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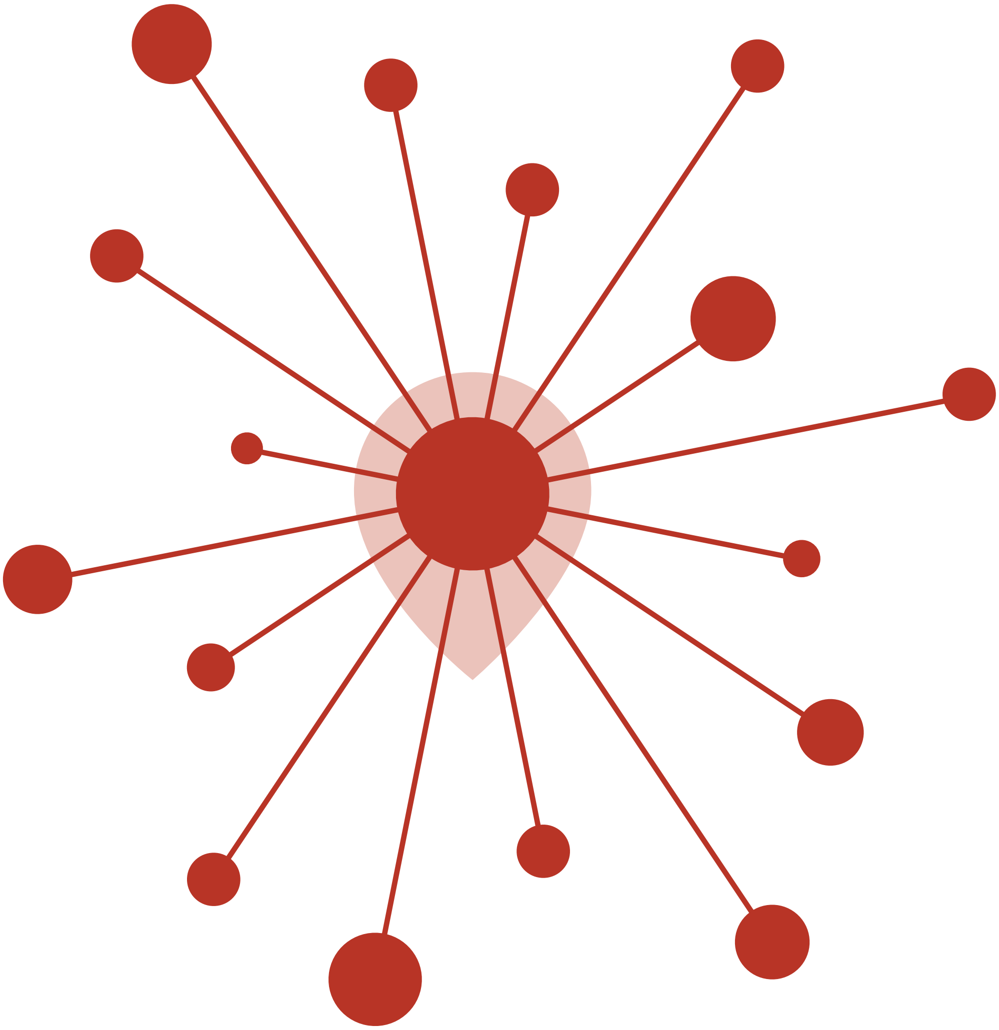

»Access is better than ownership.«

Kevin Kelly (Wired)

COPED |ˈkopæd|

Collaborative E-Bike Sharing

Bachelor thesis presented in partial fulfillment
of the requirements for the degree of
Bachelor of Arts

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ABSTRACT

As the world faces climate change and population growth, paradigm shifts in passenger transport away from fossil energy, and in consumption models from owning towards sharing, are imperative.

Technology for sustainable transport systems becomes more and more available. While e-bikes prove to be a more effectual alternative to cars than normal bicycles, their application is still lacking, not least because they are expensive.

On the other hand, information systems connect people with vast efficiency and enable sharing economies in the physical world like Airbnb that were hardly conceivable before. And this is only the first stage as the physical things themselves start to get connected.

At the intersection of these fields—transport and information technology—new concepts like the Copenhagen Wheel, a connected retrofittable e-bike solution, emerge.

The COPED concept tries to answer the question what an urban peer-to-peer e-bike sharing system could look like, based on the announced Copenhagen Wheel technology as well as existing mobile information systems.

After examining related work on the ecological, social and societal implications of various transport modes, on collaborative consumption, the internet of things and novel forms of visualising spatial range, the thesis researches the requirements of a peer-to-

peer e-bike sharing system that is based on collaborative consumption—mainly how the infrastructure and a supply/demand balancing mechanism is provided.

This lays the groundwork for the COPED e-bike sharing concept, which defines the relevant facilities, the roles and functions of providers and is demonstrated by the screen design for a mobile app and a simulated map visualisation to impart demand and supply.

Introduction

Figure 1
Traffic jam

The climate is changing.

Repeating this inconvenient truth has become rather convenient to us. Relying on its power to scare people enough to make them change their ways is unfortunately proving wrong.

For everybody who acknowledges the climate change as a fact, there is a more or less grave internal conflict: On one hand, the imperative is to lower our energy consumption, which ultimately translates to consuming less. On the other hand, self-confinement is something that most people find hard to do.
A lot of people do not even acknowledge man-made climate change and therefore do not suffer this conflict in the first place[1].

As convinced our intellects may be at the sight of the climate change's consequences that we have to change our habits fundamentally—we need to understand that our whole being is not pure intellect. We are just as much sensualists, hedonists even. Our physical and mental needs—suggested or real—rival our rationale more often than not.

To find a way out of this conflict, we can look at the difference between what we consume and what we actually physically need. Some of it has great saving potential: We can choose not to heat the apartment when we are not home and remember to switch off the lights in the day time—without missing anything. Other forms of consumption are not as easily avoidable.But our hands are not tied when it comes to resources that we cannot avoid to consume. Besides the question how environmentally and socially sustainable the source of a product is, we can always

consider the applicability of a time-proven cultural achievement: sharing.

Passenger transport is one of civilisation's most unsustainable and wasteful endeavours. Commuters drive their cars at occupancy rates of 1.5 passengers per car and less[2] because of a seeming lack of convenient alternatives.

But there are alternatives. Public transport is only one option which is not available everywhere. Some gaps can be bridged with conventional bicycles, a lot more can be bridged with e-bikes.

The growing popularity of bike sharing systems worldwide indicates that this transport alternative can indeed be conveniently shared, although e-bikes yield an additional challenge—they require a charging infrastructure.

On the other hand , today's sharing economies show that almost anything can be shared, so why not a charging infrastructure?

Finally, the latest developments in e-bike technology allow the vehicles themselves to connect to the internet, which opens up new possibilities for automated and remotely controlled sharing and managing interactions.

DESIGN QUESTION

What could an attractive urban e-bike sharing service look like, that utilizes the capabilities of connected e-bikes to collectively set up the required infrastructure and to create a user experience that meets the mobility needs of urban dwellers?

Figure 2
The author biking

PERSONAL MOTIVATION

I love biking. Not as a sportive or expensive hobby, but as something very mundane and practical. I think it is a great way to satisfy a lot of my everyday transportation needs both in a joyful and a sensible way.

I also love the internet of things and the way everyday appliances get a new potential of being useful just by making them connected. Being also a developer, I embrace the idea that hardware platforms open up to the developer community and as a result add value, use cases and new audiences to their products.

Finally, I look at the disrupting changes that web-based sharing economies like Airbnb are imposing on the markets, and despite the critical aspects, I think there is a lot of potential to use this principle for economically, socially and ecologically progressive causes.

When I first heard about the Copenhagen Wheel, I immediately started to think of ways how it could bring all of this together.

»Cycling brings an exhilarating sense of freedom and self-mastery as well as a very enjoyable sense of not spending money.«

Tom Hodgkinson[3]

RELATED WORK

Figure 3
Public transport

TRANSPORT MODES

The transport sector as a source for greenhouse gas emission is the biggest growing sector around the globe[4, 5], therefore it is crucial to identify which transport modes are accountable for this and what the alternatives are.

Car

The transport sector is the second biggest perpetrator of CO2 emissions and one of the few sectors still growing[6]. Motor cars are the main cause after road freight for the transport sector's rising CO2 emissions and also for the chronically dysfunctional traffic flow in metropolitan areas[4]. This is ascribed to the continuing growth of household incomes and number of vehicles[7]. As combustion engine fuel efficiency improved over the years, the positive effect on CO2 emissions was mostly canceled out by a lower wastage awareness and resulting higher usage. While the pollution problem can be addressed by replacing combustion engine vehicles with electric cars, the congestion problem cannot. Metropolitan areas depend on a mode shift away from private cars. Estimations suggest that 80% of car trips could theoretically be shifted to other transport modes[8].

Public Transport

An important modal shift requirement is the shift from cars to public transport[9], which requires big infrastructural investments, which in turn will not happen without the political will to make public transport attractive[4].

Bicycle

Research indicates that cycling, in comparison to other transport modes, not only reduces emission of greenhouse gases, but also provides a physically more healthy and less stressful, more enjoyable way to commute[10, 11, 12].

One big obstacle that keeps people from leaving other transport modes in favor of biking is the limited action scope. Surveys in England about commuting habits and willingness to change them[13] found that a general prerequesite for shifting modes is the work place being »within cycling distance«.

Figure 4
E-bike

Electric Bicycle

There are two main types of electric bicycles[14]:

- E-bikes with pedal-assist are referred to as Pedelecs. While adding extra torque to the users pedalling with an electric motor, they maintain the fundamental biking experience. Paddle assist is cut at a certain speed over which the bike would legally be considered a motorbike. This limit varies with countries' different legislations: In the US it is 20 mi/h, in the EU it is 25 km/h. Pedelecs that exceed this limit are called S-Pedelecs. They are classified as motorbikes.

- In e-bikes with power-on-demand, the engine is controlled by a throttle. These e-bikes are generally classified as motorbikes. There are hybrid forms that combine power-on-demand with pedal assist.

The positive effect on usability, journey range, usage frequency, and even gender equality is shown in various international studies:

Research in China shows that e-bikes increase mean trip lengths considerately[15]. Users of the e-bike

sharing system cycleUshare in Knoxville, USA, by majority state that e-bikes extend journey ranges, remove terrain barriers and are easier to start at signals and stop signs[16, 17].

A recent study in Norway found that by providing the participants with e-bikes, per-day journey frequency was raised by more than 50 per cent, mean journey lengths were more than doubled, and although the participants already did 28 per cent of their transport by bike which is high, they raised it to an average of 48 per cent[18]. Also, usage frequency was measured higher with women, who generally cycle substantially less frequently in countries with low bicycle transport mode share than men do, according to various studies[19, 20].

E-bikes can also be implemented to extend bike usage into domains that are traditionally dominated by combustion-engine-based transport modes, such as cargo transport[21].

The two greatest concerns, however, are electric range and purchase price.

Figure 5
Vélib' bike sharing, Paris

COLLABORATIVE CONSUMPTION

Product Service Systems

Product service systems (PSS) are described as collaborative consumption systems for products that do not need ownership and are more beneficially consumed by a collective[22].

The driving force behind PSS is an undergoing profound evolution in the relationship between physical products, individual ownership and self-identity. We don't want the physical products, but the needs they fulfil (not the CD, but the music it plays; not the answering machine, but the messages it saves; not the vehicle, but getting from A to B).

The main benefit of PSS is the removal of entry barriers like price, availability and social status[22].

The Waste & Resources Action Programme calculates that shifting 20 per cent of household spending from purchasing to renting would cut CO2 emissions by about 2 per cent a year[22].

Figure 6
Paris view from a private apartment

Peer-to-Peer Sharing

Peer-to-peer (P2P) sharing is a form of PPS that links individuals who own underused goods with individuals who need these goods, thereby eliminating the middleman[22]. There are two challenges:

- Convenience: Consumers need the confidence that they can get things when they need them. Therefore, a critical mass in supply and demand is essential.
- Trust: P2P sharing system need to implement security layers that back up every transaction with a contract that lays out the legal terms. This implies deposits, insurances, and communal self-regulatory review and rating tools.

Bike Sharing

Three generations of conventional bike sharing can be defined[23]:

First generation bike-share systems in the 1960s distributed bikes across an area for free, anonymous use and usually leave the bikes unlocked. They were particularly vulnerable to theft and vandalism, therefore many have ceased operation.

Second generation systems, which were introduced in the early 1990s, have designated docking stations and operate on a coin deposit, but the use is still anonymous. Theft and vandalism are still a problem, albeit less grave.

Figure 7
Koubachi
plant sensor

In the third generation from 2005, bike-sharing became IT-based with wireless electronic communication and improved user accountability with credit/debit card authentication. Although these systems are more expensive than the first and second generation, they bring vast improvements in fleet management and theft determent. This generation marks the worldwide breaktrough of large-scale bike-sharing.

A fourth generation of bike-sharing can be added[24]:

This generation is described as a new, still evolving concept of demand-responsive systems built on third-generation bike-sharing that incorporate incentive-driven smart rebalancing, multi-modal integration with public transit, GPS tracking and system analytics.

CONNECTED THINGS

The paradigm of the Internet of Things (IoT) or Connected Things is described as objects that pervasively surround us and can interact with each other through unique addressing schemes and cooperate with their neighbours to reach common goals[25].

Under-utilised assets gain tremendous potential once they are connected to and via the Internet which makes them accessible to other stakeholders. The IoT is therefore a main accelerator for collaborative consumption[26].

Smart Cities & The Spatially Enabled Society

In the past years, Smart City has become a buzz word used by different stakeholders to describe visions of future urban living. A comprehensive definition of the term measures the smartness of a city by its hard infrastructure and its attention to the environment; access to information and communication technologies for both urban population and public administration; its human and social capital; and by its participatory governance, its smart economy, its smart urban mobility, its smart environmental strategy and management of natural resources, and the presence of its self-decisive, independent, and aware citizens leading a high-quality urban life[27].

A »spatially enabled society is an evolving concept where location, place and any other spatial infor-

Figure 8 Copenhagen Wheel

mation are available to governments, citizens and businesses as a means of organizing their activities and information«[28].

Furthermore, in a spatially enabled society, location and spatial information must be considered common goods and therefore made available to the public in globally unified geospatial standards; an infrastructure for sharing spatial data must exist; and most importantly, citizens must be »spatial literates«. A good a smart city agenda needs to also implement the concept of a spatially enabled society, thus empowering the urban population[27]. Among other projects by the MIT SENSEable City Lab, the Copenhagen Wheel serves as an example of technology spatially enabling the urban population and smartening their city.

The Copenhagen Wheel

In 2009, MIT's SENSEable City Lab first introduced the Copenhagen Wheel (CW), a concept for an electric bicycle solution at the COP15 United Nations Climate Change Conference in Copenhagen. It is announced for a commercial release in 2015 [29, 30]. According to the manufacturer's specifications, the CW integrates a complete pedelec powertrain, battery and various sensors into a regularly-sized rear wheel that can be retrofitted into a majority of standard bicycles. It is—besides pedalling—solely controlled wirelessly from mobile applications. It can recuperate energy from braking and from using it in

a special exercise mode, and it can lock and unlock.

Superpedestrian announced an SDK that enables developers to write custom applications to

- control the CW’s functions (control parameters for assistance/recuperation level, locking),
- read the system and sensor values (battery level, torque, accelerometer, temperature).

The original specifications[29] contained several environmental sensors, »including CO, NOx, temperature, noise (dB) and humidity« that were meant to be »used to power applications that relate to a cyclist’s health, community or the environment«. They cannot be found in the current specifications though, so it is not sure which of them, if any, will be present in a future release version.

VISUALISING SPACIAL RANGE

Range is an important information in e-mobility. User planning depends on a well-founded idea how far they can get on the current battery level. Most motorised vehicles provide the range information in the form of a distance value. This suggests a circular range with this distance being the radius which is only an approximation to the real range.

There are several new approaches to visualising ranges in passenger transport more exactly.

Mapnificent[31] visualises a person's range from a given position in a given time with public transport for many cities around the globe. It takes the multi-modality of public transport, i.e. the combination of motorised transport and walking, into account. This causes the characteristic bubbles.

Isoscope[32] does a similar thing for passenger car transport: Based on a start position, a time span and additionally on the time of day, Isoscope visualises a car's range. This can be complemented with the walking range. The underlying data by HERE[33] takes the road network, natural obstacles, speed limits and the tides of traffic into consideration, which results in irregular shapes.

These new approaches combine a higher range prediction accuracy compared to a simple distance value with more insights into the nature of the respective transport mode.

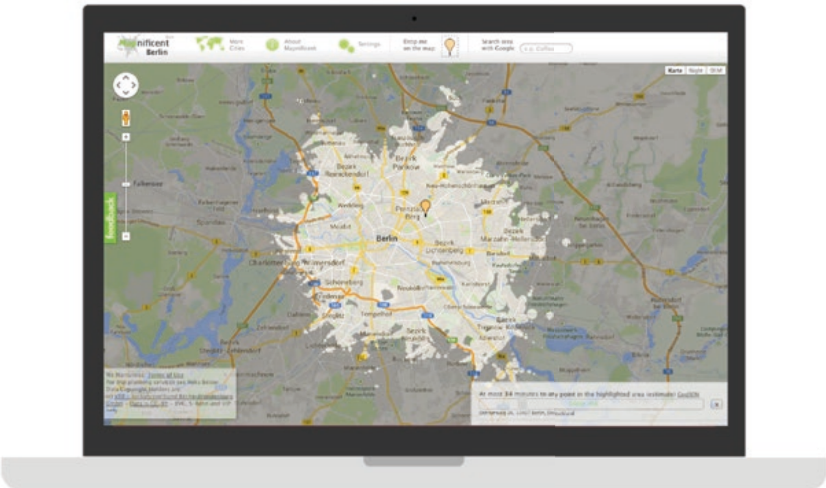


Figure 9
Mapnificent

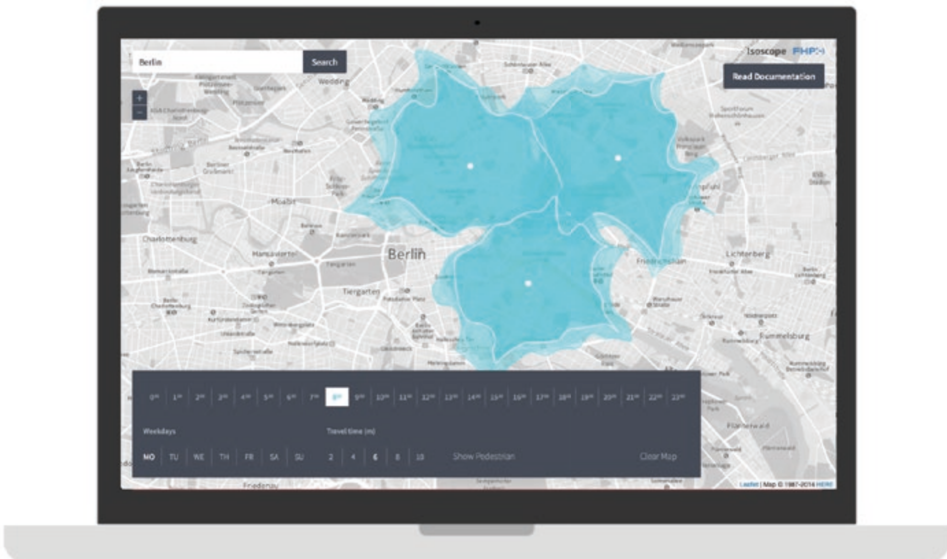


Figure 10
Isoscope

RESEARCH

As we have described, a modal shift in passenger transport away from motorcars is imperative, both for environmental and urban developmental reasons. Wherever applicable, cycling seems to be the mode implying the most advantages including health and fitness. Furthermore, the pedelec feature considerably increases bicycle applicability.

We also pointed out that the sharing economy is advancing into urban passenger transport. The trend is particularly popular with bicycle sharing systems that saw massive implementations around the globe in the past years.

This trend, however, is based on sharing systems run by local authorities in a centralised fashion, as opposed to P2P sharing systems. This holds true especially for e-bike sharing, where the charging infrastructure, in addition to expensive on-board logistics technology, seems to require a unified, closed approach.

The subject of this thesis is to research the feasibility of a fourth generation P2P sharing system for connected e-bikes, based on the Copenhagen Wheel. The questions I try answer are:

> *What are the advantages of a fourth generation peer-to-peer sharing system for connected e-bikes compared to existing solutions and how can these advantages promote the concept?*

> *What are the challenges of this system compared to existing solutions and how can these challenges be addressed in the concept?*

THE CHARACTERISTICS OF A FOURTH GENERATION P2P E-BIKE SHARING

An e-bike-sharing system must provide several components:

- the bike fleet,
- a logistic infrastructure,
- charging capabilities,
- maintenance,
- anti-theft measures,
- a mechanism for adapting supply to demand.

CROWDSOURCING THE FLEET AND LOGISTIC INFRASTRUCTURE

Existing bike-sharing systems use proprietary technology to register, locate, and track individual vehicles. A system based on connected e-bikes like the Copenhagen Wheel combined with personal smart devices comes with the necessary logistics technology built-in.

Everybody who owns a smartphone can be a leaser in this bike-sharing system, which is true for a lot of contemporary bike-sharing systems. The novelty is that everybody who owns one or more of these connected e-bikes can be a contributor of the bike-sharing system's vehicle infrastructure—a fleet provider.

To create awareness and willingness among potential fleet providers, it is essential to serve them with information about where—and when—there is demand.

CROWDSOURCING THE CHARGING INFRASTRUCTURE

Existing e-bike sharing systems rely on proprietary bike stands that are consequently equipped with charging capabilities. The question is how this can be substituted in a P2P concept that spares expensive physical docking stations.

Who can be an electricity provider in public areas on street level without taking costly infrastructure measures? This thesis assumes that the charging can be crowdsourced to local businesses. Off-license stores would be particularly suited as they already offer various shop-in-shop systems and extra services like cash machines, post office counters, or internet access; and have favourable opening hours. Other businesses with long working hours like petrol stations are also potential providers of convenient e-bike charging. All businesses, especially cafés, could utilise the effect of charging services ushering in new customers. The more businesses participate, the better their opening hours can complement each other with meeting the charging demand throughout the day.

Electricity providers should meet certain requirements to offer charging to one or multiple bikes:

1. They must have a green electricity provider to not eliminate the positive environmental effect.
2. They must make sure that their grid is stable enough to charge the bikes.
3. They must provide enough space on or in front of their premises for the bikes without obstructing traffic or pedestrian flow.

Point 2 and 3 imply that the provider must be clear about how many bikes they can host at once. The necessary hardware infrastructure only comprises enough charging cables and smartphone or tablet to run the administrator application.

To convince local businesses to participate, they need to see a benefit for themselves. The electricity for charging a bike costs only a few cents. Under certain circumstances, the expected increase in customer frequency alone could be a valuable enough benefit. Additionally, the provider could receive payments for the charging service.

Charging facilities, once installed, should be made available to all compatible bikes – not only the ones within the sharing system, but also to privately owned ones.

By analogy with vehicle contributors, to create awareness and willingness among potential electricity contributors, it is essential to provide them with information about the areas and time of day for charging demand.

CROWDSOURCING MAINTENANCE

Similar to the provision of vehicles and charging capacities, any local bike shop could contribute its service as a contractor, based on predetermined modularised repair fees.

As with the other contributors, maintenance providers need information about demand for maintenance.

ANTI-THEFT MEASURES

According to the specifications provided by the manufacturer, the Copenhagen Wheel will contain a mechanism that blocks the wheel. No other hardware security measures are documented for the release version.

It is disputable if this is enough to provide security for a bike-sharing system. The new P2P sharing system should implement an additional security layer.

The described charging stations have Bluetooth hotspots that could be used to provide gapless connectivity for the e-bikes. This way, a bike is either connected to the rider's mobile device or to a charging station's administrator app. This way, parked bikes could always be located. Unauthorised removal could be detected immediately.

At this point, the concept of charging stations can be generalised. There should be providers of parking stations who can decide if they provide charging capabilities on top.

BALANCING SUPPLY AND DEMAND

Supply information is given by the stations' occupancy rates. The source of demand information can be ascribed to requests that the individual e-bikes and e-bike users make in the mobile app: the locations where they look for a vehicle, for a parking or charging spot, where they are forced to park »in the wild«, where the batteries run low or where the user or the bike's system monitoring detects a malfunction.

The system should register demand in the following situations:

Charging demand:

- A bike user ends a journey on low battery without a vacant charging spot nearby.
- At a location without charging spots nearby, a bike user starts a journey on which battery will run flat.
- A bike user looks up nearby charging spots where there are none.
- A charging station’s capacity is maxed out constantly over longer periods.

Parking demand:

- A bike leaser leaves a bike »in the wild« with no vacant parking spots nearby.
- A bike user looks up nearby parking spots where there are none.
- A bike user uses in-app navigation to a destination with no parking spots nearby.
- A parking station’s capacity is maxed out constantly over longer periods.
- High demand at the edge of the developed bike-sharing area projects a demand into the undeveloped areas nearby.

Bike demand:

- A bike user looks up nearby vacant bikes where there are none.

We can distinguish two kinds of balancing efforts between supply and demand:

Long-Term Efforts

Long-term efforts address providers of parking facilities, charging facilities, vehicles and maintenance services to meet long-term trends in user demand with infrastructure measures, i.e. setting up new parking and charging stations or increasing capacities, circulating more vehicles, etc. Supply/demand information should be aggregated in geovisualisations that cater to the respective providers’ information needs.

Short-Term Efforts

Short-term efforts try to react on short-term fluctuation in user demand with incentives that turn users into contributors. Incentives could be given for actions like riding bikes from areas with a vehicle underflow to areas with a vehicle overflow, parking bikes with a low battery at stations with vacant charging capacities, etc.

AGENTS

The described implementation of the system components involves contributing agents on the one hand, and user agents (the leasers) on the other. Since the concept is based on a charging infrastructure for a commercially available e-bike system, it is recommended to comprise another group of user agents: the private owners of Copenhagen Wheels who are looking for publicly available charging facilities.

Private owners should be able to privately share their bike with friends over the network, therefore the definition of private owner includes everybody who can access privately owned bikes.

In summary, we define the following agents:

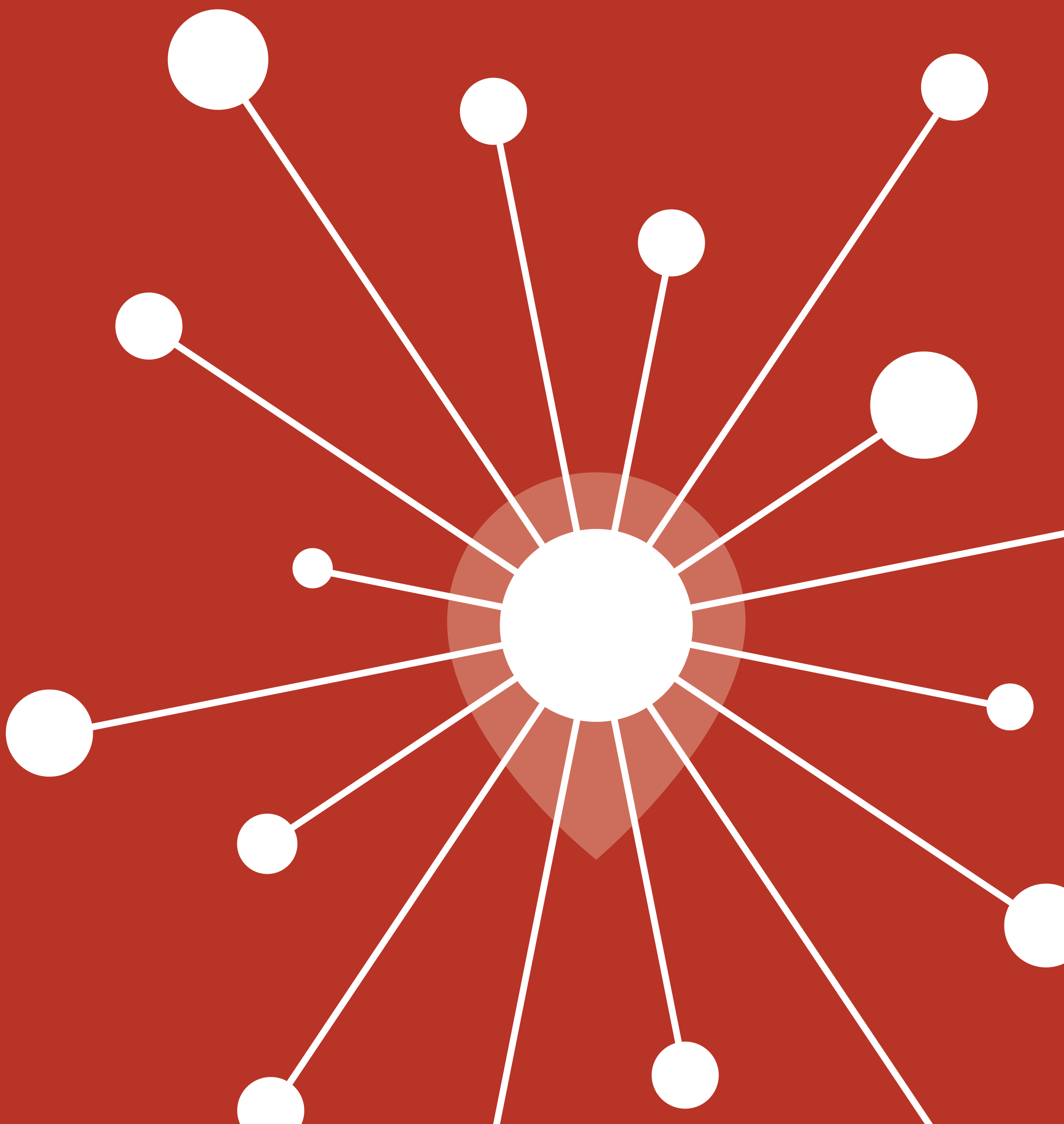
Contributors:

- Fleet provider
- Station provider (parking and optionally charging)
- Maintenance provider

Users:

- Private owner
- Leaser

CONCEPT



In this chapter, the assumptions about the requirements of a peer-to-peer e-bike sharing system made in the previous chapter are cast into a conceptual sharing service called COPED.

The COPED e-bike-sharing system is a collaborative, self-adjusting supply/demand system. It can operate at any level from micro scale at tourist spots in the countryside to coherent metropolitan areas.

A connected COPED system consists of bike stations and a fleet of free-floating bikes that can be picked up at one station and dropped off at another, or homing bikes that need to be brought back to where they were picked up from, or a mixture of free-floating and homing bikes.

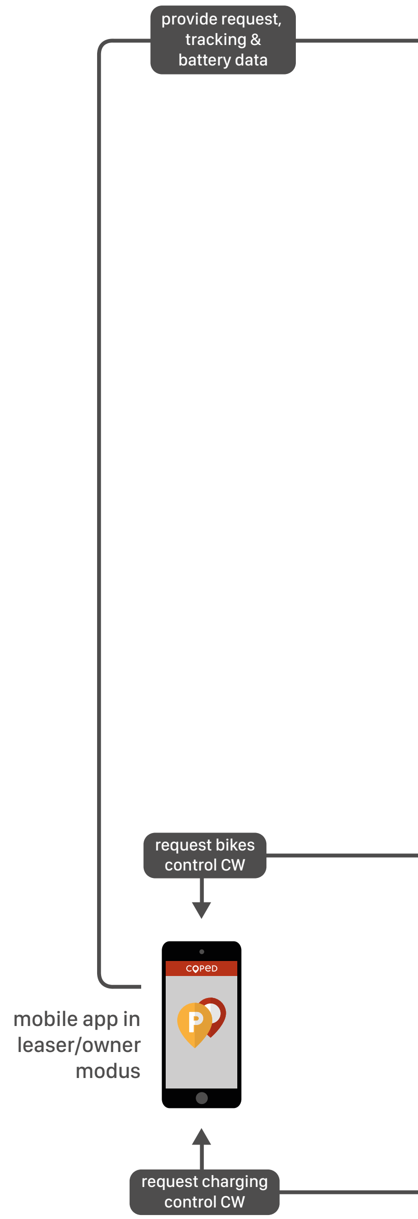
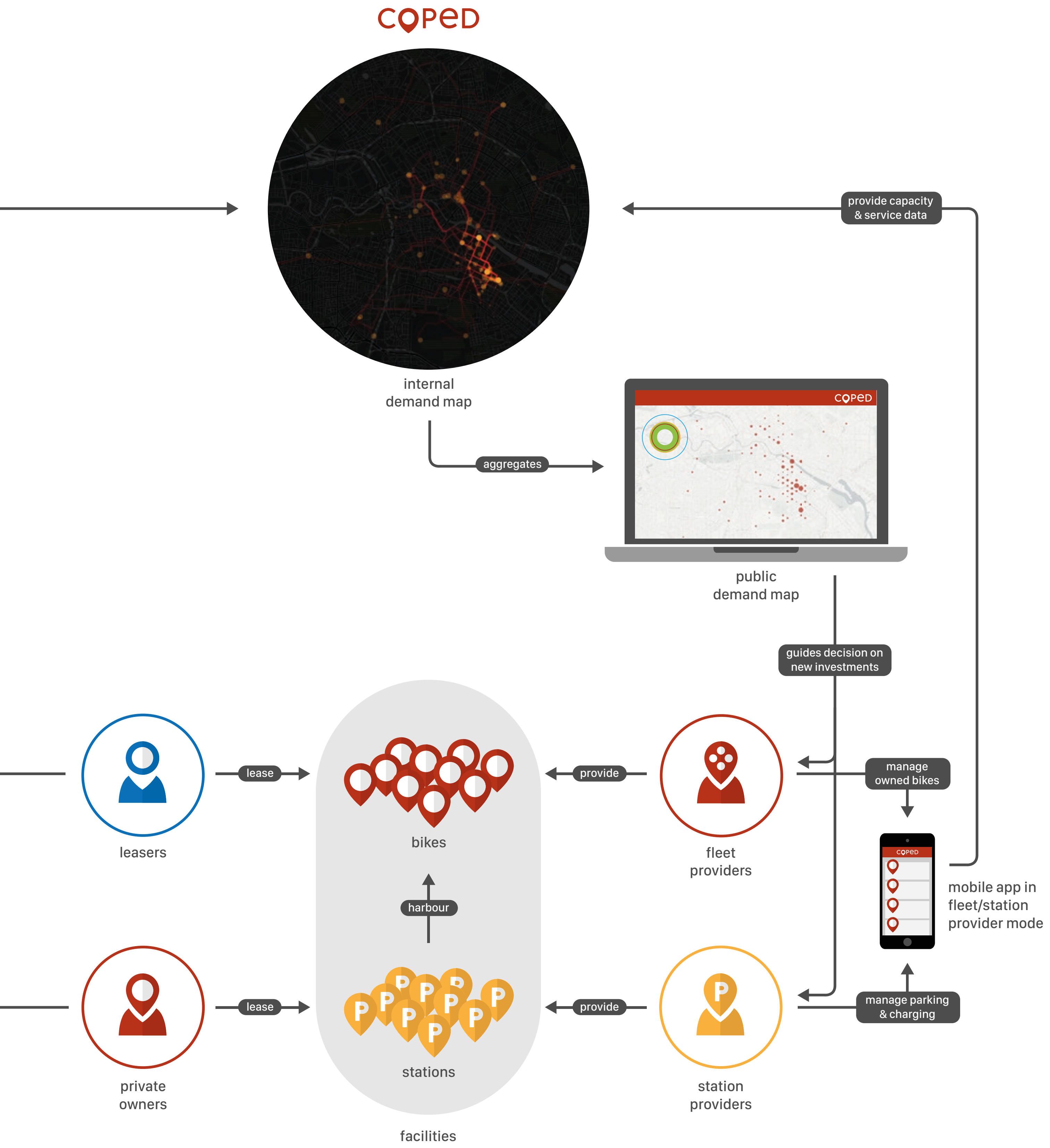


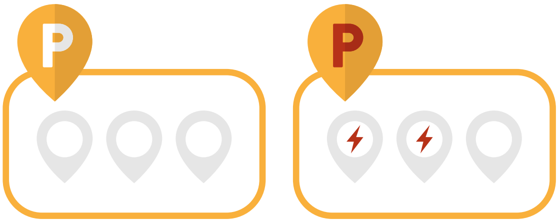
Figure 11
COPED
system overview


internal
demand map
aggregates
public
demand map
provide capacity
& service data
guides decision on
new investments
leasers
lease
bikes
provide
fleet
providers
manage
owned bikes
harbour
mobile app in
fleet/station
provider mode
private
owners
lease
stations
provide
station
providers
manage parking
& charging
facilities

FACILITIES

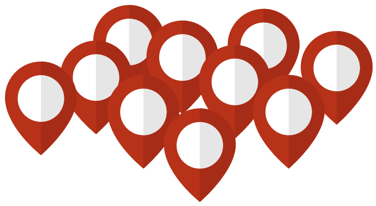
Stations

The operation area is constituted by a network of stations. A station provides a certain number of parking spots for the CW bikes. The station can additionally provide charging capabilities for some or all of the parking spaces.



Bike Fleet

The bike fleet consists of bikes that can be leased in two kinds of modes:



Bikes in free-floating mode can be leased at one station and be dropped off at another within the coherent operating area.

Bikes in homing mode must be brought back to the station where they were picked up.

Special types like cargo bikes can be offered and searched for with appropriate search filters.

USER AGENTS

The Leaser

Leasers want to lease CW bikes from the COPED bike-sharing system.

Figure 12

The Private Copenhagen Wheel Owner

Private CW owners own one or several CWs. They can use the COPED charging facilities.

Ownership of CWs can be privately shared between individuals, which makes them private CW owners too.

A private CW owner can become a part-time or full-time fleet provider agent by renting out their owned bike as part of the COPED bike fleet.

Figure 13

PROVIDER AGENTS

The Fleet Provider

Owners of one or multiple CW-equipped bikes who register these bikes in the COPED bike-sharing fleet become fleet providers. They decide whether they want to provide them in free-floating or homing mode.

Figure 14

The Station Provider

Operators of small businesses with the appropriate parking and charging capacities for CW bikes can become station providers. They decide how many bikes they let park at the station and how many of these can be charged at the same time. If they want to provide charging facilities, they must verify that they have a green electricity provider.

Figure 15

IMPLEMENTATION

The concept is implemented in the form of two components.: a mobile application screen design (COPED mobile app) and a simulated map visualisation (Public demand map).

The map simulation is based on

- real bike tracking data from three individuals in the urban area of Berlin combined with simulated battery level data and a weighting factor to simulate various numbers of private CW bike owners

- the position of 228 Berlin-based small businesses, combined with various simulated levels of charging and parking capacity contribution

- various simulated numbers of contributed fleet bikes.

The visualisations are implemented with Leaflet and d3.js.

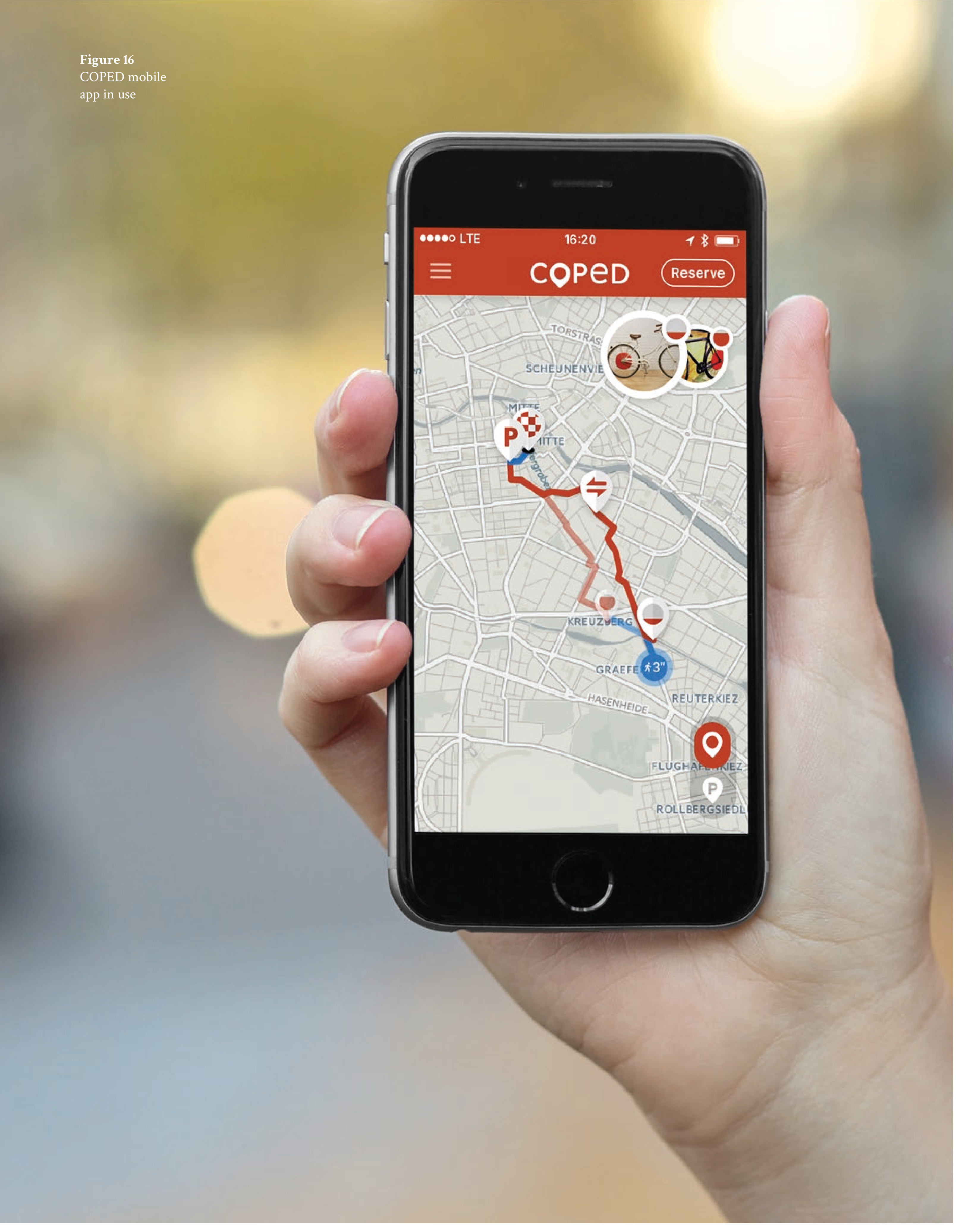


Figure 16
COPED mobile app in use

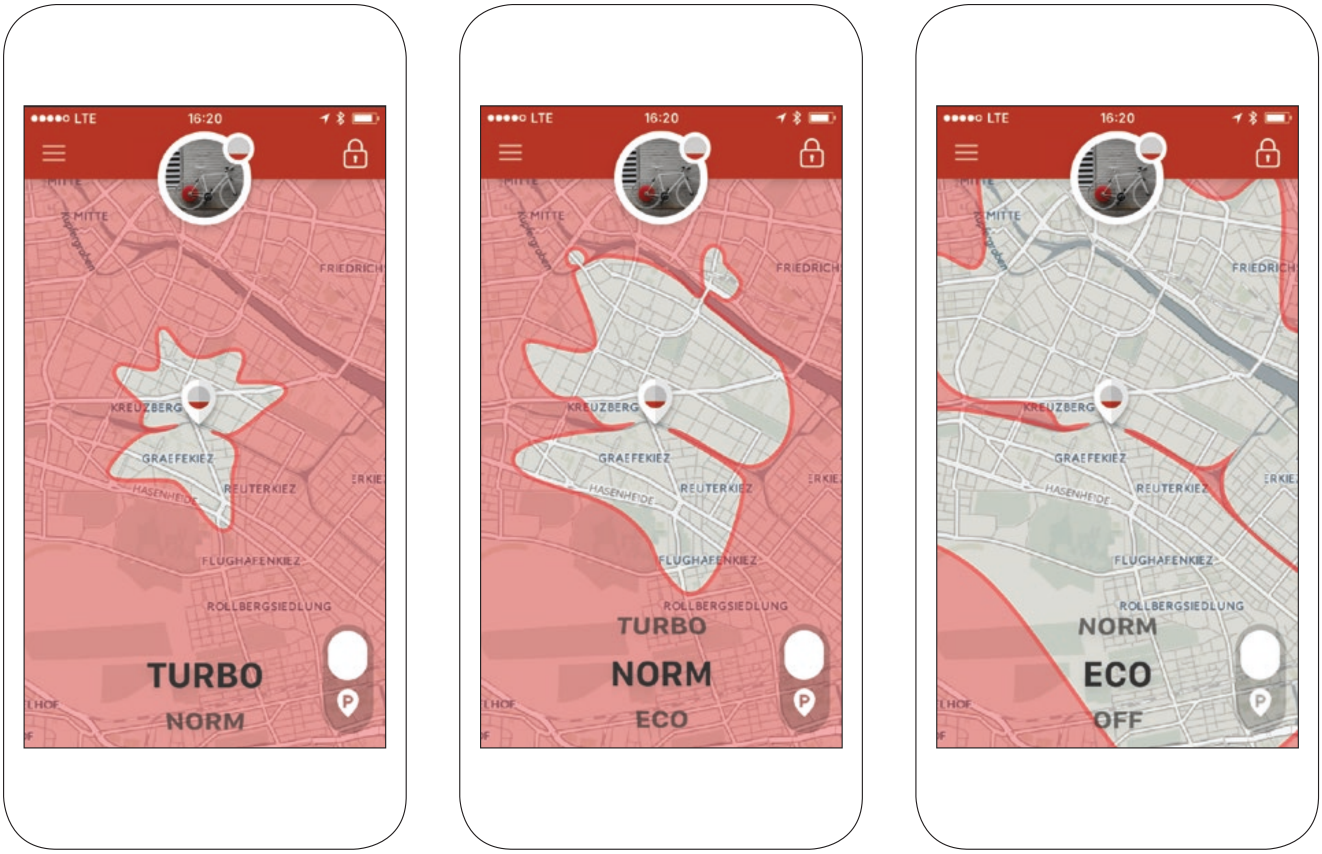
THE COPED MOBILE APP

The mobile app contains functionality for all four groups of COPED agents:

- a control interface for the Copenhagen Wheel with integrated range management
- a bike finder
- a station finder
- a bike fleet management tool
- a station management tool

There is an app mode for each group containing the appropriate subset of main functions:

	CW control interface	*Bike finder*	*Station finder*	*Fleet management*	*Station management*
Leasing Mode	•	•	•		
Owner Mode	•		•		
Fleet Provider Mode				•	
Station Provider Mode					•



Control Interface for the Copenhagen Wheel with Integrated Range Management

An important function of the app is operating the Copenhagen Wheel. Besides locking and unlocking it, the most important control mechanism is setting the assistence level. There are three different levels of linear pedaling boost (»Eco«, »Normal« and »Turbo«), an adaptive assistence mode for hills, and an »Exercise« mode that lets the user paddle harder and charge the battery.

The control interface in the app lets the user select the assistence level with a picker element. A map shows the bike's location and the expected battery range, based on

- battery level,
- assistance level,
- street routing,
- terrain, and
- geographic obstacles.

With time, the compound data of CW tracking and corresponding battery level can refine these range estimates.

Figure 16
Figure 17
Figure 18
COPED mobile app, Copenhagen Wheel control interface in assistent mode

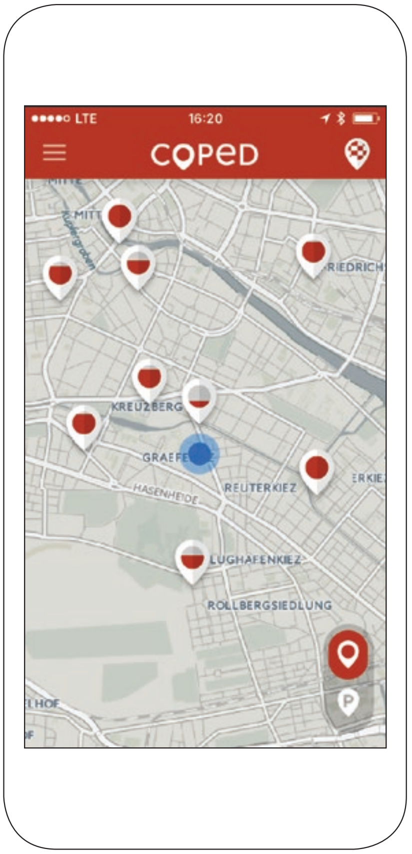
Figure 19
Figure 20
COPED mobile app, Copenhagen Wheel control interface in exercise mode

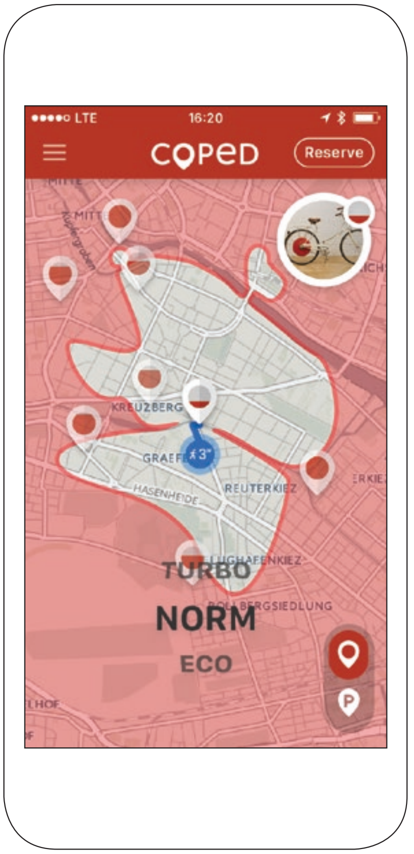
If the user selects the »negative« assistance level, i. e. »Exercise« mode, the map shows an estimate of the battery recuperation potential.

The user can also draw an exercise route directly onto the map. The path will show the expected charging potential.

Figure 21
Figure 22
COPED mobile app,
bike finder

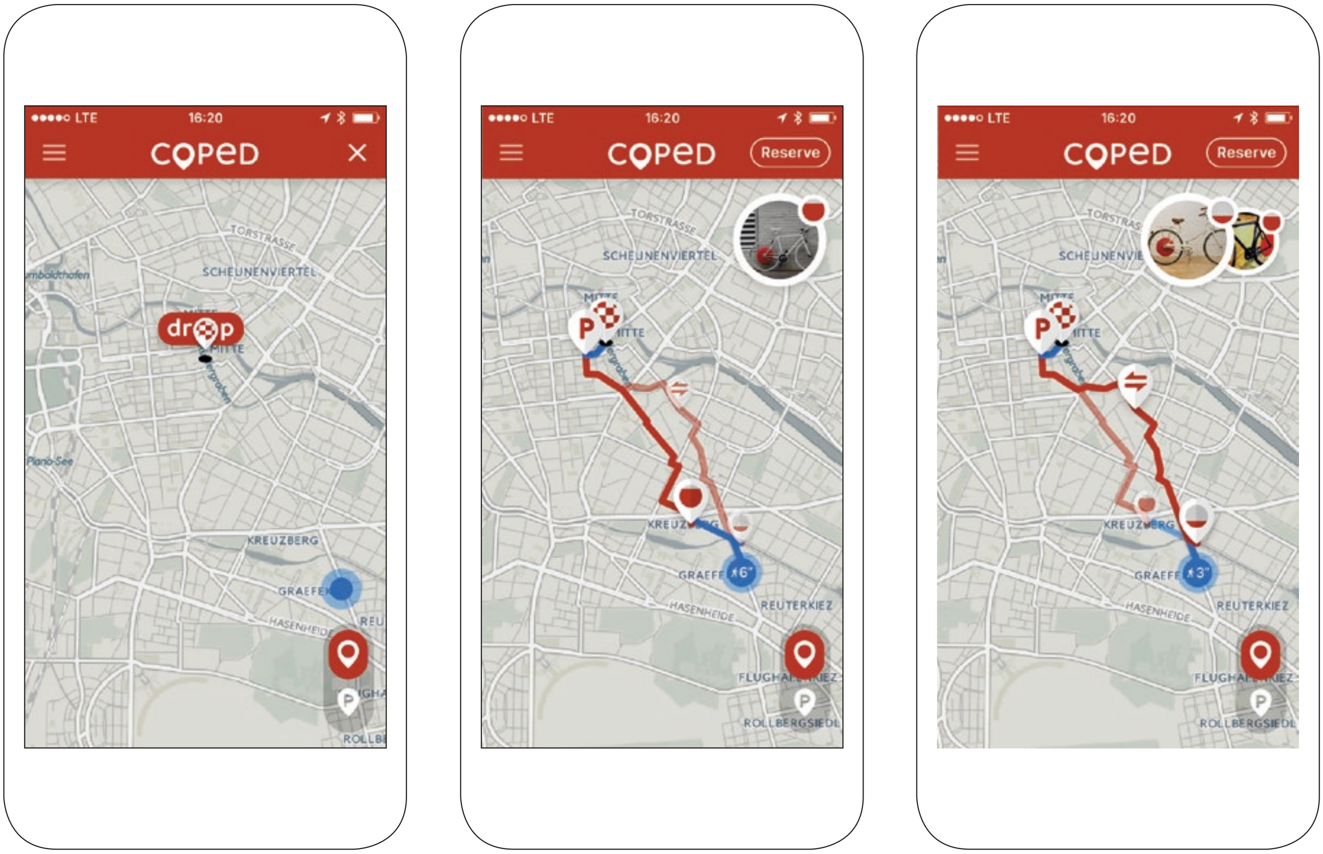
Figure 23
Figure 24
Figure 25
COPED mobile app,
journey planner





Bike Finder

Leasers use the bike finder function to lease a bike. They can find nearby vacant bikes on a map, select one, see the walking distance and range management for that bike and can reserve it from here.



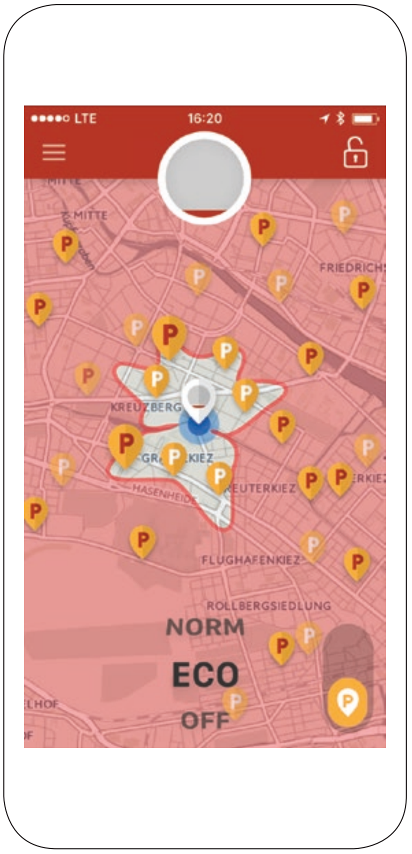
They can also plan a journey by dropping a destination pin onto the desired location. The journey planner will calculate route alternatives that may involve different walking distances and may or may not include bike swaps due to unsufficient battery levels.

Figure 26
COPED mobile app,
station finder

Figure 27
COPED mobile app,
bike fleet management
tool

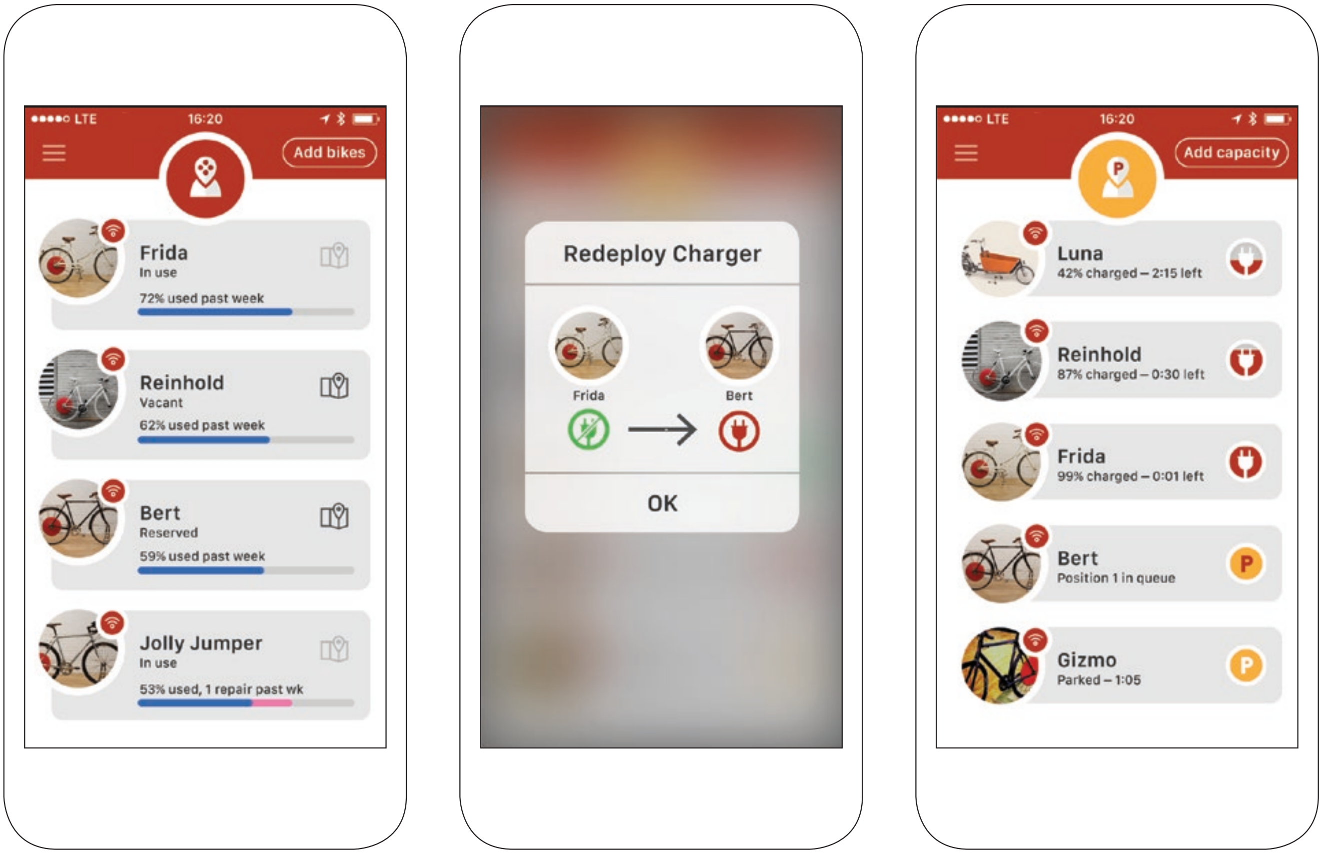
Figure 28
COPED mobile app,
notification from
station management
tool

Figure 29
COPED mobile app,
station management
tool



Station Finder

Leasers as well as private CW owners may plan a stop at a charging or parking station.



Bike Fleet Management Tool

The fleet provider's tool gives statistical information and technical status about the bikes provided by the agent and lets them add more bikes to the fleet.

Station Management Tool

The station provider's management tool notifies the station provider when a bike needs to be charged.

The management tool contains a list of all stationed bikes. Listed top-down are the least to most progressed charging processes, then there are the bikes queued for charging from most to least urgent, then there bikes that are just parked.

The station provider can add more charging and parking capacity in the management tool.

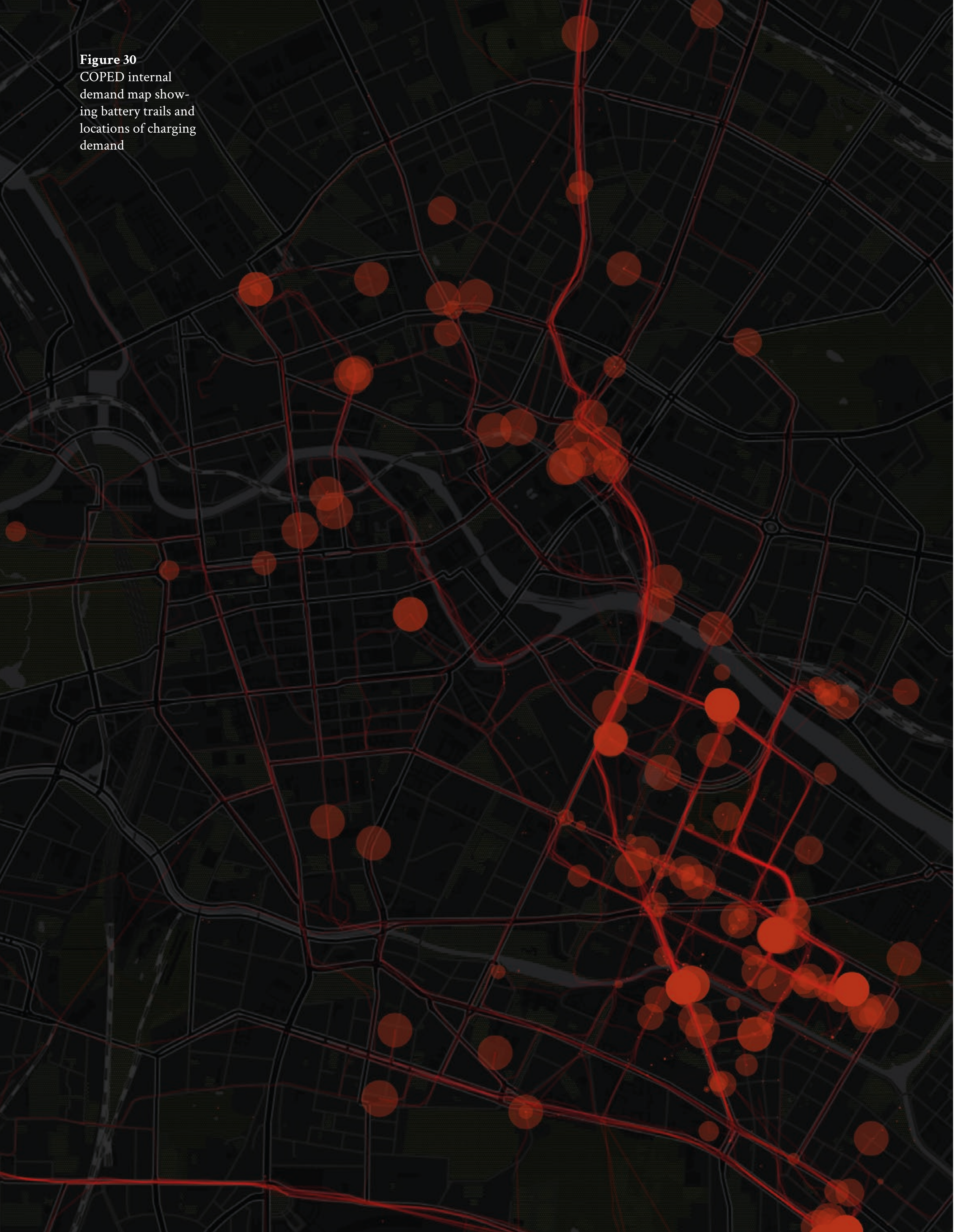


Figure 30
COPED internal demand map showing battery trails and locations of charging demand

THE COPED DEMAND MAP

The long-term efforts to balance supply and demand described in the previous chapter presume that the provider agents get relevant information about the discrepancies between supply and demand of

- stations,
- free-floating bikes,
- homing bikes and
- maintenance.

Information about station demand is location-sensitive since they are stationary.

Short-term efforts which try to answer the question how the existing bike fleet could be shifted from areas of lower demand to areas of higher demand need location-sensitive information about free-floating bikes. Information about how many free-floating bikes are needed altogether is not location-sensitive.

Bikes that are operated in homing mode are stationed. Demand information about them is, like with stations, location-based.

Maintenance demand information is also location-sensitive since it occurs location-based.

The concept presented here shows the supply/demand balancing efforts for stations and a free-floating bike fleet. The balancing efforts for homing bikes and maintenance can be regarded separately, but with an analogous systematic.

The concept is described incrementally from a state of no demand and supply, along with a suggested deployment process of the COPED e-bike sharing system.

The Kick Starter

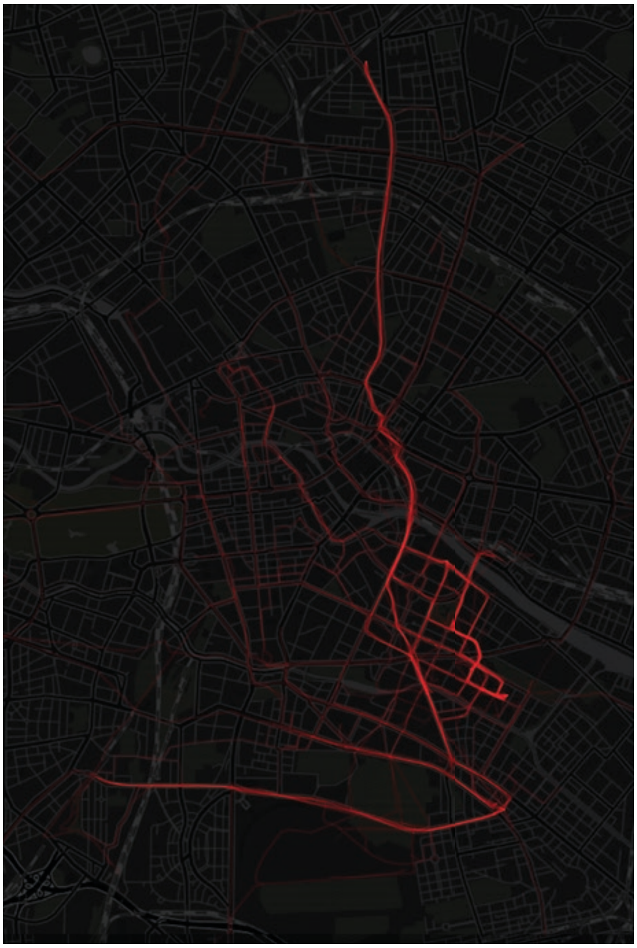
We suppose that initially there will be only private owners of Copenhagen Wheels, and that they will use the COPED mobile app because of the control interface with the integrated range management. By using this feature, they will provide location-based battery level information.

These battery »trails« can be aggregated in a map that shows where CW bikes with low battery levels moved (fig. 31).

A very basic idea is that wherever a low CW battery is, there is charging demand. This idea can be refined by restricting the locations of charging demand to where a CW bike with a low battery actually

Figure 31
COPED internal demand map showing battery trails
Figure 32
COPED internal demand map showing locations of charging demand

Figure 33
COPED public demand map showing local charging demand for cells of a hexagonal grid



stopped. Fig. 32 shows an aggregation of circles that depicts the locations where COPED app users stopped with a battery level of 20 per cent or less. The circle sizes from small to large represent the battery levels from 20 per cent to zero.

In thise state, the data is very poorly anonymised and cannot be published. Therefore it is processed further into a hexagonal grid of circles that are normalised in size to not overlap.

These circles show an approximation of where charging facilities are needed, given our presumption that private owners of CW bikes will also make use of the COPED charging network.

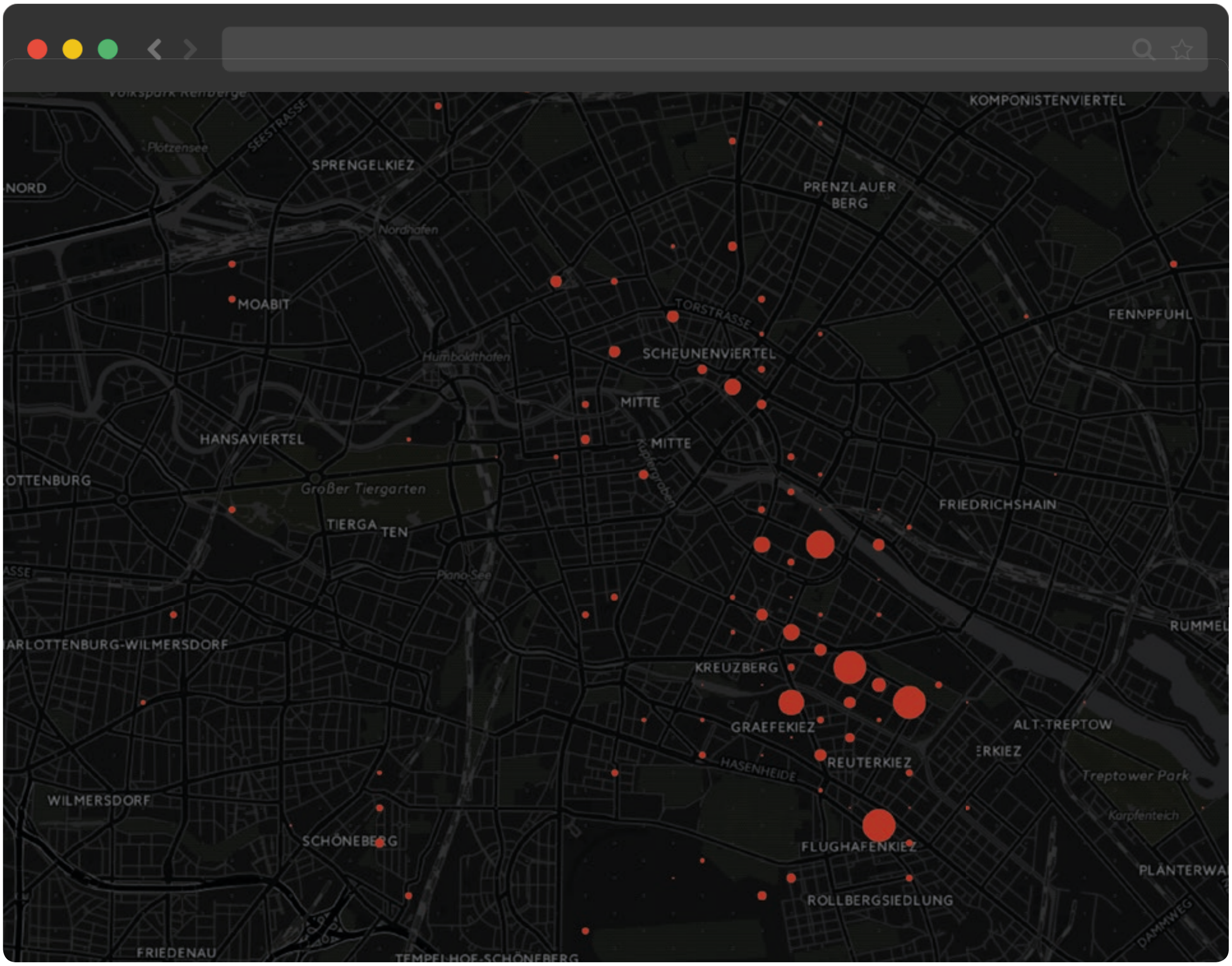
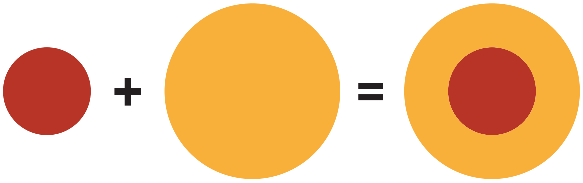
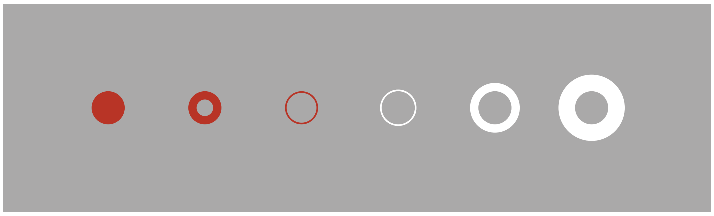
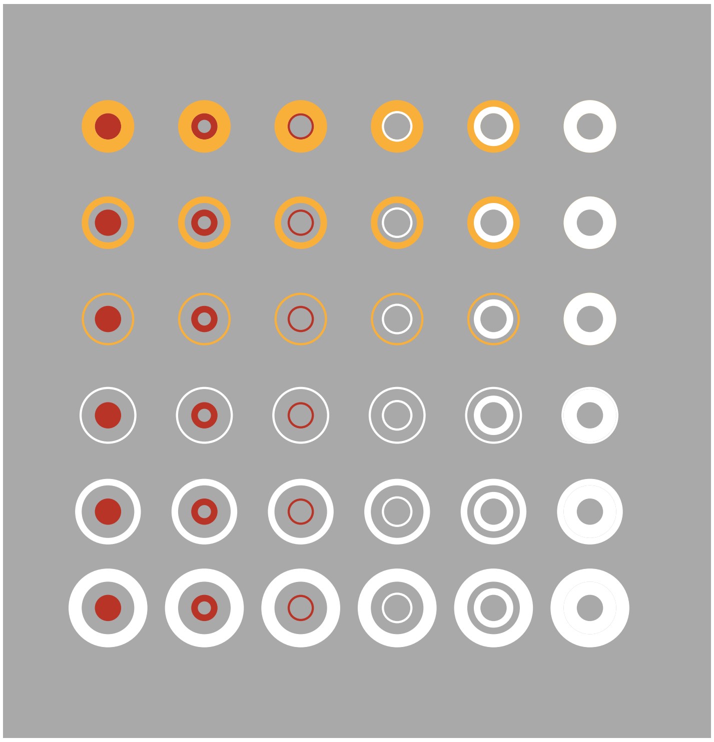


Figure 34
charging and parking demand combined
Figure 35
saturation progression for charging demand
Figure 36
multidemensional saturation progression for charging (X) and parking (Y) demand







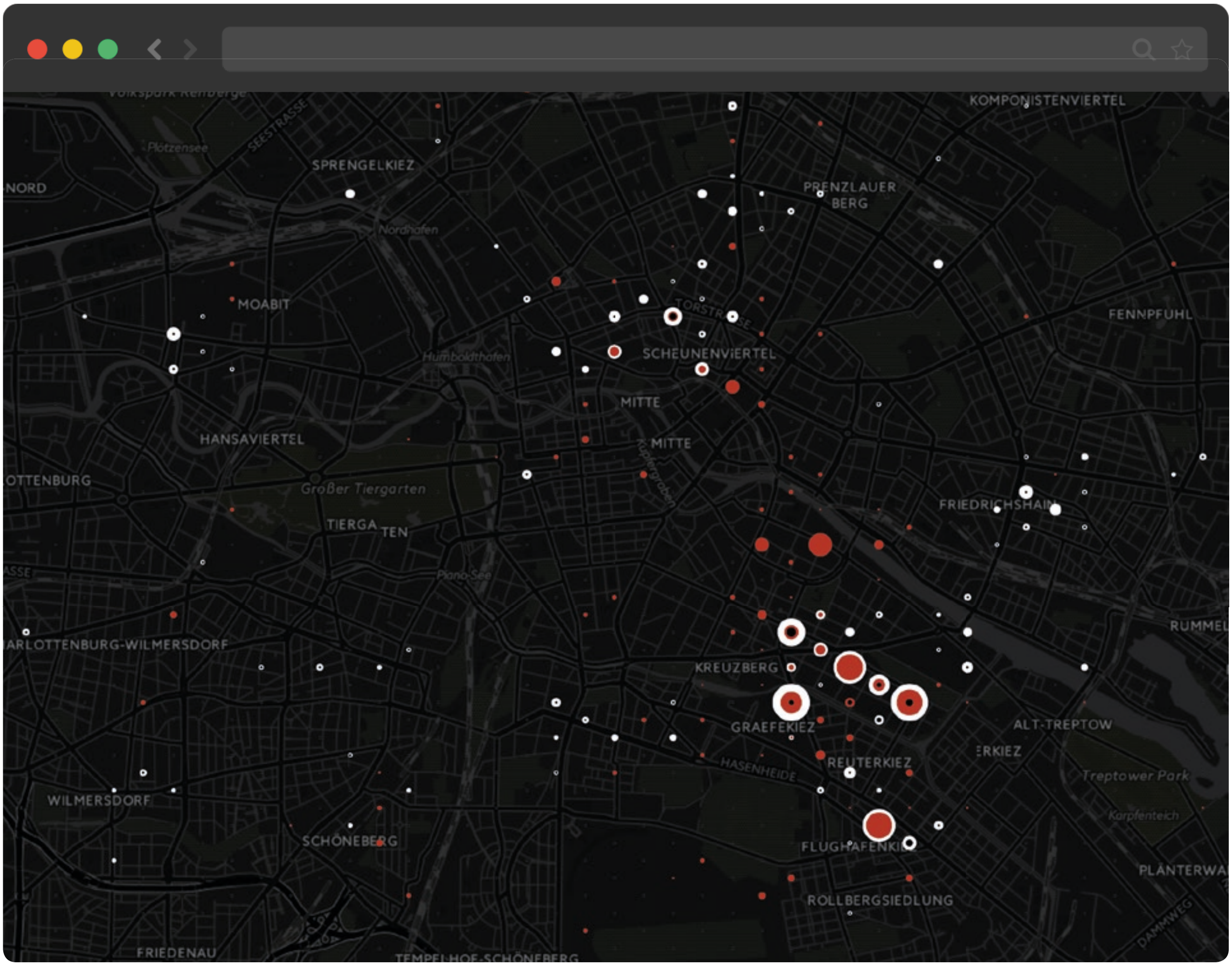
These circles that form the hexagonal grid constitute a convention we will deploy from here. We first extend the depiction of charging demand (red) to a combined depiction of charging and parking (yellow) demand as in figure 34. The concentric circle layout is convenient because all charging capacities are automatically parking capacities.

Furthermore, we define a combined depiction of a demand and the corresponding supply as outer and inner radius of a ring. The ring changes its original colour (that depends on the corresponding facility) to white to denote oversaturation as supply gets higher than demand (fig. 35).

Combining these two rules, we obtain combinations of rings for charging and parking supply/demand (fig. 36) that give information at a glance which facility is in supply and which is in demand. It can also be seen that an adequate level of oversaturation of charging facilities can substitute genuine parking supply.

We now apply this convention to the demand map that is published to involve potential station providers (fig. 33). As attending providers try to satisfy initial charging demand, they eventually create parking and charging supply that can be used for a bike fleet (fig. 37). The absence of yellow rings marks the fact that private owners generate no parking demand, but the white outer rings imply that parking capacities are already being generated. This trend will be auxiliary at the next stage.

Figure 37
COPED public demand map showing local saturation for charging and parking demand



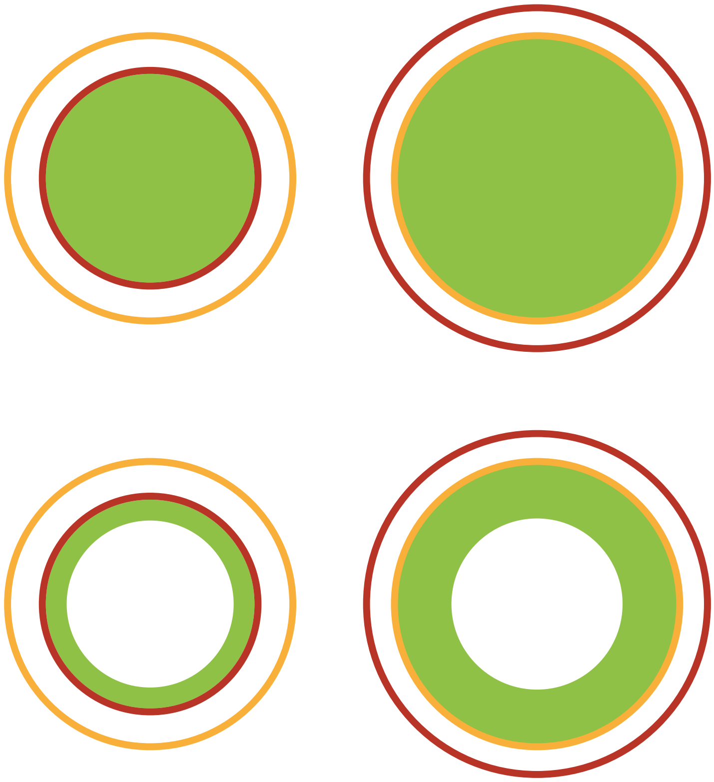


Figure 38
bike fleet saturation visualisation;
top row: no bikes provided yet;
bottom row: bike demand partially saturated;
left column: charging supply (red) under-represented, therefore restricting parameter;
right column: parking supply (yellow) under-represented, therefore restricting parameter

We now need to include information on the system's capacity for a bike fleet.

As was explained earlier, fleet demand information is not location-specific. It can be estimated cumulatively from the previous facilities:

- Fundamentally, the fleet size is limited by the fleet's container size, which is the parking capacity. There cannot be more bikes than parking spots, and it is good practice to allow for an appropriately sized buffer to avoid overfilled stations.

- If the share of charging capacities within the parking capacities is too low, the fleet size potential should also be estimated lower.

We can now set these parameters in relation to each other as shown in fig. 38. We see which one is the smallest and therefore restricting parameter.

Note that parking and charging here are relative. Say that parking and charging demand has shown that fifty per cent of parking capacities should also be charging capacities, then these circles show if this proportion is met. Notably, a red circle that is larger than the yellow circle means that there are more charging capacities than the demand reflects, although there can never be more charging than parking capabilities by definition.

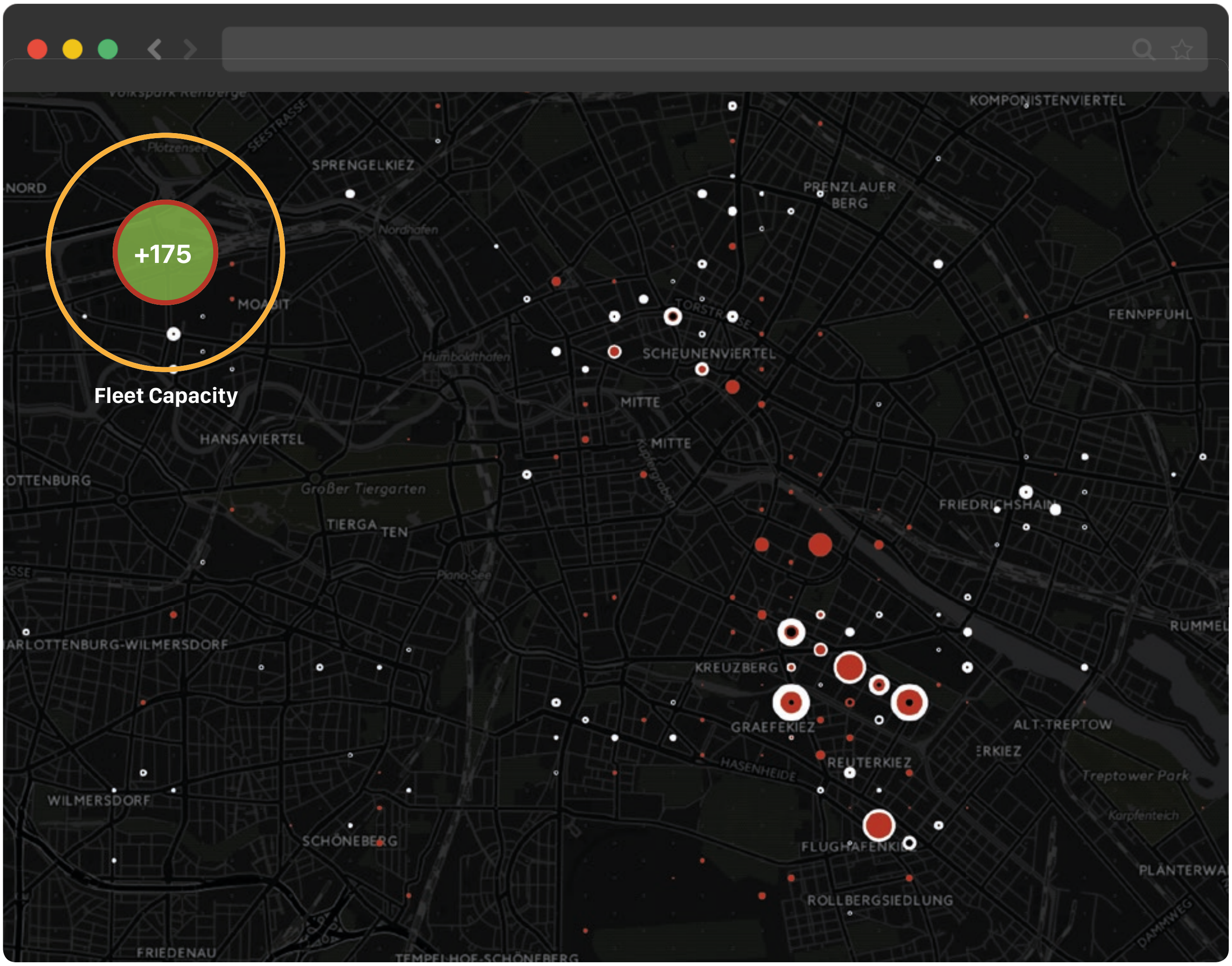
The green ring depicts the recommended bike fleet demand. The lower row shows a system state when bike fleet demand has been partly met by fleet providers.

Fig. 39 shows an integrated demand map for location-specific parking and charging demand as well as location-unspecific bike fleet supply.

Station providers have started contributing charging and parking capacities to the system. Charging capacities (red ring) are underproportionate compared to parking capacities (yellow ring) because they are used by private CW owners.

The remaining capacities are available for the bike fleet that can now be established.

Figure 39
COPED public demand map showing local saturation for charging and parking demand and bike fleet saturation visualisation



In fig. 40, fleet bike demand has started to be met by fleet providers. The established contingent of fleet bikes increases the system's relative parking demand substantially which is now the restricting resource.

Simultaniously, the grid starts to reveal parking demand.

Figure 40
COPED public demand map showing local saturation for charging and parking demand and bike fleet saturation visualisation with bike demand partially saturated

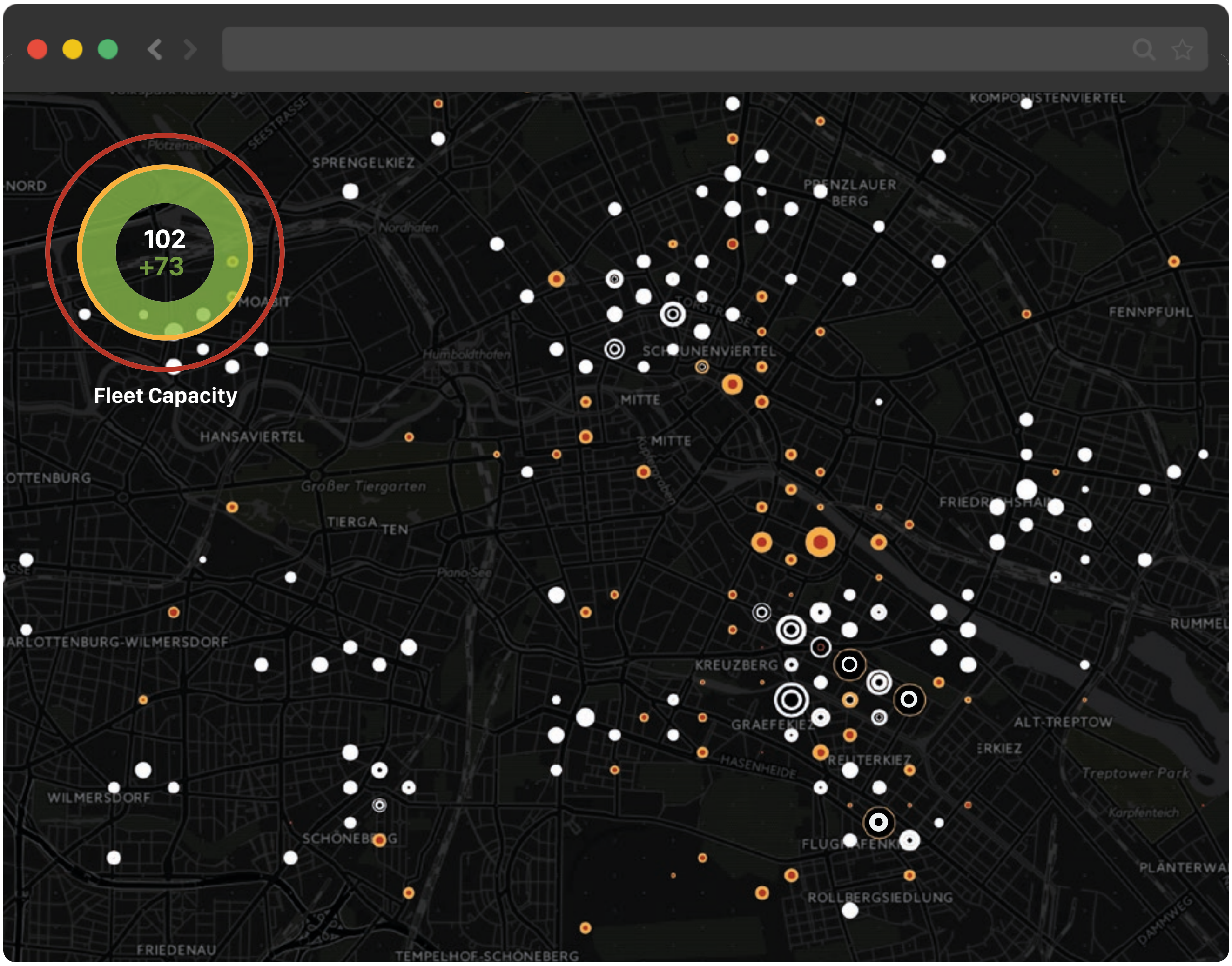
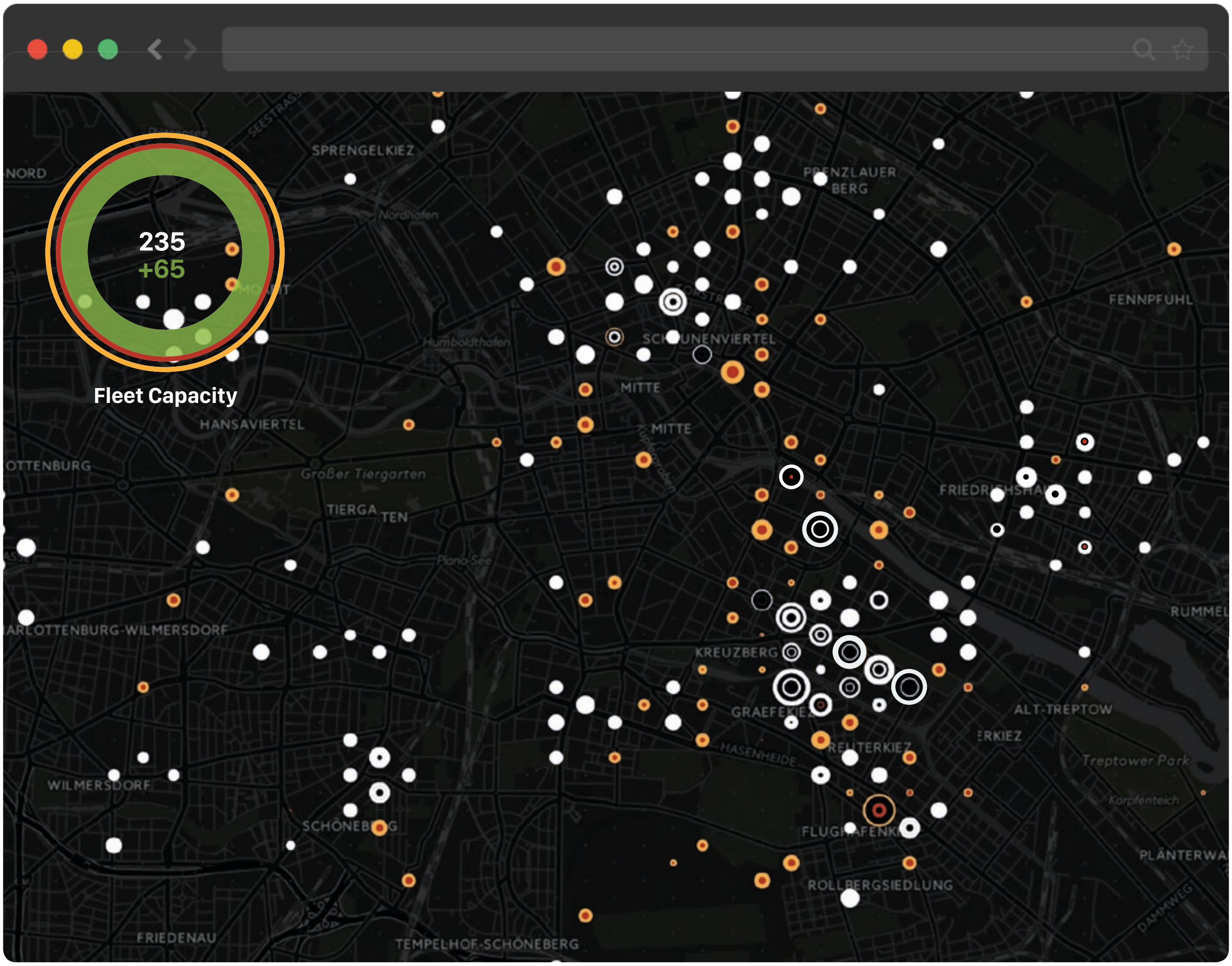


Fig. 41 shows an increased fleet. Fleet demand still exists. Charging and parking capacities are well-balanced against each other, although not evenly distributed over the whole area.

Figure 41
COPED public demand map showing local saturation for charging and parking demand and bike fleet saturation visualisation with bike demand further saturated



CONCLUSION & FUTURE WORK

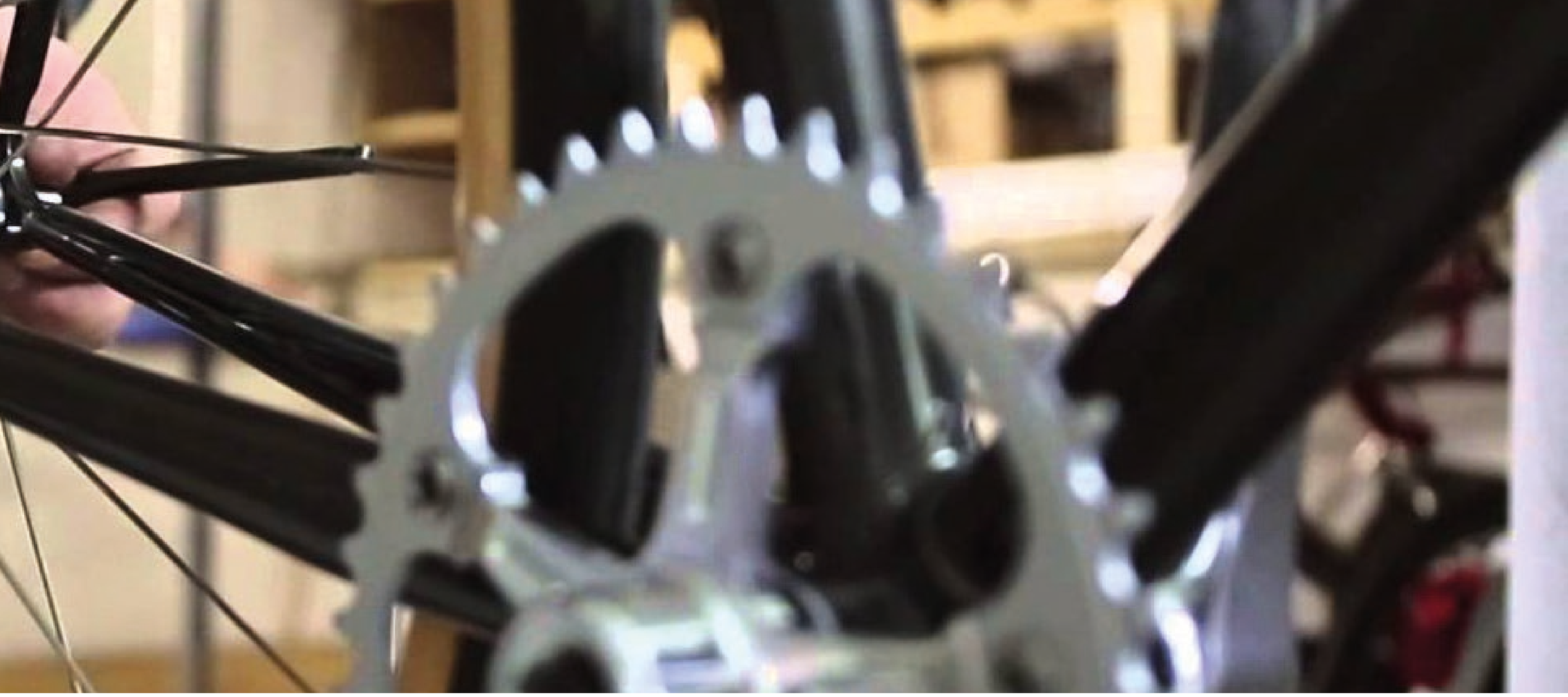
Figure 42
Bike repair shop

The concept presented in the previous chapter suggests solutions to a lot of challenges associated with the objective of setting up a fourth generation peer-to-peer e-bike sharing system. Some questions, however, remain to be researched.

INCENTIVES

While an essential part of the concept addresses long-term balancing efforts guided by the COPED demand map and expended by the provider agents, short-term balancing still needs to be addressed. As suggested, the possibilities of incentives should be explored that influence the user agents' behaviour beneficially. Incentives in sharing systems have been the subject of research in recent years (Katzev 2003, Fricker 2014). For the COPED system, various measures are imaginable:

- reducing fees on countercyclical bike rides,
- reducing fees on handing off bikes with low battery levels at vacant charging stations, or
- offering bonus minutes for riding depleted bikes in exercise mode to charge the battery.



MAINTENANCE PROVIDERS

Maintenance will need to be implemented in the COPED system. The structure of this service differs from the other facilities in that it must be manually requested. It also needs to be clarified how the bikes in need for repair or service get to the service station. Should they be picked up by the service personnel? Is it safe to let user agents bring them in for incentives?

PRICING MODELS & INSURANCE

The question how the prices for using the COPED facilities should be structured is a question of business economics and has been widely left out of the concept.

It would be particularly interesting to see if and how the pricing structure within the system can be self-regulatory while maintaining a user-friendly consistency in the connected territories.

An economic concept would also have to take into account the system costs of theft and vandalism.
A model could be examined in which the COPED system acts as an insurance provider.

HOMING BIKES

The peer-to-peer nature of the COPED system strongly suggests the support for a great variety of bikes and sharing schemes. Particularly special-interest bikes like cargo bikes are less suited for sharing in free-float mode but can still be very useful if made available in homing mode.

It is suggested that the supply and demand for each category of homing bikes is balanced analogously to station supply and demand. The charging demand of these bikes that must be satisfied by COPED's charging facilities can likely be taken into consideration like the charging demand of privately owned CW bikes.

MAP DATA

The map data processed by the COPED system should be made available to all bikers. The Copenhagen Wheel's sensor data should be closely examined for potential cycling-related and environmental insights that should also be publicly available. For example, the accelerometer data could be used to make a map of road surface structures that would be valuable for bicycle navigation to avoid bumpy routes.

THE COPENHAGEN WHEEL IN VIVO

Until the sales launch of the Copenhagen Wheel, the potential and challenges that it will involve cannot be fully apprehended. The ideas and assumptions in this concept will be subject to review once the Copenhagen Wheel is available.

APPENDIX

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Die Arbeit wurde bisher in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegt.

Ekkehard Petzold.

Berlin, den 10. Juni 2014

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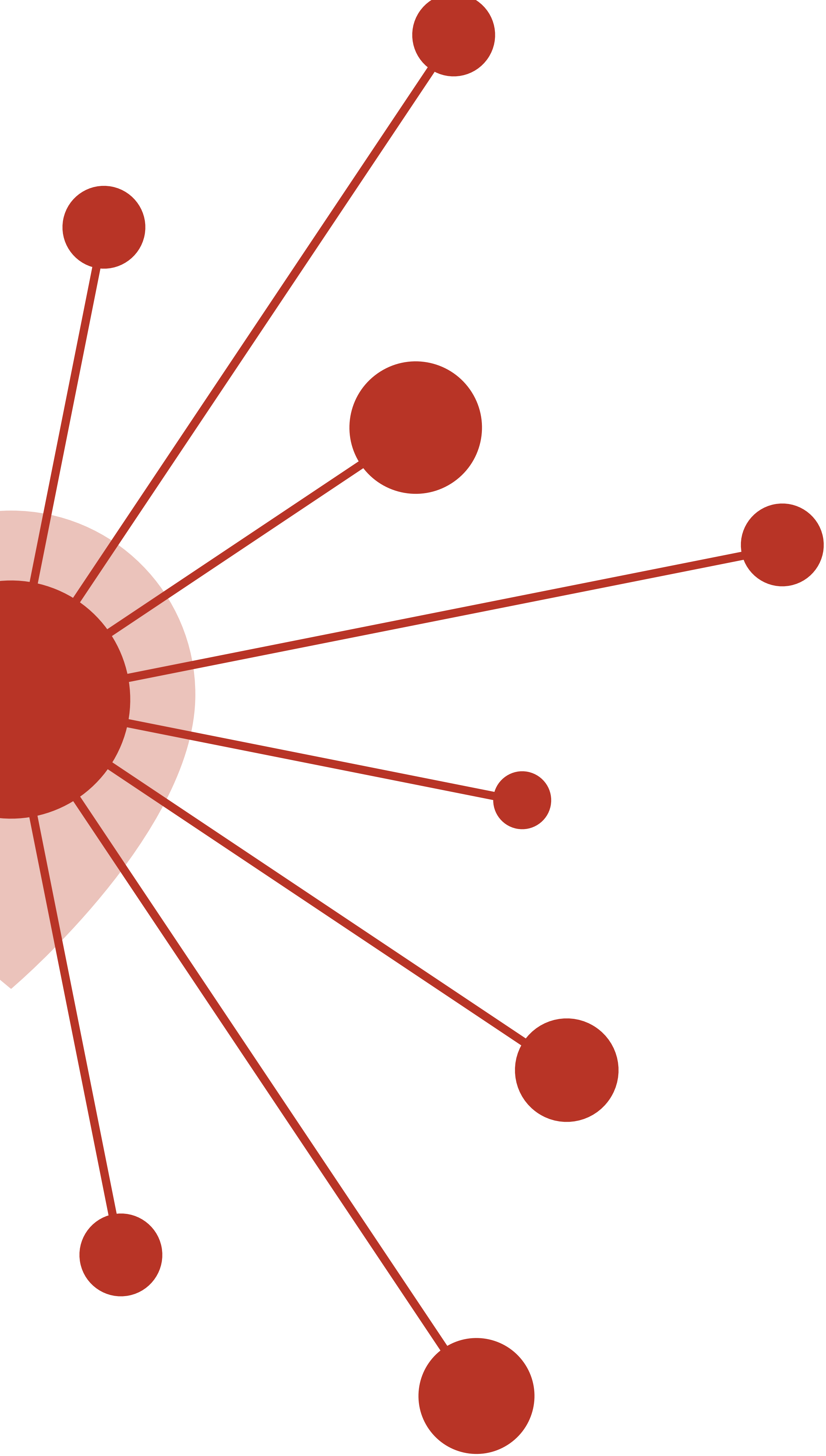

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