclists push their bicycle into an opening, pay or identify their subscription to the service and the bicycle is automatically stored in the garage. The bicycle can be returned in the same way (GIKEN, 2019; Siemens Schweiz AG, 2021).

Figure 28: Entrance to automated underground bicycle parking (Asano, 2017)

Initial Issue

Parking garages and other parking facilities are often very space intensive and can therefore not be constructed at every location.

Example

Tokyo (Japan)
Halle/Saale (Germany)
Třinec (Czech Republic)

Parking Garage

Description

Like car parking garages, bicycle parking garages are large scale parking facilities. They can be accessed either for free, through a subscription-based model or a daily payment. They offer large supply, qualitative and secure parking (Dutch Cycling Embassy, 2021). The largest bicycle garage offers more than 12.000 parking spaces (Crook, 2019). Bicycle garages are usually found at locations of great demand (e.g., public transport stations) and can either be solely designed for bicycles or offer a mix use of cars and bicycles (Crook, 2019). For a high workload it is important that their usage is simple, convenient and fast (Slaughter, 2020).

Figure 29: Utrecht parking garage (Yanan, n.a.)

Initial Issue
Public transport stations are locations of large demand and great flow of travelers. Large scale parking facilities are required to process the demand.

Example
Utrecht Central (Netherlands)
Station Houten (Netherlands)
Münster Hauptbahnhof (Germany)

Flex Parking

Description
Flex parking zones can be used to allow for additional parking capacities to cover peak hours for cyclists throughout the day e.g., for grocery stores or offices. At night or whenever required they can be used as car parking e.g., for residents (Black, 2014; City of Amsterdam, 2020; Colville-Andersen, 2011).

Figure 30: Explanation of the rights at a flexible parking zone (Maus, 2013)

Initial Issue
Parking spots are static infrastructures that cannot be changed to meet temporal demand changes.

Example
Kinkerstraat in Amsterdam (Netherlands)
Gerard Douplein in Amsterdam (Netherlands)
Nordre Frihavnsgade in Copenhagen (Denmark)

Remove Car Parking

Description
While not being an infrastructural element, removing car parking space can have multiple benefits. Depending on the size, gained space can be reallocated for pedestrian zones, bicycle lanes or bicycle parking (Nieuwenhuijsen et al., 2019). It also makes taking a car to the inner city less attractive because of the lack of parking facilities while making cycling and inner cities more appealing (Berg, 2016; Peters, 2019).

Figure 31: Before Oslo removed car parking spots (Clarence, 2017b)

<u>Initial Issue</u>
Parking spots take up large amounts of public space that could be used for other purposes. In fact, cars are usually parked for about 23 hours a day, taking away useful space (Rohwetter, 2022).

<u>Example</u>
Oslo (Norway)
Paris (France)
Barcelona (Spain)

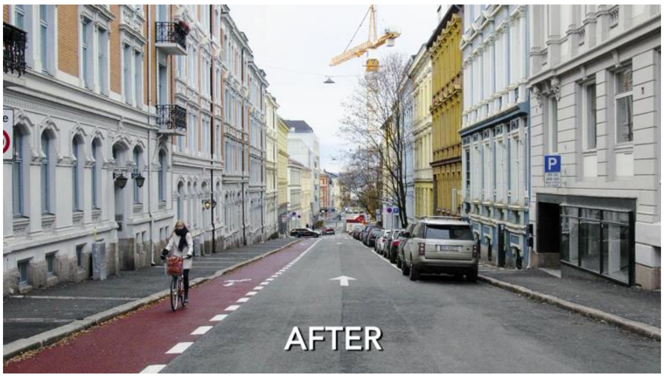

Figure 32: After Oslo removed car parking spots (Clarence, 2017a)

Cargo Bike Parking

<u>Description</u>
Cargo bike parking spots offer parking possibilities that meet the requirements of cargo bicycles and tri-wheel bicycles. It is important that those parking spots are kept free of regular bicycles. In enclosed parking facilities electric power outlets can be provided to charge electric cargo bicycles (Colville-Andersen, 2014; Colville-Andersen, 2018; Great Britain Department for Transport, 2020).

Figure 33: Cargo bike parking in Strasbourg (Eurometropole of Strasbourg, 2020)

<u>Initial Issue</u>
Cargo bicycles are increasing in numbers, yet designated parking facilities are often missing.

<u>Example</u>
Central Station in Malmö (Sweden)
Manor Place in Dublin (Ireland)
Place Dauphine in Strasbourg (France)

Bicycle Storage on PT

<u>Description</u>
Easy to use bicycle storage on public transport, especially regional trains, allows commuters to take their private bike to and from the trains station for the last mile travel. Additionally, it can create a greater customer base to train operators as seen by the Danish railway operator (Colville-Andersen, 2016; Tusl, 2016).

Figure 34: Bicycle storage on a French train (Baxter, 2021)

<u>Initial Issue</u>
Trains are usually designed to transport great numbers of passengers at a comfortable level. Transporting bicycles is often difficult because required infrastructures onboard are missing.

<u>Example</u>
Intercity Berlin by NS International (Netherlands/Germany)
SBB/Swiss Railway (Switzerland)
SNCB/Belgium Railway (Belgium)
(Charles Carnegie, 2021)

Appendix 4

Car-free city

Description

The idea of car free cities is to (fully) ban motorized road users from (inner-) cities. Thereby urban space can be dedicated to active modes of transport, especially pedestrians, and create a save environment for all vulnerable groups (Nieuwenhuijsen et al., 2019). A step towards a car-free city is a periodical/permanent street closings to motorized road users (Copenhagenize Design, 2019b).

Figure 35: Monthly car-free Sunday on the Champs Elysees in Paris (Meunier, 2015)

Initial Issue

Cars take up large amounts of inner-city areas, either through driving or parking, pollute and emit noise.

Example

Bogota (Columbia)
Oslo (Norway)
Ghent (Belgium)

30 km/h Streets and Zones

Description

In 30 km/h street or speed zones, speed limits are set to 30 km/h. This allows the coexistence of cyclists and motorized road users on the same road. Additional bicycle infrastructure is not necessarily required (BBC, 2021; Deutsches Institut für Urbanistik, 2021). Cities like Paris set the speed limit of all streets to 30 km/h with a few exceptions on major roads (Markert, 2021).

Figure 36: Tempo 30 zone in Paris with note about cyclists (European Transport Safety Council, 2021)

Initial Issue

With speeds over 30 km/h it is usually required to have separate bicycle infrastructure. Without separate infrastructure the risk and the severeness of accidents at greater speeds increases.

Example

Paris (France)
Brussels (Belgium)
Madrid (Spain)

Floating Bus Stops

Figure 37: Floating bus stop in Stratford, London (Cycling Embassy of Great Britain, 2020)

Description
The floating bus stop aims to reduce conflicts between pedestrians/bus passengers and cyclists by routing the bicycle path between walkway and bus stop. Pedestrians must cross the bicycle path as if they would cross a street. Thereby, cyclists do not need to slow down. After crossing, pedestrians can wait for public transit on a sufficiently sized bus stop island. Disembarking pedestrians do not immediately step on cycle paths rather than wait for clearance on the island. If necessary, zebra crossings can be placed to improve the safety of pedestrians. It is import that the cycle paths are both physically and optically highlighted (Black, 2014; Colville-Andersen, 2018).

Initial Issue
Bus stops constitute a great conflict region for cyclists and bus passengers.

Example
Berlin (Germany)
Stockholm (Sweden)
Houten (Netherlands)

Automated Streetlights (Smart Streetlights)

Description
Streetlights are automatically activated when cyclists pass by, creating a safe environment for cyclists and having a demand-controlled energy consumption. Smart streetlights can also detect when, how fast and how many cyclists pass a street (Hilbert, 2022; Tvilight, 2022).

Initial Issue
Traffic lights are a source for redundant energy consumption, maintenance costs and light pollution. Yet, they are essential for comfortable and save cycling.

Example
Port of Moerdijk (Netherlands)
Gera (Germany)
Mechelen (Belgium)

Wayfinding & Traffic Signs

Description

Wayfinding is key to cyclists that do not frequently or just recently started using the bicycle (Black, 2014). It enables an easy way of getting from A to B without the need to look up routes in advance. A city wide/regional wayfinding system must be coherent and self-explanatory. Traffic signs must be readable for cyclists (height, size) and stand out of traffic signs for other road users. Different routes through the city or intercity can be marked by names, numbers, or color. Good wayfinding is essential for a stress free, save and simple guidance in case of detours and road closings (Great Britain Department for Transport, 2020).

Figure 38: Simple wayfinding in Hertogenbosch (Wagenbuur, 2013)

Initial Issue
Wayfinding is an often-neglected element in bicycle infrastructure. Cyclists that do not cycle frequently have to look up their route in advance or on the go. In the instance of detours, cyclists are often forgotten about and must figure out their own way around the road closings.

Example
Utrecht (Netherlands)
Stockholm (Sweden)
Amsterdam (Netherlands)

Prioritized Maintenance on Main Artilleries

Description
While not being an infrastructural element, prioritizing maintenance (e.g., cleaning, winter service) is key to enable good cycling conditions throughout the entire year. Especially during the winter season, main artilleries must be cleared frequently and already in the morning to allow people to conveniently commute to work (Colville-Andersen, 2018; Niska, 2010).


Figure 39: Cyclist on cleared bicycle path in winter (Tulenheimo, 2021)

Initial Issue
Regular streets are often prioritized in the winter/autumn maintenance service of cities, leaving commuting cyclists behind.

Example
Copenhagen (Denmark)
Oulu (Finland)
The Hague (Netherlands)

Rain-Sensors

Description
Rain sensors spread across the street network can detect beginning rain and initiate a green wave on main artilleries to shorten their travel times (Andersen, 2016; Colville-Andersen, 2018).

Initial Issue
Cyclists are particularly exposed to weather changes compared with car drivers.

Example
Rotterdam (Netherlands)
Groningen (Netherlands)
Odense (Denmark)

Figure 40: Rain sensor in Odense(Odense Municipality, 2018)

Tram Track Fillers

Description
Filling elements made of springs, elastic plastic or rubber are used to fill the tram track gaps and thereby creating a smooth and save surface for cyclists. The filling element can be pushed down or driven over by the tram trains because of their weight (Black, 2014; Enterprise Europe Network, 2019; Laker, 2017).

Initial Issue
Tram tracks represent a serious potential for accidents if tires are caught in the tracks.

Example
Not available

Bicycle Escalator

Description
Cyclists can use an escalator to move up a steep hill by stepping of the bicycle on one side as shown in the figure on the right (Valderrama-Meiner, 2019b).

Initial Issue
Steep hills represent a physical obstacle that is difficult to overcome for disadvantaged groups. They – unintendedly – exclude people that have too little physical ability from the entire street network

Example
Trondheim (Norway)

Figure 41: Man using bicycle escalator (Valderrama-Meiner, 2019a)

Digital Trip Time Displays

Description
Displays show the live trip duration to selected destinations comparing bicycles with motorized road users. Because bicycles are usually faster on inner city trips, the time advantage can be used to convince non-cyclist to change to the bicycle (Reid, 2018). Additionally, they are a convenient way for cyclists to plan their trip. Displays can also be used to communicate relevant messages on a short notice (City of Copenhagen Technical and Environmental Administration, 2011).

Initial Issue
Communicating the benefit of urban cycling regarding trip durations is difficult (Tranter, 2012). Messages on a short notice cannot be communicated with cyclists

Example
Copenhagen (Denmark)

Figure 42: Digital display with optional messages (City of Copenhagen, 2018)

Cyclists Counter

<u>Description</u>
Cyclist counters count the number of cyclists that pass by them throughout the day and year and shop the current numbers. Besides creating a foundation for data analysis, it can achieve a motivational effect on cyclists and other road users to change mode (Black, 2014; Colville-Andersen, 2018).

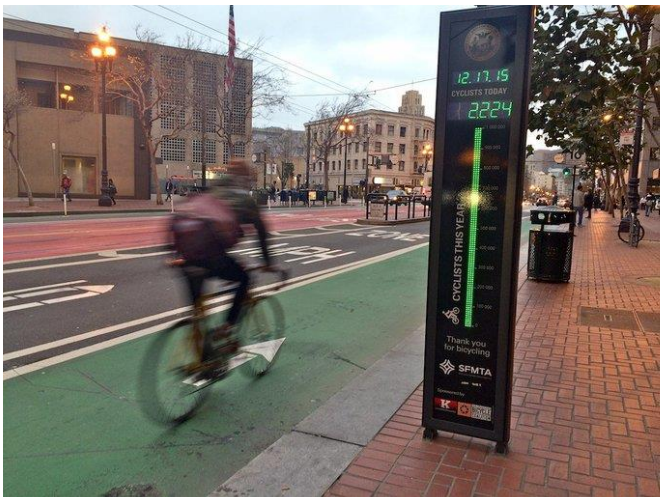

Figure 43: Cyclist counter in San Francisco (Rodriguez, 2015)

<u>Initial Issue</u>
Counting cyclists is essential for data analysis and demand control. Yet, it is usually a time intensive and costly process.

<u>Example</u>
Munich (Germany)
Oslo (Norway)
Copenhagen (Denmark)

Foot & Arm Rests

<u>Description</u>
Foot and arm rests at traffic lights or stop signs do not make cycling safer or faster, yet it improves the level of comfort. Cyclists can hold on to the rests and do not have to get off the bicycle. When traffic signals turn green or intersections are free, they can simply push themselves off and keep some of the potential energy (Colville-Andersen, 2010b; Hoe, 2018).

Figure 44: Foot and arm rest in Copenhagen (Colville-Andersen, 2010a)

<u>Initial Issue</u>
Stopping and stepping off at traffic lights takes away the momentum of a cyclist.

<u>Example</u>
Copenhagen (Denmark)
Montreal (Canada)
Berlin (Germany)

Tilted Bins

Description
Garbage bins are tilted and elevated to make garbage disposal easy for cyclists on the go without the need to stop (Hoe, 2018; Rawsthorn, 2013b).


Figure 45: Tilted bins for cyclists (Rawsthorn, 2013a)

Initial Issue
Disposing garbage on a bicycle in regular garbage bins is difficult because of their vertical orientation. Cyclists must come to (almost) a halt to dispose their garbage.

Example
Copenhagen (Denmark)

Tools and Pump

Description
Providing multiple repair stations and pumps across the cycling network allows cyclists to do simple maintenance on their bicycles themselves and at any point of time (Black, 2014; Great Britain Department for Transport, 2020).


Figure 46: Free bike tools at University College Dublin (Kearns, 2018)

Initial Issue
Cyclists often do not have the tools to do smaller maintenance works on their bicycle – at home, work or on the go.

Example
Munich (Germany)
Dublin (Ireland)
Utrecht (Netherlands)

List of Tables

List of Figures