RUGGEDISED

Designing smart, resilient cities for all

Final

Implementation report Rotterdam

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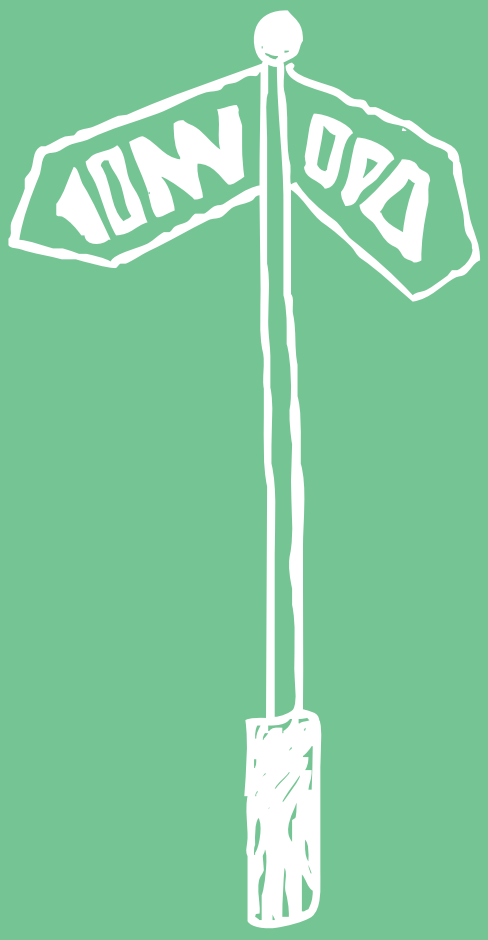


City of Rotterdam / Adrienne Wildeman

Executive summary

The Dutch City of Rotterdam has a proud, ongoing history as a global port city, is home to a socio-economically diverse population and aims to become a leading city both in digital development and sustainability. As such, the city's involvement in the EU-funded RUGGEDISED project was a way to combine these ambitions and develop one of the smartest districts in Europe in the neighbourhood of 'Hart van Zuid' or 'Heart of South'.

Even before the City was awarded funding as part of the RUGGEDISED project in 2016, to make its dream of smart sustainability leadership a reality, the City and private partners worked closely together. Since then, RUGGEDISED has helped strengthen this working relationship through the demonstration of a series of sustainable and smart urban solutions in the 'Heart of South'. The district is located in the larger area of Rotterdam South and is home to the large venue Rotterdam Ahoy – a close collaborator of the project – as well as office buildings and cultural institutions, such as a theatre, swimming pool and more.

For Rotterdam, the core work on becoming smart stems from their work on the 'Rotterdam Energy Approach Planning' (REAP) methodology, which serves as the City's main strategy on realising maximum energy efficiency in buildings and public spaces in individual districts and across the city. This strategy includes a focus on reducing energy demand, reuse of waste energy and boosting of the use of renewable energy. A central aspect of REAP today, is also the implementation on different scales which the 'Heart of South' exemplifies as a demonstration district.

Since 2016, this area has delivered on the goals described in REAP through work to validate and/or implement thirteen RUGGEDISED solutions (R1-13). The thirteen smart-city solutions are currently in different phases of implementation, an overview of which is provided in the visualisation table (see page below).

The smart solutions specifically covered:

1. **Thermal energy**
through the deployment of a Smart Thermal Grid connected to buildings, aquifer wells underground, thermal pumps and a smart management system.

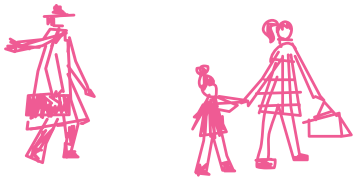
By the end of the RUGGEDISED project (October, 2022), Rotterdam had achieved many of its original goals: Most importantly, the Smart Thermal Grid (R1) is deployed and connected to the big venue Rotterdam Ahoy and to aquifer wells underground. Studies on possible heat exchange were completed for both the thermal energy from waste streams (R2) solution and the pavement heat-cold collector (R4), which are both installed and operating. A possible method of extracting energy from surface water (R3) was also assessed, but was found to be unfeasible. Today, the Smart Thermal grid is running and extracting energy locally form the aquifers with additional sources of energy being extracted from the pavement heat-cold collector and waste streams.

2. **Smart Electricity**
in the form of massive solar installations and the deployment of smart solutions – and thinking – to charge e-vehicles and installations in the area.

Extensive work, including the development of various business models and scientific studies, were undertaken on the development of photovoltaic installations and a charging station for e-Buses (R5). Meanwhile, solar panels of no less than 15,500 square metres of rooftop have been deployed in the area. The roll out of the smart charging parking facilities in the city of Rotterdam, was won through an open tender by a non-RUGGEDISED partner and therefore was not executed within the timeframe and scope of the project. However, there are plans to install several smart chargers in the planned parking garage, close to the Ahoy buildings. Important work has also been done to optimise e-charging of busses through advanced modelling (R7). In addition, the Energy Management Software Simaxx (R8) is being used by the Rotterdam Ahoy venue.

3. **A 3D Digital twin**
allowing the City of Rotterdam to become a leader in sustainable city-planning and management using data.

Rotterdam has also made great progress in the development of a 3D city operations platform (R9) and has made several Proofs of Concept to add different functionalities to the "Digital Twin" of the 'Heart of South'. Fourteen Smart Lighting poles (R11) –



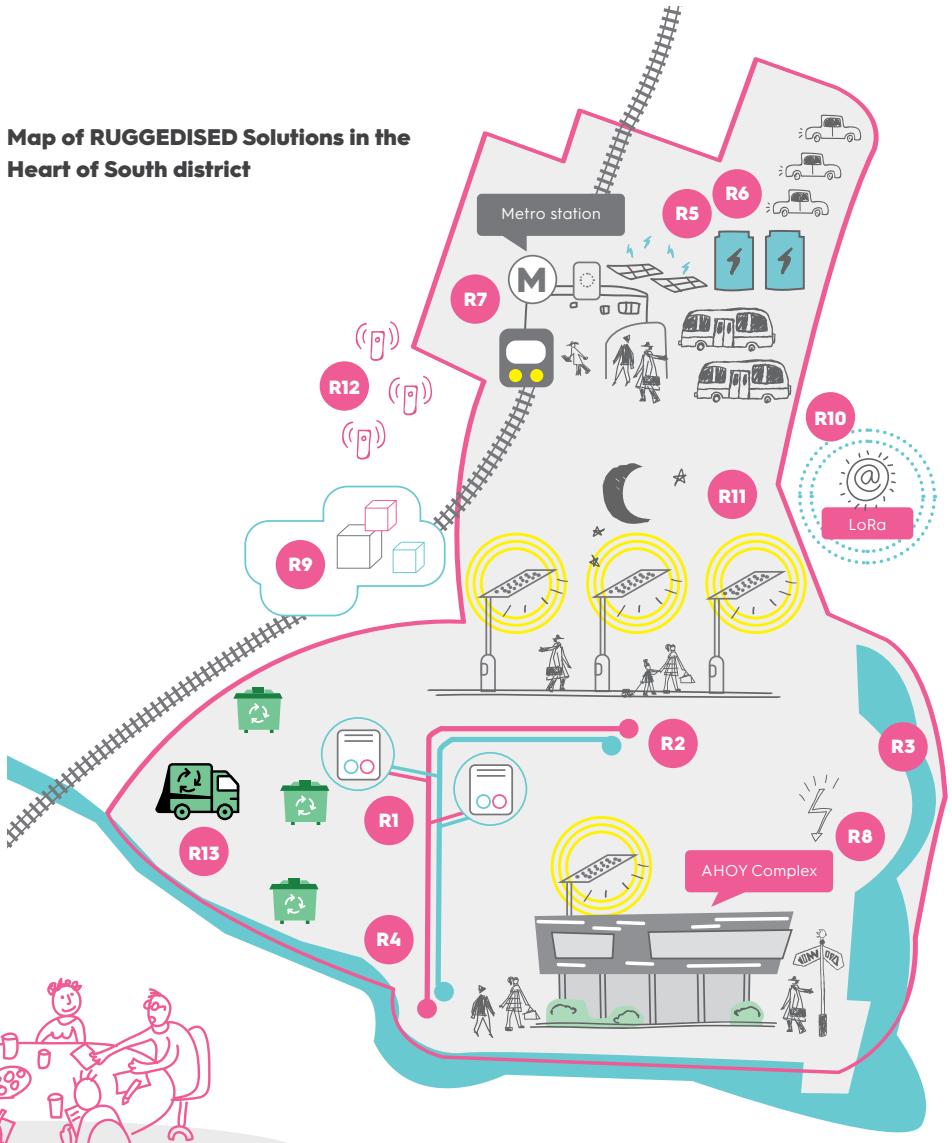
feeding data into the 3D city operations model – have been installed and a successful smart waste solution (R13) is running in the Smart District, both at the moment being upscaled at a massive scale in other parts of Rotterdam. Unfortunately, due to public procurement hurdles, none of those run on the LoRa (Long Range) network (R10) as originally foreseen. Procurement hurdles (a full tender for city-wide charging stations being won by a non-RUGGEDISED partner) also meant the smart charging stations (R6) where not implemented as part of RUGGEDISED. Finally, a feasibility study proved the possibility of installing high performance servers in residential buildings (R12), though this will not be completed as part of RUGGEDISED.

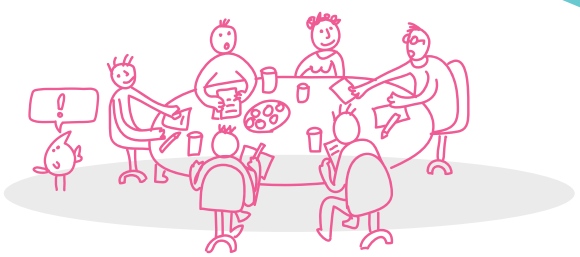
In terms of upscaling or expansion plans for all of the project themes (thermal, electric and digital). Here are the highlights: The 3D digital twin has been extended with several new functions and options. For example, to support a city development plan, the model was used to integrate and showcase several sustainability challenges in relation to each other (i.e see solar roof potential in connection to power lines). Scaling-up electric grids is difficult because of regulations. RUGGEDISED partners are consulted on the specific formulation of new legislation where the experience is beneficial. There are also concrete plans of upscaling of the thermal energy solutions in several large city area developments (two old city harbours – Rijnhaven and Merwe-Vierhaven - and Feyenoord City) based on the learnings of RUGGEDISED. The potential of extracting energy from wastewater has also been mapped for the whole city to potentially exploit this.

In 2022, thermal energy is a hot item in all of Rotterdam. The team that is working on RUGGEDISED has grown and is working fulltime on energy related projects throughout the city. The cooperation with the municipal policymakers and city developers has intensified. Finally, the cooperation between the partners of RUGGEDISED – and key external players – has been strengthened significantly as a result of dealing with the implementation of the RUGGEDISED project. Today, the lessons learned in the 'Heart of South' are already in use for further developments in Rotterdam, and are thus serving as valuable demonstrations or experiences as the REAP Methodology had originally envisioned.

This is the final implementation report from Rotterdam and covers the entire RUGGEDISED period from November 2016 to October 2022

Map of RUGGEDISED Solutions in the Heart of South district





Progress summary visualisation table

Progress summary visualisation table	R1 Geothermal heat-cold storage and heat pumps	R2 Thermal energy from waste streams	R3* Surface water heat-cold collection	R4 Pavement heat-cold collector	R5 DC grid, PV and storage for mobility	R6 Smart charging parking lots	R7 Optimising the E-bus fleet	R8 Energy management	R9 3-D City operations model	R10 LoRa-network	R11* Efficient and intelligent street lighting	R12 High performance servers in homes	R13 Smart waste management
Business model development Business model feasibility proven	✓ / 🏆	✓ / 🏆	✓ / ⛔	✓ / 🏆	✓ / N/A	✓ / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / 🕒	✓ / 🏆	✓ / 🏆	✓ / 🏆
Financial plan Finances approved by investors	✓ / 🏆	✓ / 🏆	✓ / ⛔	✓ / 🏆	✓ / N/A	✓ / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / ⛔	✓ / 🏆	✓ / 🏆
Partners' Cooperation agreements cooperation agreements signed	✓ / 🏆	✓ / 🏆	N/A / ⛔	✓ / 🏆	✓ / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / 🕒	N/A / ⛔	✓ / 🏆	✓ / 🏆
Project implementation plan development Project plan approved	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	N/A / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	N/A / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆
Approval/permit procedures All permissions and notifications procured	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	N/A / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	✓ / 🏆
Procurement process Key components procured	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	N/A / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	✓ / 🏆
Project implementation Project commissioned	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	N/A / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	✓ / 🏆	N/A / N/A	✓ / 🏆	✓ / 🏆
Monitoring phase Monitoring completed	▬ / 🕒	▬ / 🕒	N/A / N/A	▬ / 🕒	N/A / N/A	N/A / N/A	✓ / 🏆	✓ / 🏆	✓ / 🏆	N/A / N/A	N/A / N/A	N/A / N/A	✓ / 🏆
Upscaling phase Plans for upscaling	▬ / 🕒	▬ / 🕒	N/A / N/A	▬ / 🕒	▬ / 🕒	N/A / N/A	✓ / 🏆	N/A / N/A	✓ / 🏆	N/A / N/A	✓ / 🏆	N/A / N/A	✓ / 🏆
Replication phase Replication planned	▬ / 🕒	▬ / 🕒	N/A / N/A	N/A / 🕒	N/A / 🕒	N/A / 🕒	▬ / 🕒	▬ / 🕒	▬ / 🕒	N/A / N/A	▬ / 🕒	▬ / 🕒	▬ / 🕒

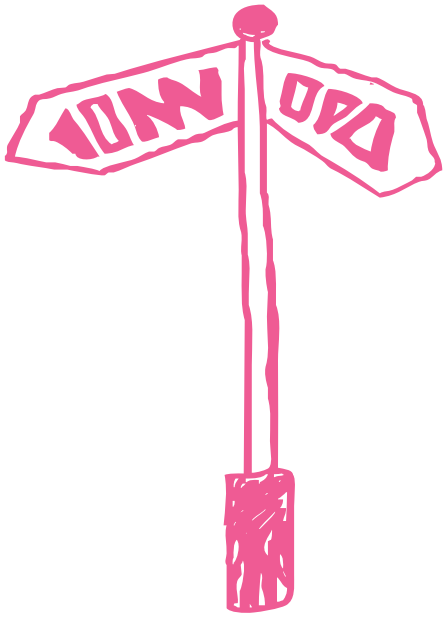
▬ In progress ✓ Done 🏆 Go decision 🕒 Pending decision **N/A** Not applicable ⛔ No-go Decision

* This solution is still expected to be executed, but outside the scope and timeframe of the RUGGEDISED project.


City of Rotterdam / Claire Droppert

Rotterdam drivers for RUGGEDISED

The current period in which we live is characterised by rapid technological development, the continuing globalisation of (social and economic) activities and a need to protect our living environment and to ensure social stability. As part of the European-funded Smart City project RUGGEDISED, the three lighthouse cities of Rotterdam, Umea, and Glasgow worked together with a number of partners from academic, business and consultancy backgrounds to develop and test smart solutions in support of sustainable urban development opportunities.



The three overall aims of RUGGEDISED were:

1. Improving citizens' quality of life by offering a clean, safe, attractive, inclusive and affordable living environment.

2. Reducing the environmental impacts of activities, amongst others, by achieving a significant reduction of CO_2 emissions, a major increase in the investment and usage of renewable energy sources and an increase in the deployment of electric vehicles.

3. Creating a stimulating environment for sustainable economic development by generating more sustainable jobs, stimulating community involvement in smart solutions (as consumers and as producers) and boosting start-up and existing companies' ability to exploit the opportunities of the green digital economy and Internet of Things.

Rotterdam chose to focus its RUGGEDISED Smart City work on an area known as the "Heart of South." This district is part of the larger area of Rotterdam South and has 200,000 inhabitants who have diverse backgrounds spanning no less than 169 different nationalities.

Rotterdam South faces significant socio-economic challenges, such as low education levels, below-average incomes, higher unemployment levels, poor quality of housing, and an unattractive business climate. The area has been dominated by an infrastructure that mainly focuses on cars.

Prior to RUGGEDISED, the 'Heart of South' district had already been chosen to undergo a serious transition in the upcoming years, consisting of the renovation of an outdated shopping centre, public transport hub, as well as various large-scale multifunctional buildings (e.g., a swimming pool, arts building, exhibition halls, congress centre).

Furthermore, public space in the area was planned for drastic redevelopment. The City of Rotterdam is preparing Rotterdam South for the future, with RUGGEDISED supporting the city's plans for the 'Heart of South'. The redevelopment aims to achieve maximum energy efficiency and CO_2 reductions, as well as to have a major socio-economic impact (e.g., creating jobs, increasing levels of participation among citizens, increasing quality of life, etc.). **The redevelopment of the area began in 2016 and is ongoing as RUGGEDISED ends in October 2022**.

Rotterdam's main objective within the RUGGEDISED project was to conduct feasible studies and/or plan, implement and monitor thirteen RUGGEDISED Smart

City demonstration solutions in the 'Heart of South' area, to prove the feasibility of smart solutions for further implementation in Rotterdam and beyond.

The specific objectives set out for RUGGEDISED in Rotterdam were:

- To produce a majority of consumed-energy locally, by using and testing a variety of solutions.
- To increase the share of Renewable Energy Sources (RES) substantially and to optimise the use of RES for heating and cooling in the Heart of South.
- To expand the use of thermal waste streams.
- To reduce CO_2 emissions and air pollution, and improve local air quality by securing the roll out of electric vehicles (e-buses).
- To enable more efficient planning to optimise charging and use of the e-bus fleet.
- To create business models that enable the local generation and selling of electricity and/or heating and cooling energy.

The planned redevelopment of the 'Heart of South' was using an innovative tendering process, combined with a twenty-year agreement on maintaining of the area. A coalition led by the developers Ballast Nedam and Heijmans won the tender in 2013, and the actual renovation and construction of new buildings is set to end in 2023. With the 'Heart of South' project, the Municipality of Rotterdam and Ballast Nedam/Heijmans underlined their significant ambitions for the area.

These very high ambitions could be substantially supported by carefully using a smart city methodology and in redeveloping the area ensuring an increase in the local production and reuse of energy. **Hence, the RUGGEDISED Smart City idea was born in Rotterdam**.

Drivers that led Rotterdam to join RUGGEDISED

Partners in Rotterdam had multiple reasons to join forces and become a team in the RUGGEDISED consortium.

- Rotterdam's Smart City policy was adopted following periods of research, conclusion and next step planning, executed by the strategic global consultant Jeremy Rifkin and his TIR Consulting Group LCC. In this context, the time was right to start the RUGGEDISED project, which suited the policy and political climate.
- The RUGGEDISED project applied to become part of the second European Commission Horizon 2020 program call on Smart Cities and Communities Lighthouse Projects. High ambitions among lighthouse cities were thus a necessity and provided Rotterdam a chance to stand out.
- Since the sustainability aspects of the original 'Heart of South' development project had to be omitted during the years of global financial crisis, the RUGGEDISED project was a welcome incentive for the municipality and Ballast Nedam/Heijmans to work together to achieve the ambitious sustainability goals for the area, while advancing ongoing work on a smart thermal grid.
- Joining the RUGGEDISED project opened doors to build a more citizen-friendly environment and would allow Rotterdam to experiment with the local production of energy and draw important lessons for future efforts.

Rotterdam smart city vision

Rotterdam's Smart City measures - that address energy and integrated infrastructures - apply the '**Rotterdam Energy Approach Planning**' (REAP) methodology, which serves as the City's main strategy on realising maximum energy efficiency in buildings and public spaces in individual districts and across the city.

The REAP entails a three stepped approach: The first focuses on reducing energy demand as much as possible (based on the high Return on Investment (ROI) associated with these measures). The second pillar aims to reuse waste energy as much as possible, while the third looks at remaining energy demand. This residual energy demand must be supplied by renewable energy sources where possible in order to facilitate the desired energy transition.

To support the development of the ICT aspects of being a Smart City, Rotterdam had established 'Sensible Smart Rotterdam' (CODE 010). This platform placed the City of Rotterdam in a position to embrace the digital economy by offering a suite of (public and private) ICT systems that support initiatives for the common good of residents.

Rotterdam acknowledged early that digitalisation is a basic necessity. All citizens, companies and institutions in Rotterdam should have access to open digital infrastructure, both physically and wirelessly (e.g., 5G). This is not only a precondition for establishing and maintaining an innovative, attractive and future-proof business climate, but also a requirement for digital services, such as healthcare applications, online banking, shopping, news services, social media and much more.

Rotterdam is a "thick market" (i.e., high density, with a lot of interaction and therefore a lot of data) for profit-driven platforms. The local government therefore has good reason to set requirements for digital companies to follow, in order to ensure fairness. However, the municipality's role as a 'market master' will only be accepted if administrative leadership is demonstrated. There also needs to be sufficient operational expertise and a clear mandate in order to make binding agreements with market parties and social organisations about the use of digital data, and regarding the preconditions (rules) required for platforms to be admitted into Rotterdam's digital public space. **This digital vision** formed another important driver for the innovative digitalisation work in RUGGEDISED.

RUGGEDISED in Rotterdam

The process of prioritising smart solutions

RUGGEDISED in Rotterdam was from the beginning a private-public partnership, meant to serve as a demonstration for making areas of the city sustainable and smart. From the side of the main private partners, Ballast Nedam and Heijmans — both Dutch construction and development companies —, there was a strong desire, almost a requirement, to bring sustainability goals back within the scope of work already planned in Rotterdam South. The companies wanted to experiment with smart thermal and electrical grids, and the 'Heart of South' was the perfect place to do so. The area contained (and contains) a large public transport hub, the large venue Rotterdam Ahoy, several public buildings (swimming pool, arts building/library) and some new commercial buildings (convention centre, cinema and hotel), which were all primed for experimentation.

A change of ownership meant the priorities of Ballast Nedam/Heijmans ultimately shifted away from such experimental projects, with focus remaining on their contractual obligations in the wider redevelopment of the area. The energy company Eneco took their place as the leading private company in the RUGGEDISED project in Rotterdam. As an energy company and not a building contractor, Eneco took a different approach to renewable energy sources and energy policies overall. This led to intense collaboration of and dialogue between the public and private partners. To prioritise which smart solutions to work with, two creative sessions were arranged for all parties to share and discuss ideas.

These ideas were divided into three sub-groups:

1. Thermal energy
2. Electricity
3. 3D Digital Twin

For work related to the Thermal Grid and the Electrical Grid (STG & SEG), it was necessary to phase the different steps. First: the thermal storage, aquifer, and heat exchangers had to be realised. Prior to RUGGEDISED these were owned by the venue Rotterdam Ahoy, but were not being used to their full capacities. Within the RUGGEDISED project Eneco has taken over ownership from Ahoy and redesigned the thermal grid to make the best use of the thermal storage and aquifer. A backbone also had to connect the different buildings to the aquifer, allowing it to be enriched with other sources, like sewage, asphalt and surface water, and to balance the grid.

"Sustainability and energy savings in all buildings in the Heart of South are of utmost importance."

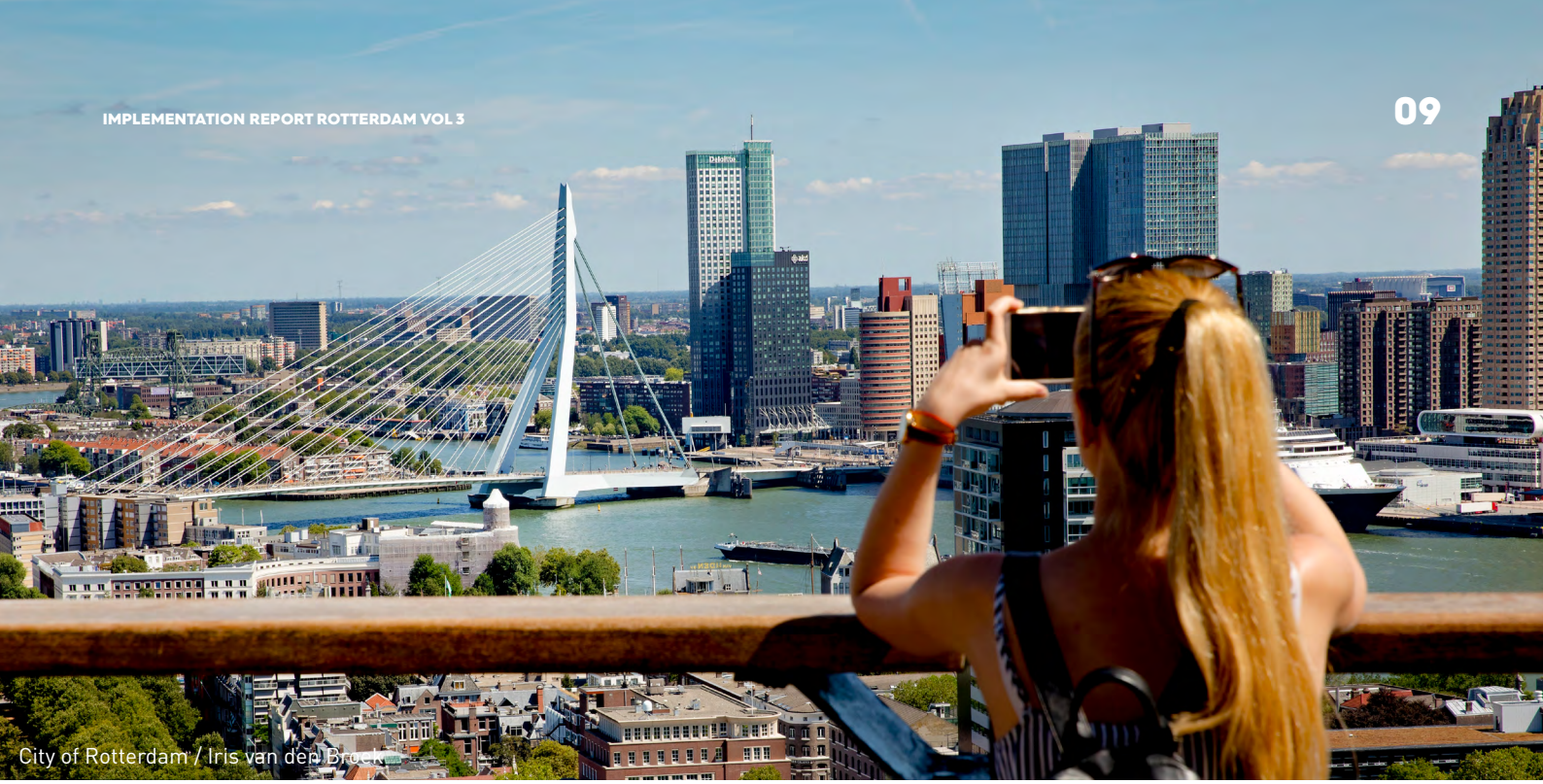
Rotterdam smart city vision

Unfortunately, an early setback in the overall RUGGEDISED process in Rotterdam, was that the project area did not receive the necessary "experimental status" designation from the government that would have been necessary to pursue electrical grid optimisation. Furthermore, renewable energy sources are not part of the European grant, and concessions for placing smart charging poles in the public area were not granted to RUGGEDISED partners. These factors restricted the possibility to implement some of the experiments, most notably the smart lighting.

To exploit the data in the smartest way possible, Rotterdam uses a "3D Digital Twin," designed to integrate all solutions within the RUGGEDSIED project, to visualise the impact of the smart solutions and to allow stakeholders to improve where possible based on the information provided in a unifying platform. The development of such a digital platform for the city is a learning process in itself. Both platform development and the process of feeding data (energy or public transport) into the system are continuously being optimised.

The three pillars of REAP ('Rotterdam Energy Approach Planning')

1: Reduce energy demand
2: Reuse waste energy
3: Use renewable energy



City of Rotterdam / Iris van den Broek

COVID-19 Impact

During the first 'wave' of COVID-19, the Ahoy venue was designated an emergency hospital. Therefore, for a couple of months, no one from the project was able to enter the Ahoy perimeter. This especially affected the progress of smart solution R3: the pavement collector. Because the road in which the collector was to be placed was part of the Ahoy perimeter, and the technical room placed inside the building, it caused disruptive delays meaning the full implementation of solutions only occurred in June-September, 2022. The pumping station from smart solution R2: 'thermal energy from waste streams' is also located on Ahoy's site. Small parts of the COVID virus were found in the sewage system, which made that nobody was allowed to enter this pumping station building. Not even colleagues from the maintenance department or the contractor who cleans the building were able to enter for a period of more than three months. This affected the progress of this project as well.

There were also some positive effects for this project that were experienced during the COVID-period. In this time, when most people were working from home, the (underground) waste bins (R13) were filled much more quickly compared to 'normal' times. As a result, the advantages of the smart waste sensors were proven helpful as demand was easily monitored and met through adjusted services. It is now possible to empty the waste bins on demand, so that no waste is misplaced next to the bins. Because of the success of this solution, and a busy schedule for the drivers, an extra waste truck was ordered.

The delays, caused by COVID, also affected the project material-wise. Solutions had to be postponed to allow for the disruption, but also the costs of materials and products increased and complicated implementations as originally foreseen.

City vision and RUGGEDISED efforts

The renovation of the 'Heart of South' district was always central in the RUGGEDISED project, but also served as part of a greater mission for the City of Rotterdam. The renovation began in 2016 and is ongoing while the RUGGEDISED project ends:

Main subprojects foreseen were:

- integration of a 50-metre swimming pool in a former office block (2016-2018);
- integration of a cultural centre and an arts building (2018-2020);
- renovation of the existing Ahoy exhibition halls (2017-2019);
- construction of a new convention centre (2018-2020);
- renovation of the bus and metro station (2020-2022);
- construction of a cinema and hotel (2020-2023); and
- modernisation and expansion of the shopping centre (2021-2023).

In addition to the specific measures, RUGGEDISED has introduced several its innovative solutions to make sure that the goals of the project were met and extensive work has been done to establish the partnerships needed to succeed.

These partnerships included the RUGGEDISED partners as the core group, but extended far beyond to also include key partners in the wider redevelopment of the area, and big players for Rotterdam's transition in general. The challenge for Rotterdam was not so much convincing these private actors, research groups, consultants and public players, that the energy transition is of the utmost importance – on this they all agreed – but rather agree who was responsible for taking what action. It became apparent in RUGGEDISED, that diverging interests were mainly about the concrete actions to be taken, and the City of Rotterdam led intense discussions to find common ground on pushing forward the individual implementations.

This cooperation spanned different levels and initiatives:

- **Regular contact between the 'implementors'**: At the district level, the City of Rotterdam had a close and ongoing dialogue between the implementing staff on the technical issues, and on the concrete implementation. This partnership was anchored with staff from the City of Rotterdam, but included the energy company Eneco, staff from Rotterdam Ahoy and from many of the other organisations.

- **High level dialogue and support**: An important aspect of the RUGGEDISED' achievements in Rotterdam was the level of high-level support for the wider transition in the 'Heart of South' area. At crucial times in the project, change was pushed from the top through agreements between the political level in the City of Rotterdam and the top levels of Eneco, Rotterdam Ahoy and other partners.

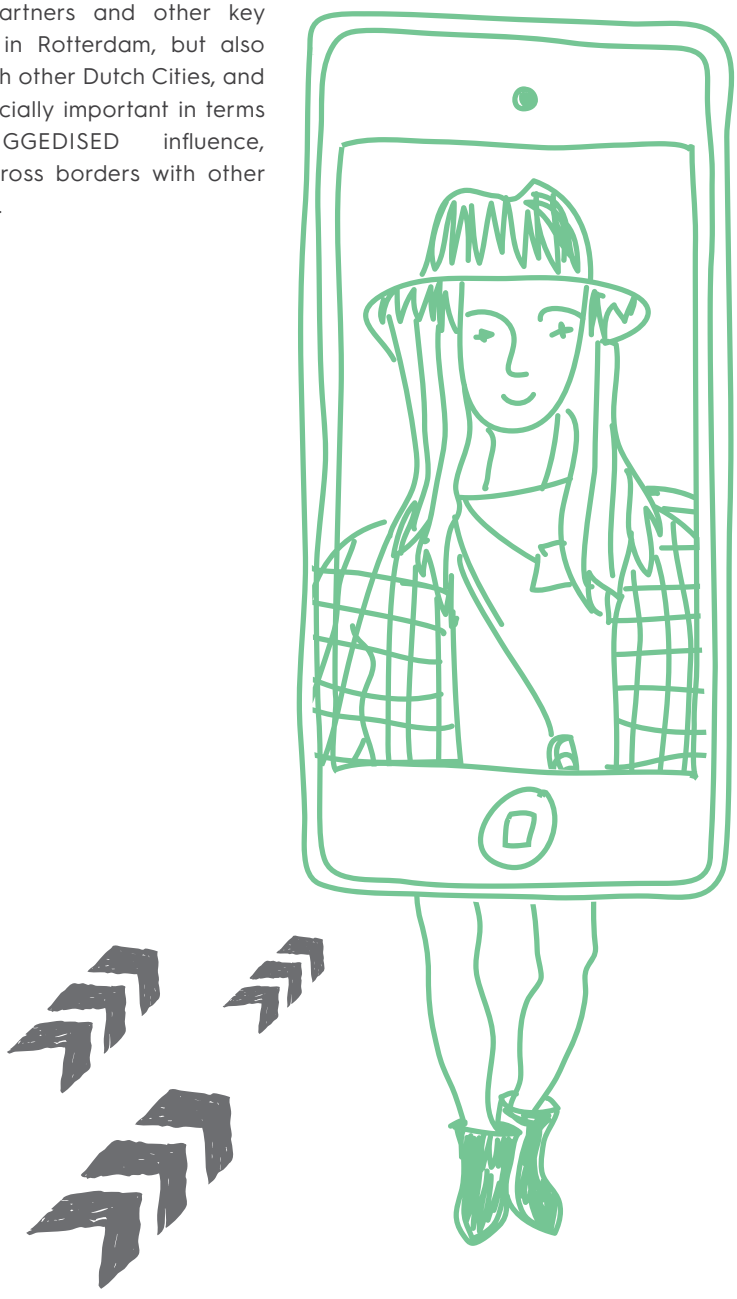
- **Consultation on legislation**: As the project progressed and hurdles were taken, staff working on RUGGEDISED was increasingly included in the preparation of new legislation on the local and national level. Benefitting from knowledge on the practical roadblocks, partners were able to share concerns and input. Consultation for example took place on the 'Transition to Fossil Free Rotterdam' (in Dutch: Transitievisie Warmte Rotterdam) and the lobby for the public ownership of (city) heating infrastructure (In Dutch: Wet Collectieve Warmte).

- **Inclusion in developments of new areas**: Rotterdam has ambitions far beyond the 'Heart of South' and several areas are currently being prepared for – or already in the process of – redevelopment to increase their sustainability and the quality of life for citizens. Benefitting from their experience in the Heart of South, partners in RUGGEDISED from the City of Rotterdam are included in the planning groups for these developments.

Rotterdam as a climate neutral city

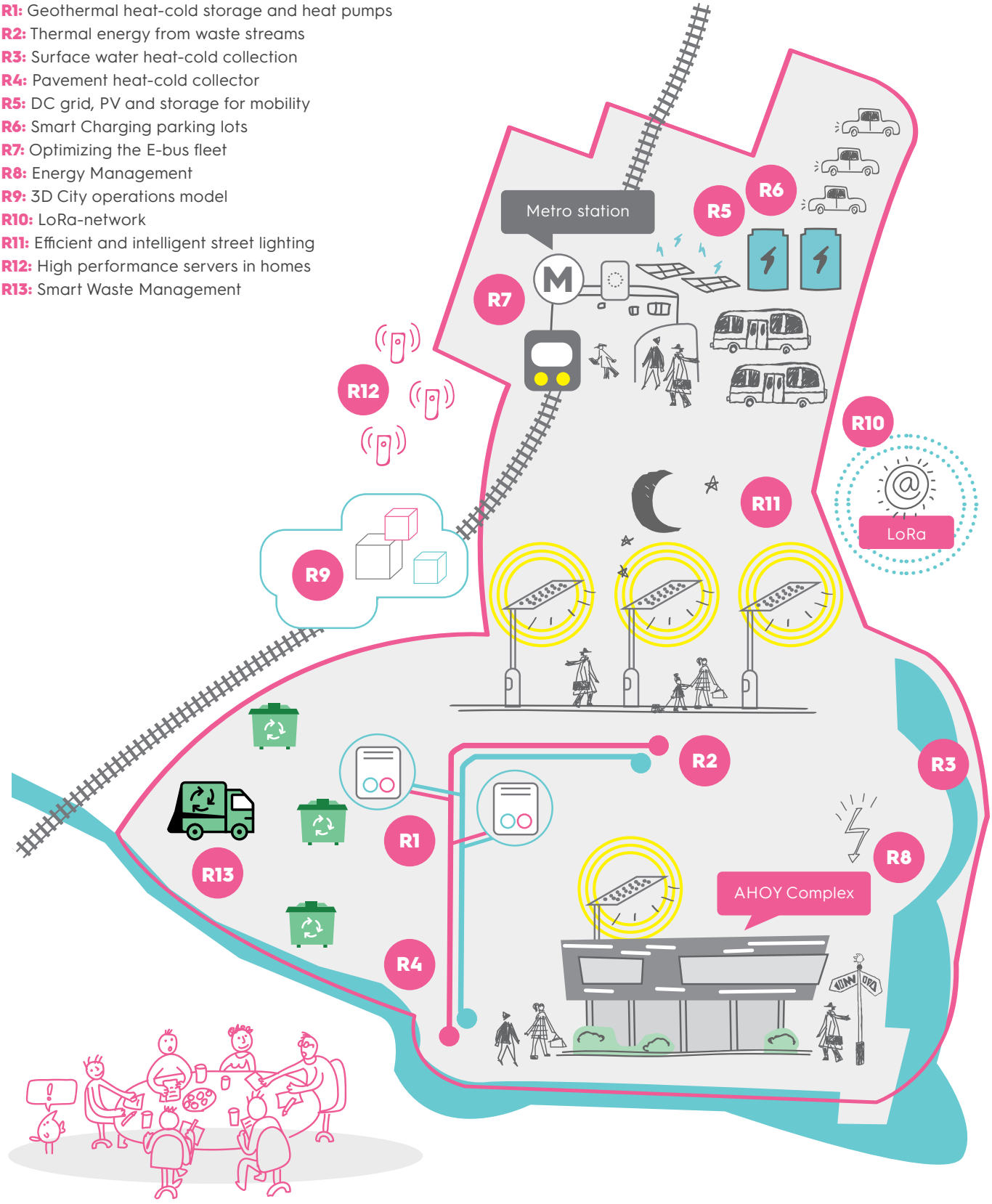
When the European Commission announced the 112 Cities chosen to join the EU Mission on climate neutral and smart cities, Rotterdam was among the ambitious cities on the list. While neither the decision to apply nor the fact the City was chosen to join the list can be directly accredited the implementation of the RUGGEDISED project, Rotterdam has drawn valuable lessons through the project, preparing them for future efforts. Partners were consulted on Rotterdam joining the Mission, and shared lessons on how to proactively work towards climate neutrality. These lessons include the formalised (or informal) cooperation with private partners and other key players locally in Rotterdam, but also cooperation with other Dutch Cities, and – perhaps especially important in terms of the RUGGEDISED influence, cooperation across borders with other European Cities.

Throughout RUGGEDISED, Rotterdam has been a major contributor to the "community" of Smart Cities Lighthouse Projects today know as Scalable Cities. Within this partnership, Rotterdam has helped push forward the idea and ambitions of climate neutral and in pointing to concrete actions – such as supporting the connection between city needs and available finance – from the community as whole. These experiences, which has been highlighted in a **report from RUGGEDISED on the project's contribution to the European Smart Cities Community**, will support Rotterdam's future effort, as the city aims to become climate neutral and smart.



Map of RUGGEDISED Solutions in the Heart of South district

R1: Geothermal heat-cold storage and heat pumps
R2: Thermal energy from waste streams
R3: Surface water heat-cold collection
R4: Pavement heat-cold collector
R5: DC grid, PV and storage for mobility
R6: Smart Charging parking lots
R7: Optimizing the E-bus fleet
R8: Energy Management
R9: 3D City operations model
R10: LoRa-network
R11: Efficient and intelligent street lighting
R12: High performance servers in homes
R13: Smart Waste Management



Description of Smart Solutions

SOLUTION R1: Geothermal heat-cold storage and heat pumps

General description: A central goal of this solution was to connect the large buildings in the area to a single thermal grid. This means enabling local heat and cold exchange to lower the use of energy and the cost of ownership. To maximise the use of waste heat/cold derived from heating and cooling the various buildings, seasonal storage in a geothermal layer was planned for implementation (heat-cold storage). Over time, more buildings will be connected to a low temperature grid and provided with a heat pump to meet heat requirements. The generated waste heat feeds back into the heat-cold storage. Reversely, cooling is provided for the warmest days directly from the Smart Thermal Grid.

Expected impact: When connected to the Smart Thermal Grid – in combination with connection to city heating – it would be possible to disconnect the entire Ahoy complex from natural gas. Because of the diversity of functions of the connected buildings and the energy sources, peak demands will, at different times, need a lower total base load. This was expected to save costs on installations due to the decreasing total energy demand. The expected decrease in energy consumption was 924.000 kWh per year; which equals an annual CO_2 equivalents reduction of 70 tons. These expectations were based on less energy needed from the central energy system of the city, thus lowering the total emissions according to the emissions factor of the central system.

Final implementation stage: In the first stage the (existing) Aquifer Thermal Energy Storage (ATES: heat-cold storage located deep underground) were revitalised and tested by the energy supplier Eneco. Based on these tests, various improvements have been made to bring the storage up to the standards required for the inclusion of R1 to work, including a higher quality pumping system. In the second phase of the project the so called 'back bone' was installed in Ahoy, in both the existing halls and the newly built Convention Centre. In the final phase two other smart solutions – the pavement collector (R4) and the energy from waste streams (R2) – were connected to the Smart Thermal Grid as sources. The back bone was extended to the pumping station (were the energy is collected from waste streams). In a next phase the back bone will hopefully also connects to the soon to be built cinema.

A key aspect to successfully implement this solution was changing the ownership of the physical infrastructure. Originally, ownership was with the venue Rotterdam Ahoy but this made it impossible for Eneco to implement the solution. Therefore, following intense talks and negotiations lasting almost two years – with support from the City of Rotterdam – ownership of the infrastructure was changed to Eneco. In addition, Eneco was made supplier to Ahoy, which combined made the experimental implementations feasible. This sort of change was not limited to Eneco and Ahoy but had to include several other parties due to its complexity. The agreements had to include the users, investors, owners and contractors – all related to the buildings, the site and the physical installations.

Innovation: Innovation included combining the Smart Thermal Grid with the aquifer, and combining heat pumps with various features such as waste-water heating/cooling and asphalt heat recovery. Due to the diversity of functions of the connected buildings and connected energy sources, peak demand occurs at different times and therefore the system as a whole will then require a lower total base load of energy.

Connection to other smart solutions: This solution links to the thermal energy from waste streams solution (R2) and pavement heat/cold collector (R4). These two smart solutions (R2 and R4) are connected to the Smart Thermal Grid.

Results: Because of the Smart Thermal Grid, the entire Ahoy complex is now independent from fossil fuel energy sources. Most of the heat, cold and electricity is produced locally, on-site or extracted from underground.

Upscaling plans: The existing Smart Thermal Grid can be extended. Both in newly connected buildings as well as new heat and cold sources. There are concrete plans to extend the grid to a new cinema building, close to Ahoy. In general, the idea of so-called 4th and 5th generation thermal grids is becoming more common. Research from other areas in the city exploring local grids is becoming 'mainstream'. In these investigations, lessons learnt from RUGGEDISED and the situation in and around Ahoy are taken into account. Through this research, Eneco and the municipality learned about vital business cases, the possible difficulties faced when working with (local) energy sources, and further insights in the combination of a smart grid and city heating.

Replication Assessment: The Smart Thermal Grid as such is replicable in many other parts of the Netherlands and Europe. The implementation of such a Smart Grid can take place both in cities with pre-existing District Heating systems or cities without. The biggest limitation for replication would be the energy governance in the specific area and the need for buildings in an area to either be very similar – or be willing to adapt to the system. A combination of new and old buildings, for example, would need refurbishment to establish convergence between the buildings.

The solution is being brought forward in RUGGEDISED fellow City of Brno, for their plans for the Špitálka District.

SOLUTION R2: Thermal energy from waste streams

General description: In addition to a thermal storage facility and heat pumps (such as those implemented in Solution R1), the use of thermal energy of waste streams can be deployed by making further connections to a Smart Thermal Grid. At the district scale level, heat respectively cold of the sewage water from nearby households is used by adding this source to the grid. Depending on the need, it can be used directly or stored to refill storage and help create a thermal balance.

Expected impact: The thermal energy from waste streams was to be used to balance the Aquifer Thermal Energy Storage (ATES) and is therefore a (potential) profitable part of the grid. The expected decrease in energy consumption was 136.000 kWh per year, which would lead to an annual CO_2 equivalents reduction of 28 tons. These expectations were based on less energy needed from the central energy system of the city, thus lowering the total emissions according to the emissions factor of the central system

Final implementation stage: Implementation of this solution was completed in August 2022 and required close cooperation between the Municipality of Rotterdam (owner of the sewer) and Eneco (operator of the Smart Thermal Grid).

Several options to implement a heat exchanger in the sewage system were considered. Due to replacement of a sewage pipe in the coming years and too tight corners in the piping to fit the elements amongst others, implementing a heat collector in a sewage pipe was not preferable, as the pipes will be replaced in the coming years. Therefore, the final and chosen option was to place the heat collector panels in the basin of a pumping station located next to Ahoy's buildings.

A heat collector in a pumping station's basin is not common, so German specialist contractor Uhrig Bau made a dedicated design for the panels. Uhrig Is one of Europe's leading contracting companies in extracting thermal energy from waste water known as 'riothermia').

To complete the design of the system, a technical room was created inside the pumping station to fit in the heat exchanger and pumps.

In June 2022 the heat collector panels were installed by Uhrig Bau. In June and July all piping and electrical connections were made. In August 2022 the skid (heat exchanger and pumps) were placed and connected to and connected to the Smart Thermal Grid (R1).

Innovation: A thermal heat recovery system in the sewage system, in combination with a Smart Thermal Grid, has the potential to increase the impact of both solutions. The combination of such solutions is the innovative aspect.

Connection to other smart solutions: The recovery of heat and cold from waste streams is connected to the other thermal grid solutions in Rotterdam.

Results: Smart solution started operating in the first week of September 2022. Monitoring started at that time and data is flowing, although there are no concrete results processed.

Upscaling plans: Smart thermal grid solutions are being integrated into the development of other areas in Rotterdam to use (smart) thermal waste as source in local heating and cooling systems. Lessons learned from this smart solution process, and its implementation, are helpful in the design phase of these other projects.

The potential use of thermal energy from waste water streams is being mapped for the whole city. The city itself – to be more precise the city's maintenance department – is the owner of the sewage system, including all pumping stations. Therefor the maintenance department also sees the potentials for this innovation. Currently they are investigating to install a heat collector in another pumping station. Besides of this, there is also a project ongoing about placing a heat collector in a sewage pipe, as was the original idea of RUGGEDISED. One of the city's largest museums is supposed to be the user of the energy.

The technical room connecting R2 to the Smart Thermal Grid.

Replication Assessment: As an energy source for the thermal grid or a nearby building, thermal energy from wastewater has great potential. Almost every street in Europe includes sewage piping which makes this smart solution potentially very replicable. The contractor for the heat exchanger in Rotterdam is one of Europe's leading companies in this with work undertaken in several countries.

Another relevant reference of thermal energy as a source comes from another Horizon 2020 city: Stavanger, Norway. Here, the heat exchangers are successfully installed in the sewer tunnels of the city.

The solution is also being brought forward in RUGGEDISED fellow City of Brno, for their plans for the Špitálka District.

Further readings:
Plan for re-use of waste streams to produce thermal energy

SOLUTION R3: Surface water heat-cold collection

General description: Open surface water heat is another source of thermal energy that can be used directly or stored in the Aquifer Thermal Energy Storage (ATES) to help regenerate the storage and create a thermal balance. A pond in the 'Heart of South' area was considered for this solution.

Expected impact: The thermal energy from the surface water could be used to balance the ATES and was therefore an add-on potential source for the grid. The expected decrease in energy consumption was 39.000 kWh per year, which would equal to an annual CO_2 equivalents reduction of 19 tons. These expectations were based on less energy needed from the central energy system of the city, thus lowering the total emissions according to the emissions factor of the central system.

Final implementation stage: Unexpectedly, an analysis showed that the solution is not economically feasible. The situation on the ground, combined with experience from projects elsewhere in the Netherlands, showed that installing a surface water system in a pond with little water flow leads to exorbitant maintenance costs caused by a layer of "biofilm" (a sheet of organic material including bacteria and algae). Together with the Dutch Water Board, in charge of the maintenance of ponds, investigations were undertaken as to whether or not the local drainage system (designed to manage water levels during heavy rainfall) could be used to create the necessary flow in the water system. However, calculations showed the additional energy required for pumps to create a flow would amount to more than the heat collected from the system.

As this would run contrary to the expected CO_2 reduction goals, other ways to implement this solution are being investigated.

In 2020, the feasibility study of thermal energy recovered from surface water was re-started. A new location, at the back of Ahoy and close to the pavement collector smart solution, was analysed. The advantage of this location was that it was closer to the technical room in Ahoy and piping could potentially be shared with the pavement collector. Unfortunately, this study also showed that the costs were higher than the yields. Therefore, this solution was not implemented.

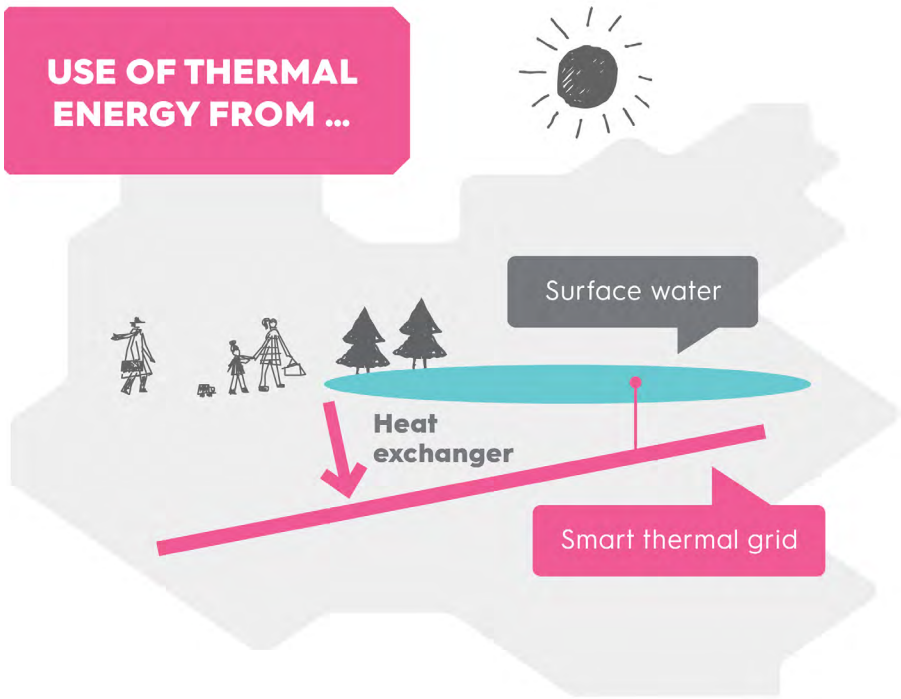
Connection to other smart solutions: This smart solution would have been connected to the other smart thermal grid solutions (R1, R2 and R4).

Results: No results available as the smart solution was not implemented.

Upscaling plans: In theory, thermal energy from surface water has potential for the city of Rotterdam. There is a lot of surface water, especially in the river Meuse. The potential of thermal energy from surface water is limited by infrastructure costs. For developments further away from the river or other waters, the investment need in infrastructure is too high. Financing the project is not profitable, therefore there are no upscaling plans at the moment.

Replication assessment: For towns and cities with (larger) flowing open waters or rivers, this might be a profitable solution to replicate. To avoid exorbitant costs, it is important that the source of water is not too far away situated from the installations. The location and temperature of the water, in winter as well as in summer, has a lot of influence. It is important to keep the effect of this system on water quality in mind.

Further readings:
Plan for balancing geothermal heat-cold storage system by using surface water



SOLUTION R4: Pavement heat-cold collector

General description: This solution involved the testing of a pavement-heating system, which was used to keep an areaof 400m^2 paved sidewalk frost-free in winter times. Several possible locations were considered for scaling-up the pavement heat collector in the 'Heart of South'.

This solution involves balancing the Aquifer Thermal Energy Storage (ATES) by using the mass of pavement as a heat-cold collector. Heat and cold are extracted from the heat exchanger situated under the surface of the pavement. At the same time, the pavement heat-cold collector can keep the pavement frost-free during the winter while during summer, the pavement is cooled, which could benefit its lifetime and help decrease the urban heat island effect as a result of such large paved areas.

Expected impact: The thermal energy extracted from the pavement collector was planned to balance the ATES and serve as a useful part of the grid. The expected decrease in energy consumption was 108.000 kWh per year, this would equal an annual CO_2 equivalent reduction of 52 tons. In winter the road will be slightly heated so the pavement will not freeze. These expectations were based on less energy needed from the central energy system of the city, thus lowering the total emissions according to the emissions factor of the central system.

Final implementation stage: After considering several locations for the pavement heat-cold collector, a location behind the Ahoy Exhibition Complex was selected. The location was chosen due to its proximity to the heat pumps of the Smart Thermal Grid and due to the re-paving of an existing asphalt road which would anyhow take place.

Installation of the pavement collector was executed in August 2022.

Innovation: A pavement heat collecting system in combination with the Smart Thermal Grid in the 'Heart of South' area. The pavement itself is innovative, but the added value by combining it with other energy sources in the thermal energy grid make it even more beneficial.

Connection to other smart solutions: The solution is connected to the other Smart Thermal Grid (R1).

Results: Smart solution started operating in the first week of September 2022. Monitoring started at the end of September, first use data is collected at the moment of this implementation report being published, and expected long term data collection results is pending for upcoming processing.

Upscaling plans: If this solution proves to be effective in dealing with heat stress during summer time, it has huge upscaling potential in other areas of Rotterdam. Within the city centre there are quite a lot of squares that cause intense heat stress during summer. At the moment there are no upscaling plans; results from RUGGEDISED may help to explore potential areas for implementation.

Replication assessment: Since every town or city has paved streets, this solution certainly has potential. A required element is that there is space for storage of both heat and cold. The solution is useful for southern European countries, since it can extract a lot of heat, but also potentially cool the surface of pavements. Northern European countries could benefit from non-frozen pavement in winter time.

The RUGGEDISED Fellow city of Brno is not actively working on replication of this solution as RUGGEDISED ends, but has included it as an option to include in future iterations of its Smart City District Špitálka.

Further readings:
Plan for balancing geothermal heat-cold storage system by using heat exchanger under pavement/road

Installation of the tubing for the pavement heat/cold collector.

SOLUTION R5: DC grid, PV and storage for mobility

General description: The existing grid at the bus station could not provide enough power necessary for the fast charging of electric buses in Rotterdam. The public transport operator and RUGGEDISED partner RET, investigated placing photovoltaic (PV) panels on the roof of the bus and metro station in order to deliver renewable energy directly from the PV panels into the charging stations of the buses. The original idea was to implement these PV panels on top of the bus station, which was later changed to also installing them on top of Rotterdam Ahoy.

Expected impact: The expected decrease in energy consumption was 1.800 kWh per year, this would equal an annual CO_2 equivalents reduction of one ton. These expectations were based on less energy needed from the central electricity network and a more efficient local solution with energy storage, thus lowering the total emissions according to the emissions factor of the network.

Current implementation stage: In the initial period, the RUGGEDISED team worked on the design and calculations for the local electrical grid (I.e. connection from PV Panels to charging infrastructure). Technical options were discussed to further specify the design of the needed components (e.g., PV panels, small wind turbines). Possible integration of the electrical grid with the data hub, which links energy management (R8) and the 3-D City Model (R9), was also discussed.

After the technical discussion, looking into the weight of the PV-panels and the capacity of buildings in the area, the contract for adding PV panels on the roof of the existing Ahoy building and the new Convention Centre was signed. The installation of solar panels was thus included in the design of the Ahoy Convention Centre, another hall of Ahoy, the bus station, the metro station and the cultural centre.

PV panels on top of Ahoy would increase the noise pollution stemming from concerts as they would amplify the sound waves. A study helped to suggest what angle to place the PV installations to reduce resonance.

A feasibility study revealed that there was no potential for peak energy shaving if a local battery, in combination with a small, new net connection, were to be installed. However, a follow-up study showed that connecting solar panels directly to the fast charging system of the new E-buses (in combination with a small connection to the main grid) provided the best business case. Because of this, installing a new, big connection to the main network could be avoided. This meant increased electricity demand for the main power station will be avoided.

Approximately 15.500 square meters of photovoltaic panels are installed on several roofs in the 'Heart of South' area. Both on already existing buildings as well as the newly built RACC (Rotterdam Ahoy Convention Centre). The majority of the solar panels are placed on the Ahoy centre, around 12.000 square meters. Approximately a quarter of all electric energy used in Ahoy is now produced by the PV-panels.

Connection to other smart solutions: The smart solution 'DC grid, PV and storage for mobility' is connected to the other smart grid solutions (R8 and R9.)

Results: Monitoring in progress. Using the Simaxx software (solution R8), the energy consumption of every hall of Ahoy can be monitored.

The 15.500 square meters of solar panels leads to a total of over 2.500.000 kWh energy yield a year. This equals to an annual CO_2 saving of 1200 ton. In the original scope of RUGGEDISED only a small number of solar panels were planned.

The solar panels on the roof of Rotterdam Ahoy and the bus station were originally not in the scope of RUGGEDISED, however since there is a close connection between these installed solar panels and some smart solutions, the results can also be credited to RUGGEDISED.

Upscaling plans: In the transition towards a full electric bus fleet, RET, the public transport operator, also needs to change their garages, charging facilities and digital infrastructure. The development of a new garage for the (electrical) busses is ongoing. One of the design possibilities is a canopy with solar panels above the terrain.

Replication assessment: Solar panels are a common feature when looking to harness renewable energy. The possibilities and regulations for exchanging electricity between buildings or users may differ from country to country. It is also possible to return energy to the grid, but regulations on this are different in each country.

In connection to the RUGGEDISED project, solar panels were installed on the top of Rotterdam Ahoy. On the photo is Ahoy director Jolanda Jansen, Former Rotterdam Alderman Arno Bonte and the CEO of Eneco As Tempelman.

SOLUTION R6: Smart charging parking lots

General description: The goal of this smart solution was to reduce peak load through introducing smart charging stations at parking lots. This smart system is based on the idea of controlled charging at times when electricity demand in the grid is low. The cars would be charged when extra capacity is available from the network.

In January 2019, Eneco investigated the possibility of installing 25 charging stations at the Ahoy premises. It was not possible to place the charging stations in the parking area because Ahoy is using this area as a festival space and, therefore, it must be free of obstacles at times.

Expected impact: The expected decrease in energy non-sustainable consumption was 5.750 kWh per year; this would equal an annual CO_2 reduction of 3 tons. These expectations were based on less energy needed from the electricity network of the city, thus lowering the total emissions according to the emissions factor of the network.

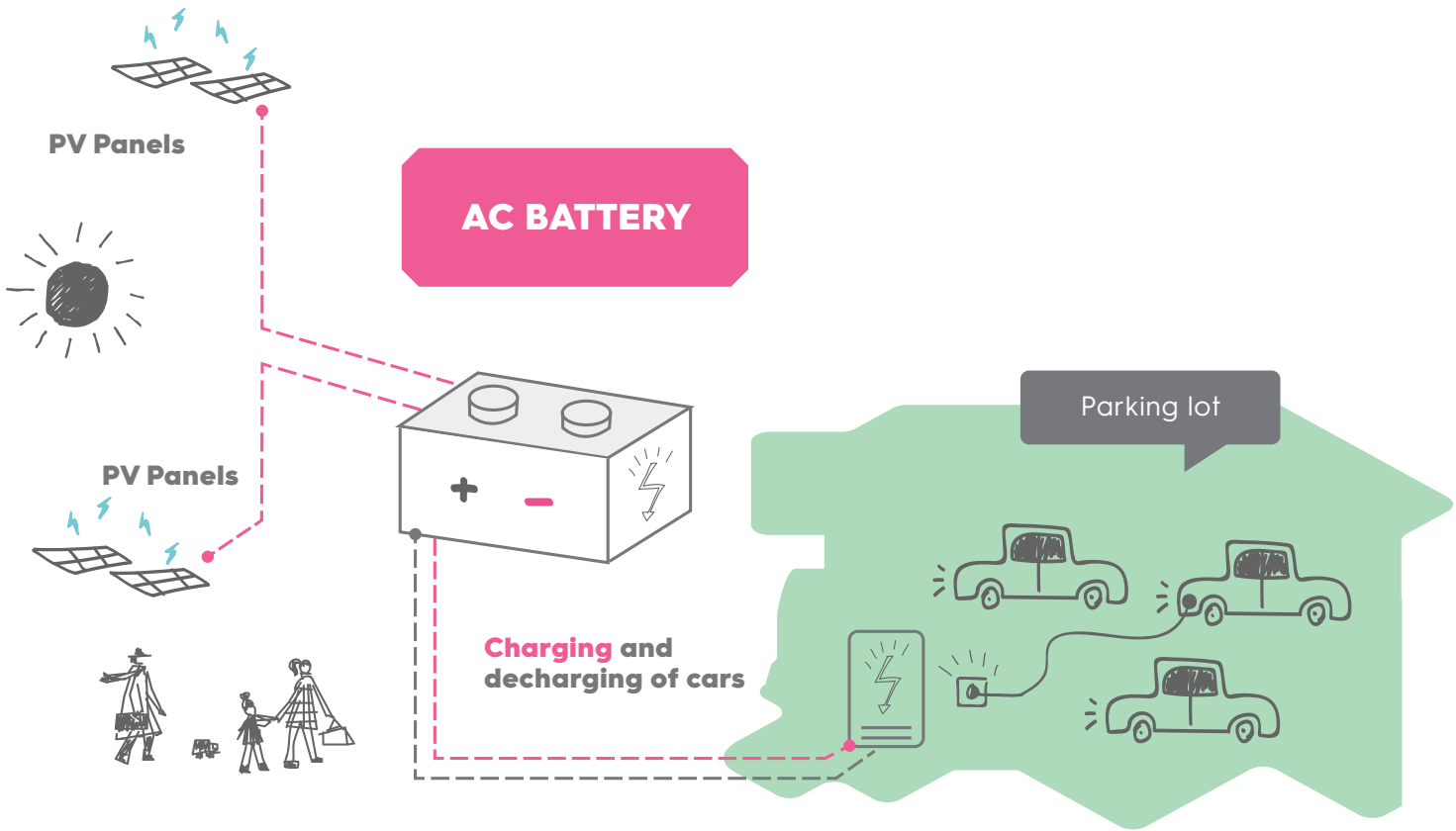
Final implementation: In early 2017, the public procurement to get the contract to place electric charging stations throughout the entire city of Rotterdam was won by the energy company Engie, meaning Eneco would be unable to place two-way charging stations (G2V-V2G) anywhere on public city property and thus neither in the 'Heart of South' area.

Results: Smart solution not executed, therefore no results available.

Upscaling plans: Currently there are no concrete plans to install smart chargers in the city of Rotterdam. However, in the coming years, around ten thousand (normal) electric charging poles will be installed in the city of Rotterdam.

Replication Assessment: This is a good example of a realistic solution for replication despite the lack of direct implementation. PV panels are becoming a standard for new buildings and electrical cars are also replacing fossil fuelled vehicles. Cities are in transition, buildings and cars both need power. This solution tries to balance and is therefore replicable for other cities embarking on an energy transition.

While the solution was not implemented, the City of Brno is benefitting from the lessons learnt and has included plans for such combination of PV panels and parking with the plans for the Špitálka District.



SOLUTION R7: Optimising the E-bus fleet

General description: The bus station in the 'Heart of South' is part of a dense public transport network in which a consistent number of buses of RET needs recharging. Therefore, the energy produced by the solar panels can be stored or used by the electric buses immediately (G2V). This solution aims to support the transition from conventional diesel buses toward battery powered electric buses. A main aspect was developing a model for optimisation.

Expected impact: The introduction of electric buses and the charging infrastructure is not just a matter of implementing new technology; it is a matter of introducing a completely new transport system that is more similar to a tramway than to bus deployment. The expected decrease in energy consumption was 1.900.000 kWh per year, this would equal an annual CO_2 equivalents reduction of 780 tons. Baseline is the situation before (2018) with diesel fuelled buses. Impact is then actual energy/fuel consumption 2019-2022. In this way also automatically the impact of the new optimized routing is taken into account.

Final implementation stage: The first step toward achieving this solution was to develop an evaluation tool to quantify any potential impacts of the transition on current RET bus schedules. By running the tool for different parameter concerning energy consumption, like the number of buses, and the charging infrastructure setup, it was possible to evaluate the impact of transitioning to an electric bus network under varying circumstances and to identify the most important factors for related costs.

After this initial investigation, focus was placed on how to develop tailored schedules for an electric bus network. This process consisted of two main decisions: 1) assignment of trips to buses and 2) scheduling of charging activities. For the first decision, RET purchased planning software that was able to optimise bus schedules for electric buses.

However, this planning software was not able to consider the scheduling of charging activities. Hence, Erasmus University has studied this challenge in close collaboration with RET.

This process has resulted in two types of models. First, a simulation model that evaluates different charging strategies was developed. A charging strategy specifies where, when, and for how long each bus should charge. Common sense strategies include a first-come, first-serve rule (where a bus charges whenever it has time to use an available charger) and a lowest State of Charge highest priority strategy. According to the latter strategy, a bus with a lower State of Charge (SOC) can take the charger from a bus with a higher SOC. By adding data accounting for delays to the simulation, it became possible to evaluate the impact of delays on the feasibility of the schedules.

Secondly, Erasmus University developed an optimisation model that could determine an optimal charging schedule with respect to two objectives: 1) minimise the number of charging activities and 2) minimise the charging cost. The first part of the model aims to minimise the number of charging activities by defining a strategic schedule. The second objective is to ensure charging occurs at cheaper, off-peak hours.

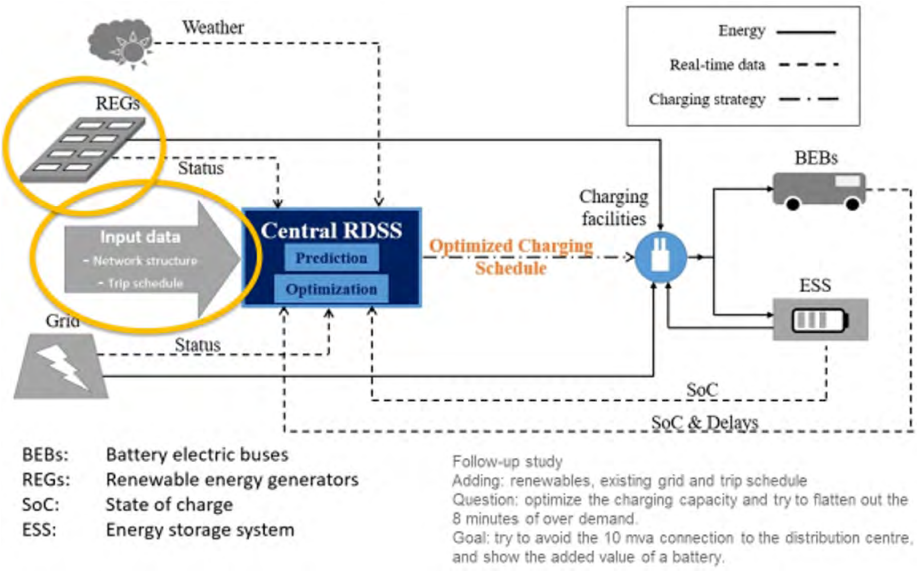
In close collaboration with RET, both the simulation model and the optimisation model were tested on a fleet of 50 electric buses, charged at the 'Heart of South' bus terminal. The first results showed that, under planned conditions, the schedules are feasible, but the schedules are not adequate when experiencing delays. Re-optimisation during the day will be necessary to achieve a feasible schedule. Currently, the models are being adapted to allow re-optimisation, based on real-time data.

Originally, RET was planning to start with six e-buses, but the transition to electric buses will be implemented at a faster pace than foreseen.

This transition requires a significant shift in the deployment of the bus fleet. One challenge revolves around the reliability of public timetables on a large scale. Thus, RET tested the reliability of the ICT software in real-time to see the effects on the complex logistic operations. In addition, to obtain optimal results, simulation models from the Erasmus University of Rotterdam, in collaboration with RUGGEDISED, were also used.

Connection to other smart solutions: This simulation model proves that most of the generated renewable energy can be used directly to charge the buses. As a result, the added value of installing a battery (R5) is

Schematic overview of the studies being done to optimise the battery buses charging scheme.



limited. The solution also feeds into the energy management of the 'Heart of South' (R8) and the 3D City-Model (R9).

Results: Based on the implementation of 55 e-busses a total of 5.925.000 kWh a year is saved. This equals a CO_2 equivalents saving of 3.150 ton. In the original scope it was expected to introduce fewer busses, therefore the saving numbers are higher than the expected impact.

Besides the quantifiable results, several lessons can be drawn:

- The introduction of chargers into a city environment is a complex, time consuming challenge for the municipality, the grid provider and the public transport company.
- Calculations (about range, energy consumption, state of charge and so on) are theoretical and need to be proven in practice. Because many issues influence the calculations, the practical outcome can be significantly different from the theoretical assumption.
- Careful planning of charging moments can reduce the impact on the grid in terms of maximum available capacity.

Upscaling plans:

- The start of the electric bus fleet contract (55 buses) in December 2019 also marked the transition towards zero emission bus transport. In mid-2022 the second batch of electric buses was introduced on the roads. To make this possible, a lot of infrastructure and bus schedules were changed. The final 150 buses is foreseen between 2025 and 2030 and will replace all buses equipped with combustion engines for zero emission vehicles.
- Transition towards zero emission buses, i.e., transition to electric transport is faster than originally expected.

Replication Assessment: The introduction of electric busses is already occurring in most other cities in Europe, and the potential for optimized scheduling is large. In some instances this will require new knowledge – or outside assistance – from the Public Transport Operator and RUGGEDISED has shared its results in Open Access Publications for others to benefit from.

The Fellow City of Parma is also bringing forward the lessons as the city has included plans for local transport planning in its replication plan.

Further readings:

- **Introduction first six zero emission e-buses**
- **Journal article: Online Optimization to Enable Sustainable Public Transport**
- **Journal article: Evaluating and Optimizing Opportunity Fast-Charging Schedules in Transit Battery Electric Bus Networks**

SOLUTION R8: Energy Management

General description: The energy and building management software Simaxx was implemented at the Ahoy Convention Centre as part of RUGGEDISED. Eventually, the ambition is to have Simaxx software implemented in all buildings in the 'Heart of South', which will allow for the visualisation and optimisation of energy consumption, production, etc., of the buildings. The Simaxx software at building level can visualise and optimise energy usage, comfort level and heating, ventilation and air conditioning (HVAC) operations.

Expected impact: The expected decrease in energy consumption was 164.000 kWh per year, this would equal an annual CO_2 equivalents reduction of 66 tons. These expectations were based on optimising the energy usages in the buildings, thus lowering the total use of energy

Current implementation stage: Currently Ahoy is using the Simaxx software for their energy management. This helps Ahoy to monitor the energy consumption of the different exhibition and congress halls. Besides Ahoy, also the swimming pool is making use of Simaxx.

Innovation: Making the energy usage of the buildings in 'Heart of South', which are connected to the Smart Thermal Grid, visible and optimal.

Connection to other smart solutions: The Energy Management solution is connected to the different solutions related to the Smart Thermal Grid (R1-R4).

Results: The results for this smart solution cannot be substantiated numerically. However, the energy management system is useful for Ahoy. They use Simaxx, which allows them to monitor energy use per hall and therefore are now able to bill renters separate.

The actual low temperature heating system is different in use than the previous high temperature heating system in Ahoy. As a result, instead of heating up an event hall two hours before the public comes in, now Ahoy has to start heating a day in advance. The smart energy management system help the technical department of Ahoy in better understanding the new system.

Upscaling plans: No upscaling plans are known at the moment.

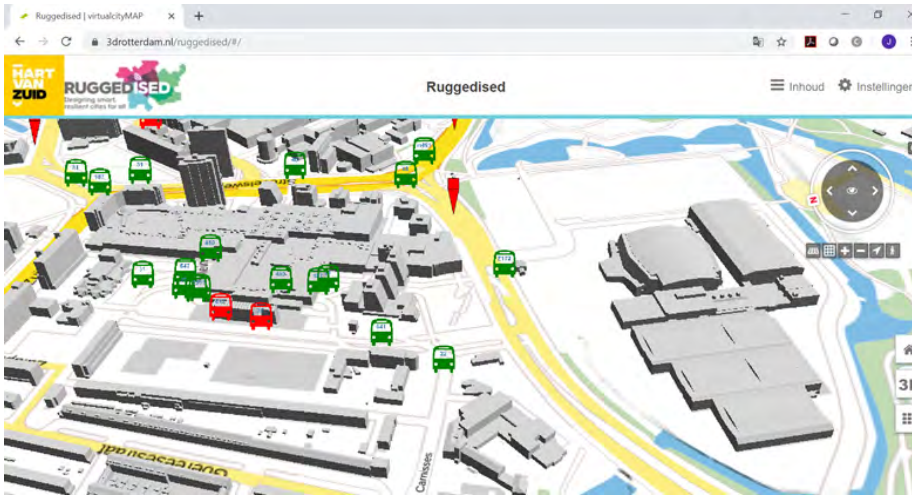
Replication assessment: A smart solution like this one has the potential to be replicated throughout Europe. The possible impact elsewhere depends on the number of data points and whether it is possible to connect it to smart grids – like in Rotterdam.

The Fellow Cities of Parma and Brno have both included Energy Management software and this R8 Solution in their replication plans.

SOLUTION R9: 3-D City operations model

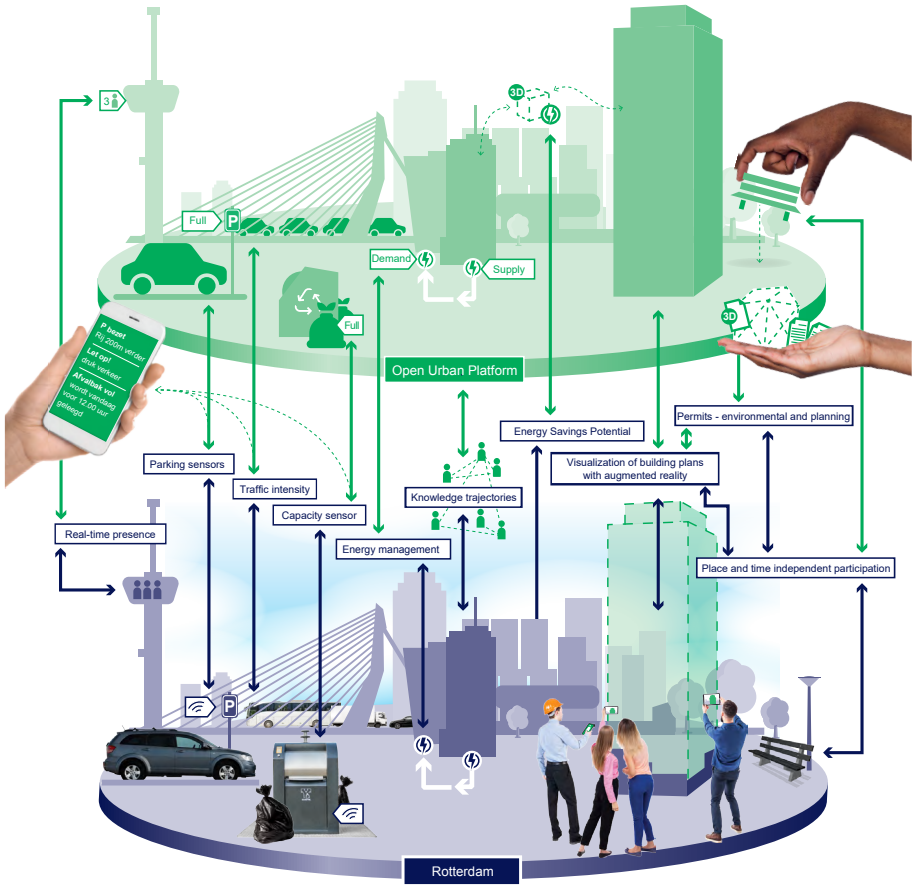
General description: The development of the 3D city operations platform is an iterative process of learning. Learning by understanding happens through studies and engaging with peers. The main research question here is how to organise the governance of the platform and which role the municipality of Rotterdam plays in this.

The development of the platform took place through three phases, in which the idea of 'proof of concept' was applied, two of those phases were held within the timeframe of RUGGEDISED. The 3-D City operations model will become a digital twin of the 'Heart of South'.



Screenshot from the proof of concept focusing on the 'Heart of South'.

Infographic on Rotterdam's Digital City vision (2021).



Expected impact: The expected impact was to have more insight in ongoing processes and creating possibilities to make them more effective. Furthermore, this solution was expected to open up space for other innovations and increase the overall impact of other smart solutions, including beyond the scope of energy.

Final implementation stage: A proof of concept (PoC) has been done at different times throughout the project and the platform now successfully includes a number of features.

In the first proof of concept, the goal was to prove that the municipal vision of the platform was technically feasible. To do this, real parking lot data was successfully integrated in the 3D City Model.

Information was the central aspect of the second proof of concept. The platform is technically feasible, but is it still flexible enough to give answers to real-life questions? And which functional components are needed in the platform? In this second PoC, real-time data concerning traffic mobility, public transport and open bridges was shared in the 3D City Model. Several open data standards were also tested. This PoC offered a lot of feedback about open data standards and about the process of disclosing real-time data that is owned by the municipality, but comes from (private) data sources. In the meantime, different scientific studies led to a much better understanding of the functionalities needed for the platform.

The support of RUGGEDISED was very useful for the first implementation phase of the digital twin in Rotterdam. In 2023 the City of Rotterdam will open an innovative tender to select a stakeholder for the development of the next phase of the city's Smart City Platform. Most of the new possibilities and features of the model will extend beyond the scope of RUGGEDISED.

Results: The results from the 3D city operations model cannot be substantiated numerically. This smart solution however provides the motive for further innovation and development.

Lessons learnt:

- The municipality does not want to be the owner of data that is employed by a solution that the municipality itself has developed and paid for.
- The municipality usually was the main user.
- The municipality has not made any agreements on how data should be 'transported'. No agreements have been made as to the format of the data.
- The use of open data is more complicated than often thought of, but should be seen as an investment that pays of in the long run.
- Not all open data standards are accessible and easy to use. The municipality has to test these itself or use the experiences of other municipalities.
- Experience developing the basic functionalities for an urban platform (storage, conversion, geo-functionality, context management, security and privacy, market place, 3D digital twin) has been gained.

Upscaling plans: The City of Rotterdam will continue to build on the city's 3D model. The municipality will also add new features and possibilities. For example, the idea of using the digital twin to visualize new building plans through augmented reality is being explored. Also, the possibility of energy savings calculations and PV panel potential is being assessed. Lessons learnt from the RUGGEDISED project will be implemented in future models and versions.

Replication Assessment: The concept behind a digital twin is replicable. The content is of course developed specifically for the city of Rotterdam, but every city can develop the content itself, with topics related to the local situation. To learn more about developing Urban Data Platforms or Digital Twins, find the RUGGEDISED materials on the topic on the RUGGEDISED website.

Replication of this solution / concept has also been ongoing throughout the project, with both the City of Gdańsk and the City of Brno having taken important (and parallel) steps on the development of Urban Data Platforms. The City of Parma has also included an Urban Data Platform specifically in its replication plan.

Further readings:

- **Stay up-to-date on the website of Digital Rotterdam**
- **Find all the outcomes from RUGGEDISED's work on urban data on the RUGGEDISED website**

SOLUTION R10: LoRa-network

General description: One part of the RUGGEDISED project included the introduction and rollout of the LoRa (Long Range) network by partner KPN. The LoRa network ensures that Wi-Fi and/or 4G is not required. The LoRa-network would make dozens of applications possible. The network is meant for equipment that does not constantly need its own internet connection.

Expected impact: The expected decrease in energy consumption was 339.000 kWh per year, which would equal an annual CO_2 equivalents reduction of 104 tons. These expectations were based on a more efficient system than alternatives. LoRa is using less energy than WiFi and/or 4G.

Current implementation stage: The LoRa network has not been implemented in the 'Heart of South' area. The two test cases that were supposed to use LoRa were not able to continue using the LoRa network. The implementation of LoRa began early in the RUGGEDISED project with the smart waste bin solution, but stopped due to the "law of the inhibiting lead".

The two other RUGGEDISED solutions, 'efficient and intelligent street lighting' (R11) and 'Smart Waste Management' (R12), originally thought of benefitting from LoRa, did in the end not make use of the LoRa network.

For the intelligent street lighting, the LoRa network is not required as there is a dedicated power line available, which makes the low power aspect of LoRa redundant. Regarding the smart waste management, during the procurement process a different sensor system was selected for use.

Connection to other smart solutions: There are no use cases or solutions using LoRa for connectivity thus far. The smart waste and smart street lighting solutions were originally meant to be equipped with LoRa. This will not happen due to the lack of it being a condition in the final terms of these solutions' public tenders.

Results: Smart solution not implemented.

Upscaling plans: There are no plans for upscaling in Rotterdam at this point.

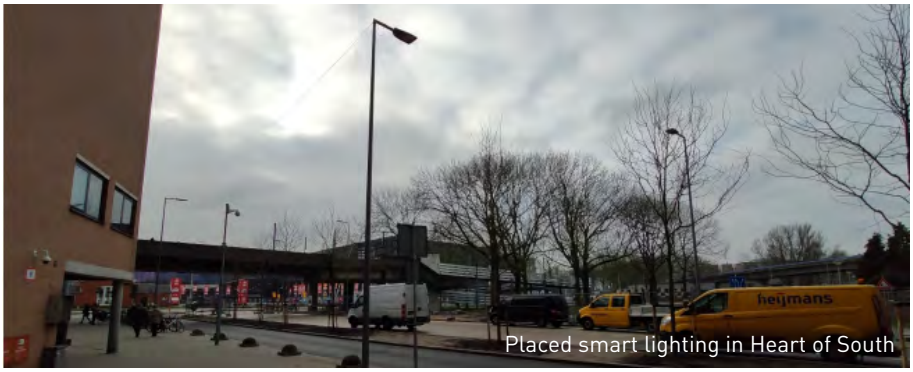
Replication Assessment: Although not installed in the 'Heart of South', there is possibility for replication. It might be a solution for smart connectivity. The LoRa system is patented. There are over 500 members of the LoRa association.

Further readings:

Full report on the LoRa process in the 'Heart of South'

SOLUTION R11: Efficient and intelligent street lighting

General description: The lamp posts being used within the 'Heart of South' retain, serve and enhance the principal obligations of street lighting (navigation, public safety). By using LED lighting, the lamp posts have lower emissions. They are connected as a network, enabling system wide control (i.e. a central management system) and the integration of sensors that have power 24/7 to enable continuous smart services.



Placed smart lighting in Heart of South

Expected impact: The expected decrease in energy consumption was 29.000 kWh per year, this would lead to an annual CO_2 reduction of 14 tons. These expectations were based on more efficient street lighting, therefore using less energy from the electricity network of the city, thus lowering the total emissions according to the emissions factor of the network.

Innovation: the innovation of smart lighting in the 'Heart of South' lies in the fact that each lamppost can be controlled separately, as well as a group of lampposts in the area at once. The lighting can be controlled remotely, so that the intensity of the lighting can be adjusted. Because all lamps are connected to a central system, it is possible to monitor for each lamp column and detect whether there are defects in a lamp.

Final implementation stage: in October 2019 the implementation of the smart lighting in the 'Heart of South' district started with six light poles. They were used as a test case, located between the swimming pool and the bus station. Currently all light poles in the area are replaced by smart fixtures based on this test case. In the meantime, a Maintenance Management System has been purchased that can monitor the data from the various telemetry systems via APIs so that the fault handling is automated. The six test case lampposts are equipped with a tele-management system and LED lights. From a distance, they can be controlled, monitored and insights on their energy use can be obtained. The energy use data can be fed into the 3D model of the digital twin to provide insight on their performance.

Connection to other smart solutions: The smart lighting feeds data into the digital twin (Solution R9). Currently only data from the city's management system for the public area can be used in the digital twin. In the future also the data from the telemetry systems can be used.

Results: The decrease in annual energy consumption is 5.992.000 kWh. This equals 6.900 ton of CO_2 equivalents savings a year. Those numbers are based on the introduction of efficient and intelligent street lighting in the whole city of Rotterdam, which is underway.

Upscaling plans: In the coming years all fixtures in Rotterdam will be replaced by LED including telemetry, in 2025 approximately 100,000 fixtures will be equipped with smart light management. Lessons from RUGGEDISED and insight from the applied technologies will be included in the plans.

Replication Assessment: As street lighting is common in most streets, this solution has excellent potential for replication. One of the requirements is a tele-management system connected to, for example, Wi-Fi or LoRa. The Fellow Cities of Parma and Brno have both included intelligent lampposts in their replication plans.

Further readings:
RUGGEDISED report on the smart lighting

SOLUTION 12: High performance servers in homes

General description: A feasibility study was conducted by Eneco and the start-up Nerdalize (partially owned by Eneco) to explore whether high performance servers in residential buildings (built by Ballast Nedam) could provide highly distributed computing power (computing facilities, data centres) while, at the same time, heating homes for free by using its excessive heat produced to reduce CO_2 emissions. The results of this innovative proposition were promising and Ballast Nedam and the municipality were enthusiastic. Unfortunately, Nerdalize declared bankruptcy in late 2018.

Innovation: Reducing CO_2 emissions by recovering heat from computing power facilities and data centres.

Final implementation stage: As Nerdalize declared bankruptcy in late 2018 this solution was not implemented.

Results: The results in terms of reducing CO_2 emissions were promising in the analysis before Nerdalize declared bankruptcy. Although Nerdalize was declared bankrupt, the development of the building continued. All buildings are net zero-energy houses.

Upscaling plans: No upscaling plans are known at the moment.

Replication Assessment: Replication of this solution is possible, although there is a prerequisite for a nearby power facility or local data centre. Recovering heat from (bigger) data centres might prove more beneficial.

SOLUTION R13: Smart Waste Management

General description: In Rotterdam, there are approximately 6,500 underground waste containers. RUGGEDISED partners equipped all the textile, paper and glass waste containers in the 'Heart of South' with a smart sensor. The so-called 'filling degree meter' in the waste container measures every hour how full the container is. Based on this information, the system determines when the container should be emptied. The routes for the drivers are included in this decision support, and are automatically generated, based on the collected data to allow for 'dynamic route planning'. All drivers are equipped with a tablet/ navigation system, which shows them the ideal route to collect the waste. This, for example, allows for planning in-time pick-up, at the moment the waste containers are approximately 75 percent filled.

Expected impact: The expected decrease in energy consumption was 315.000 kWh per year, which equals to an annual CO_2 equivalents reduction of 72 tons. These expectations were based on more efficient waste collecting and less driven kilometres, thus lowering the total emissions according to the emissions factor of the network.

Current implementation stage: The smart solution is successfully implemented in the 'Heart of South' district (and the rest of the city).

Innovation: A static waste collection turned into a smart dynamic waste collection, with efficient use of people and equipment.

Results: With the sensors in the waste containers, the City of Rotterdam contributes to a more efficient management of the waste containers and better service for the people of Rotterdam. Data is collected to better understand the savings in driven kilometres and thus CO_2 equivalents savings (both by optimised energy use as well vehicle emissions).

In quantifiable numbers, the introduction of smart waste management for the whole city of Rotterdam would sum up to a saving total of 1.017.000 kWh a year. This equals 351 ton of annual CO_2 equivalents savings. Those numbers are higher than stated in the expected impact, because the smart waste management is introduced in the whole city and not only in the southern part of the city.

Previously the total number of driven kilometres by waste collecting trucks was 883.000 a year. The most recent numbers showed that the current number of kilometres driven is 700.000. The efficient routing resulted in saving 183.000 kilometres by often heavy-duty vehicles.

The 'collecting ratio', the number of collected waste per liter fuel is increased by 21%. From 401 kg/liter diesel to 486kg per liter diesel. Moreover emissions on the go are saved as well.

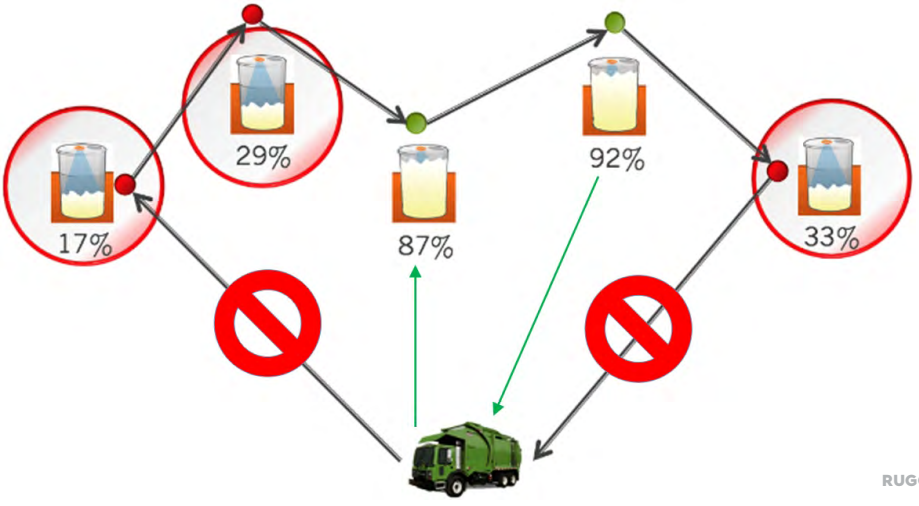
Upscaling plans: After a successful two-year test in the 'Heart of South' area, the smart waste collection system was implemented in all other parts of the city of Rotterdam. By the end of 2018, all underground waste containers in the city of Rotterdam were equipped with a smart sensor.

Lessons learnt: During the procurement process of smart waste systems, the city did not state that the use of the LoRa network was mandatory for the smart waste system. The chosen software provider uses 4G instead of LoRa, which was not foreseen by the department responsible for the smart waste containers. The desired and/or preferred network should be specified in the procurement phase.

Replication Assessment: This smart solution does have replication possibilities for cities with underground waste bins or other types of waste collection where smart sensor installation is possible. For optimal use of this system, it is necessary to monitor the amount of waste in a container or bin. The Fellow Cities of Parma and Brno have both included smart waste in their replication plans.

Driver checking his route for the day and collecting the designated bins

Schematic overview of the optimised garbage collection



Conclusions

Rotterdam's experience in RUGGEDISED has been one full of successes, but also proved to be a bumpy road full of challenges that in some aspects proved insurmountable for specific aspects of the project. At its most basic level, the project's purpose in Rotterdam was to showcase and strengthen Rotterdam as a sustainable champion on the national and European scene through the deployment of smart solutions in the 'Heart of South'. This, the project has delivered and in many ways the progress achieved in Rotterdam's Smart District will serve as a springboard for moving the rest of the city closer towards climate neutrality as part of the EU's Mission to deliver 100 climate neutral and smart cities by 2030.

At the moment the RUGGEDISED project ends, in October 2022, the Smart Thermal Grid (R1) is deployed and connected to the big venue Rotterdam Ahoy and to aquifer wells underground. Combined with the thermal energy from waste streams (R2) heat-cold pavement collector (R4), this system ensures the 'Heart of South' is capable of producing vast amounts of thermal energy locally (1.2M kWh annually expected from thermal grid alone) and without the use of fossil fuels. At the same time, moving parallel to the RUGGEDISED work, more than 15,500 square metres of solar panels have been deployed on rooftops in the area (R5) and the City of Rotterdam is moving towards a fully electric bus fleet at a pace much faster than anticipated by the original project application (R7).

At the same time, legislative hurdles, procurement complications, contractual obligations and insolvency of one of the SMEs meant these solutions rarely moved as fast as hoped, when the plans for these experimental implementations were made. It also caused specific solutions to not be (possible to be) implemented following initial analyses and attempted workarounds proving them to not be feasible in the 'Heart of South'.

In addition to the physical implementation in the 'Heart of South' already producing renewable energy locally, the city-wide work for Rotterdam's sustainability and digitalization has also benefitted from RUGGEDISED. Throughout RUGGEDISED, the City's work on its Urban Data Platform / Digital Twin (R9) has moved from being an ambitious idea to concrete plans for procuring what can be considered to be one of the most all-encompassing digital platforms for any city in Europe. The city has, parallel to the period of RUGGEDISED, added a 'digital layer' to how the city sees its role and performs its services. In addition to the traditional social layer and physical layer, this 'digital layer' will be an important aspect for supporting the green transition moving forward.

At the same time, what started as a small demonstration project in the 'Heart of South' with "Smart Waste (R13) has been rolled out city-wide and already did achieve impressive impacts, proven extremely helpful especially throughout the COVID-19 pandemic. In much the same way, albeit not directly following RUGGEDISED testing, the city of Rotterdam has moved from testing six smart lampposts in RUGGEDISED, to rolling out smart lampposts city wide.

With all these implementations, results, and complications one outcome wraps it all up: '**the importance of getting better connected and introduce so-called feedback loops**'.

Getting better connected is not an outcome from one specific RUGGEDISED solution, nor is it limited to only include RUGGEDISED partners or for that matter the local partners in Rotterdam. Rotterdam, as the Project Coordinator of RUGGEDISED has also increased its connections with other cities, supported the European efforts on smart cities in numerous ways, and they have done so while remaining focused also on the local partnerships driving chance for their citizens. From tight working groups with local implementors to ambitious local leaders, all the way through various working groups in the European sphere, RUGGEDISED's work in Rotterdam has helped push forward smart and sustainable change in cites.

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Designing smart, resilient cities for all

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RUGGEDISED was a smart city project funded under the European Union's Horizon 2020 research and innovation programme. It brought together three lighthouse cities: Rotterdam, Glasgow and Umeå and three fellow cities: Brno, Gdansk and Parma to test, implement and accelerate the smart city model across Europe. Working in partnership with businesses and research centres these six cities demonstrated how to combine ICT, e-mobility and energy solutions to design smart, resilient cities for all.

About the publication
This is the third in a series of three implementation reports from the European Smart Cities and Communities Lighthouse City of Rotterdam. It details the work Rotterdam has done through RUGGEDISED to become an even smarter and more sustainable city.

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