GREEN QUAYS

Generic model of the nature-inclusive quay construction

O4.2.1

Preface generic model nature-inclusive quay wall construcion

In Breda, the river is being daylighted and restored to its former glory. The Nieuwe Mark will again become a continuous navigable river stream, which will be an ecological water and green connection along the edge of the old city center. In the UIA GreenQuays project, the stretch between Markendaalseweg and Nieuweweg will receive new quay walls with traditional brick cladding in keeping with the historic city center. The City of Breda wants to green these walls and the quays of the Nieuwe Mark with trees, (wall) plants and mosses. The design starting point was a lushly vegetated quay wall with a rich and varied flora and fauna where trees even hang over the water at an angle from the quay. Inspired by the photo to the right.

But plants and strong low-maintenance brick-clad modern quay structures do not always go well together. Wall flora often grow only after several decades when the wall is already considerably weathered, eroded, degenerated. Plants only want to grow when there is room to root and sufficient moisture and nutrients. Importantly, enough organic material has to accumulate in holes and crevices. Mosses and algae will grow on mortar joints that have become less alkaline over time. Modern quay wall construction is made with steel sheet piling, is no longer porous and the lining surface therefore is far too dry for wall plants to flourish. Trees growing through the quay walls can severely disrupt them. Solutions to these dilemmas have been found in GreenQuays.

This is the generic model of the developed nature-inclusive quay wall construction. Generic because we want to show how we tried to reconcile the contradiction of natural plant growth and structural consistency and strength to help others develop similar nature-inclusive quay structures in other cities. But also particularly local: because the cladding with brick is typical for aesthetically adjustment to the brickwork of historic Dutch towns. What we have done is to give this beautiful but otherwise “useless” lining an urban ecological function. This brochure shows the dilemmas, considerations and choices we made for the construction in different project phases. The other brochures explain ecological design, climate adjusted design and nature-inclusive participatory urban development.

The New Mark will once again become a navigable river. First at 1 the river will be deepened and connected to the Nieuwe Haven. Here the river will have brick quays and stairs at different heights, connecting to the oldest city center. At 2, the river is re-excavated and provided with green natural banks that connect to Seelig Park.

The quay walls completed within the "Real Life Verification" phase of GreenQuays are located within the red circle. This was also the location for the test setup of the 'Small Scale Pilot'.

The development phases of the GreenQuays project

The development can be divided into three research phases. In the laboratory phase, research was conducted at the material and element level. In the Small Scale Pilot phase, test setups were made on site in the existing shallow water basin. In the Real Life Verification phase, a few hundred meters of river embankments were actually constructed and will be monitored over the next few years to see how nature develops here.

Preliminary Design and Laboratory Phase

The preliminary design for the plan area was completed before GreenQuays. There will be high quays with low terraces just above the ordinary water level, and the ground retaining quay structure will consist of a steel sheet pile wall with a brick lining at a 5-degree slope. The brick is placed on a z-shaped concrete apron suspended over the sheet piling. This has become a common construction in the Netherlands to match the image of the monumental historical inner city with apparent brick quays.

The plan contains a number of elements that were the starting point for the GreenQuays research. Important elements in the plan are:

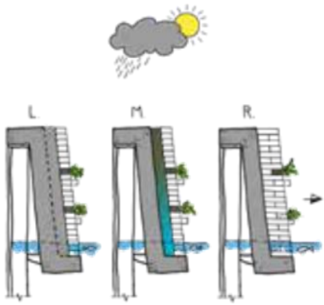
- trees growing sideways from the quay walls over the water, from a growth space between sheet piling and concrete apron
- brick-clad quay walls witha robust and diverse population of wall plants
- nesting and hiding places for birds, fish and insects
- water misting to cool on extremely hot days

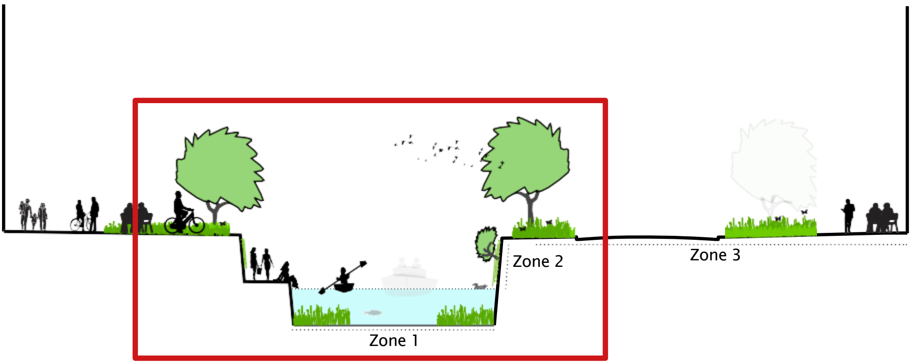
impression of preliminary design with trees growing sideways out of the quay walls and with a brick lining overgrown with wall plants and ferns

phase 1.
laboratory
research

phase 2.
small scale
pilot

phase 3.
real life
verification





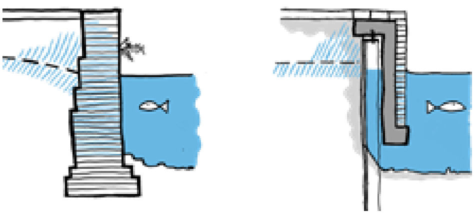
Within this generic description of the quay walls, the focus is on where zones 1 and 2 meet - the area both above and below water of the quay walls.

Dilemmas

With the GreenQuays project in Breda, there are various aspects that sometimes conflict with each other and between which a compromise must then be found. These include ecology versus recreation, nature-inclusiveness in relation to structural strength and maintenance, the (im)possibilities of the existing built environment, construction costs, construction time, etc. Here is a small overview of questions and dilemmas.

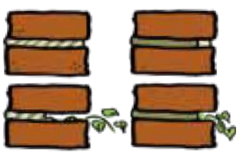
Nature or park? Should urban green space function ecologically or be beautiful for urban enjoyment? See the booklet Ecological Design.

Recreation and ecology?
Will recreational boating of the river soon harm plants and animals? See the Ecological Design booklet.



In a traditional quay wall, the brick itself is in contact with the soil and therefore remains damp. With a lining wall for a steel sheet pile wall, it does not. What provisions are needed for the growth of wall plants?

Rainwater alone is not enough. The brick buffers, but hardly draws water upwards. Is capillary substrate needed to suck up river water to keep the brick lining permanently moist?

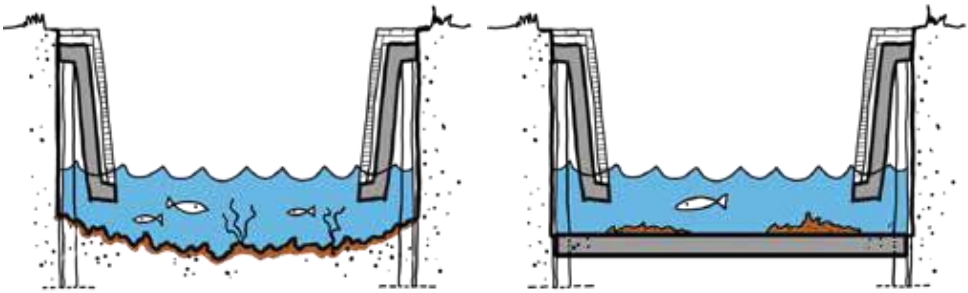


Should the structural joint between the brick itself be bioreceptive or can it be limited to just a plant-friendly pointing joint?

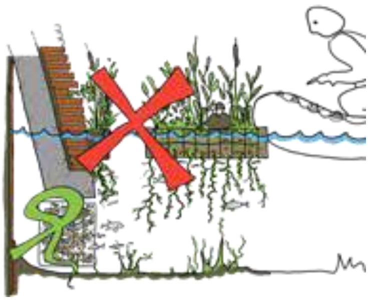
Should plant seeds and spores naturally colonize or is it okay for humans to give the quay wall a hand?

Bioreceptive and/or low maintenance?
What is the balance between erosion and degeneration desired for plant growth in relation to strength and maintenance costs?

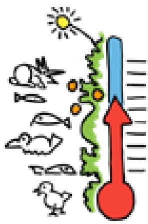
How will the design's diagonally growing trees from the embankment wall be prevented from disrupting the masonry lining?



Can the new river have a natural bottom or is a concrete floor necessary because of the foundation of quay walls and close-by existing buildings?



Are ecological features such as vegetated floats, fenders or gabion baskets possible or will the river no longer be safe for water recreationists?



Climate change?
Does a nature-inclusive quay for contemparary local plants and animals neglect possible new species of a future climate?

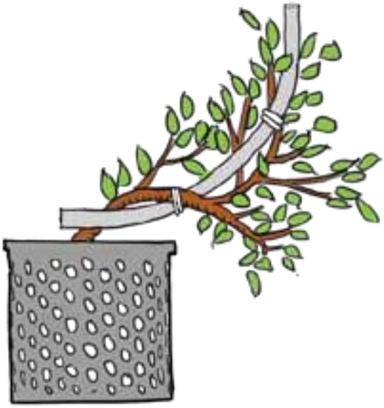
Laboratory phase - trees growing diagonally from the quay

An eye-catching element in the design are the trees growing sideways out of the quay wall, which will allow downtown recreationists and residents to experience the area's new flowing water connection as much greener and more natural. The quay wall trees, along with the green vegetated quay wall, play an important role in this. In the laboratory phase of GreenQuays the most suitable trees and shrubs for this were investigated.

In the tree nursery of Gebr. Van den Berk, trees and shrubs were tested for this growth habit by growing them up in the limited growing space of a round 'airpot' with a diameter and height of 40 cm. The limited growing space and holes in the airpot wall make the trees not developing long roots but rather a dense root ball with many fine hair roots. The trees receive 4 liters of water per day. The stem of the plants is guided at right angles out of the pot along a round galvanized steel tube to form the plant in the shape they have to grow through the holes in the quay wall.

The test shows that Field Maple (Acer campestra), Grey Willow (Salix cinerea) and Fluttering Elm (Ulmus laevis) do well. Butterfly-bush (Buddleja davidii) is also doing well. The Silver Birch (Betula pendula) is not doing well under these conditions and the Black Alder (Alnus glutinosa) is suffering from stem burn. A contributing factor may have been that the plants were placed in the airpot too late and had too little branching at the base of the trunk.

Further reading: UIA GreenQuays D4.3.2 Report on lab tests on NIQ techniques linked to trees



In the nursery, the trees were raised on airpot where the plant was guided horizontally for a growth form sideways from the quay wall.

Acer campestre

Alnus glutinosa

Buddleja davidii

Salix cinerea

Ulmus leavis

Betula pendula

Small Scale Pilot - quay wall trees

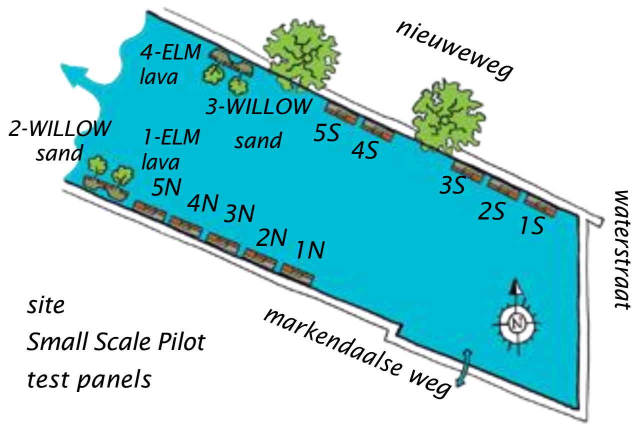
For both vegetated quay walls and trees growing out of quay walls, the question is how orientation affects plant development. For the Small Scale Pilot, at the Nieuweweg-Waterstraat-Markendaalseweg location, test panels were placed in the water on both sides.

The growing site for the trees in the Small Scale Pilot is a steel box structure with two chambers formed on the bank side by corrugated sheet piling to which a steel box structure is welded on the water side, with the trees growing through circular portholes. Elm on the left, willow on the right. A corner profile is welded to this box structure on which underwater brick cladding is placed. The containers are placed on the river bottom. On the north side the water is deeper and the test panel has a height of 3.26m - on the south side 2.66m. At the top there is an opening for test equipment that measures oxygen and moisture of the soil.

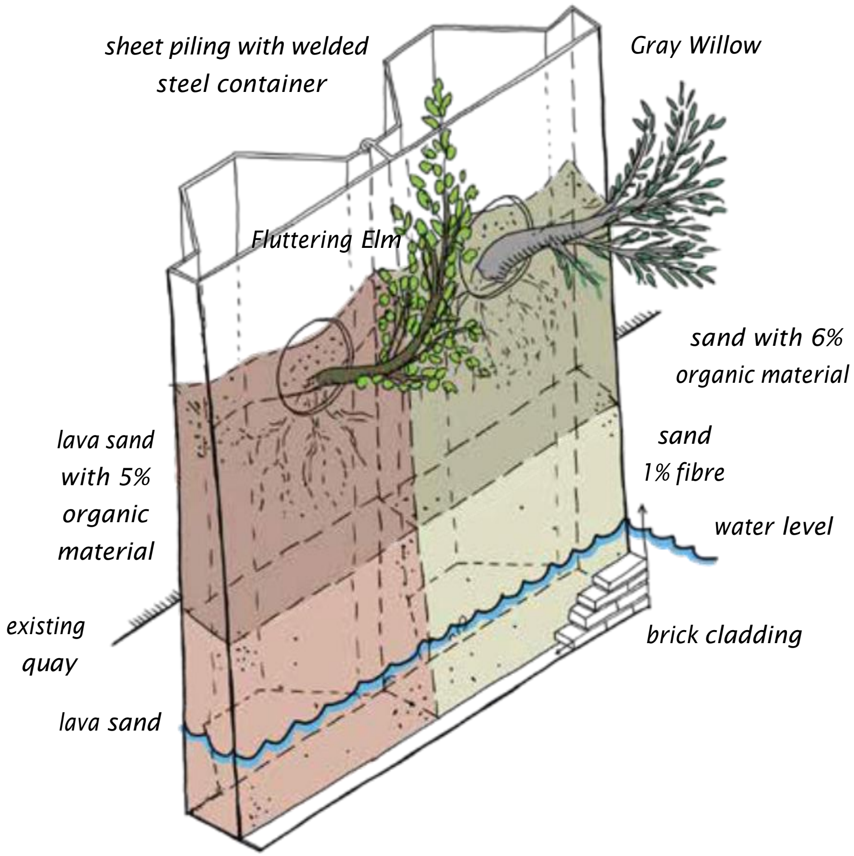
A different substrate combination was tested at the left and right chambers of both test panels. The substrate in the elm test chambers consists of a subsoil of lava sand with no organic matter to prevent oxygen depletion and the production of oxygen expelling methane gas unfavorable to trees. However, 1% capillary fiber is added. The top substrate contains 5% organic material in addition to lava sand.
In the willow test tanks, sand of average grain size of about 0.3 mm was used, to which a fraction of perlite and natural lava fiber was added. The top substrate here consists of the same sand base, but now supplemented with 6% organic material.

At three different heights, both moisture and oxygen levels were monitored in each of the four test tanks. The lava mixture has a somewhat higher moisture content than the sand mixture. At the bottom around 38%, at the top 28%. In both mixtures, the oxygen content is around 20% and thus at the desired level.

Fearther reading: UIA GreemQuays D4.4.1 Work plan for small-scale pilot testing & D 4.4.2 design part trees
UIA GreenQuays rapport O4.4.1 Evaluation of SSP



The Small Scale Pilot test set-up for trees from the quay walls and for vegetated masonry is at the GreenQuays site itself, where a shallow pond had already previously been created, which will be excavated for the Real Life Verification phase into the streaming New Mark River.



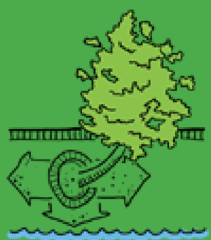
Small Scale Pilot - monitoring of quay wall trees

At the start, the trees took some time to get used to their new growing location. During this adjustment period of three months, the trees were watered extra, which was also necessary for the capillary action of the substrate. At first there was a lot of leaf loss, but eventually both the elms and willows regained full leaves and the trees made a healthy impression.

In the end, the lava mixture for the elms showed a slightly higher moisture content than the sand mixture for the willows. With the sand mixture, there was a difference in the water-holding capacity on the north and south sides. On the south side, i.e. on the Markendaalseweg, the top measuring point in the sand mixture showed a moisture content of 19%, while on the other side, where the willow is right facing south, with 26% it was actually more moist at the top. Therefore, the lava mixture was chosen for Real Life Verification.

If only one-year-old trees are planted, they will form more naturally: three- or four-year-old trees have the advantage that the shape can be determined more precisely in advance. However, the trees must be guided and anchored against the wind for a longer period of time. The accessibility of the container via a removable railing is highly recommended for maintenance work on the tree. Van den Berk Nurseries would also like to add additional aeration holes for the trees in here. However, the design was guided by the image of a continuous brick frame edge. This means that all access to the tree's growing site and root ball will have to take place through the porthole.

Further reading: UIA GreenQuays rapport O4.4.1 Evaluation of SSP



The maximum size of the trees will be determined by the constraints of the growing site. In the Small Scale Pilot, each tree had its own container. However, for the Real Life Verification, adjacent tree bins will be connected.

For accessibility to the tree box, it would be preferable if the lid gap could be opened on the quay edge. However, a robust continuous brick rowlock edge was chosen in the design.

Above: The tree boxes are placed. A guiding structure ensures that the Fluttering Elm (left) and the Gray Willow (right) continue to grow into the desired shape for a while and are secured from the wind.

Below: The result after two years. Left on Markendaalseweg, right on Nieuweweg.

Which brick-mortar combination is sufficiently strong and most bioreceptive for a quay wall overgrown with wall plants? This was investigated by selecting bricks and mortars for an growth test and, on from there, choosing the best combination for mechanical testing of composite masonry.

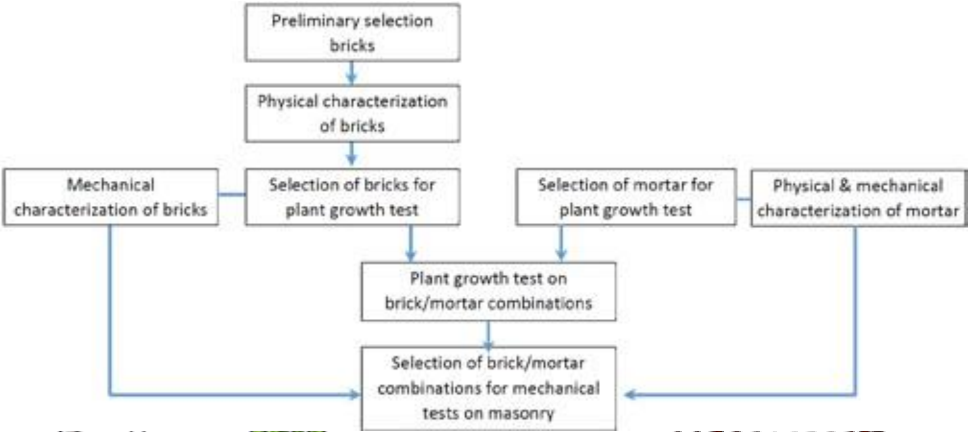
Laboratory phase - the brick

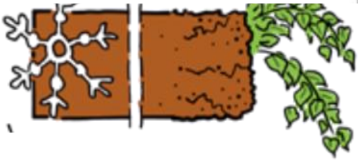
Wall plants seem to grow on quay walls mainly in old joints and in crevices and holes and never on the brick itself. Still, we wanted to know if the brick type was also an influence. A brick itself is capable of absorbing a little water. This water can be used by the wall plants. However, the question is whether brick is also capable of retaining rainwater for a longer period of time and sucking the water up high from the canal via capillary action. How high a brick sucks up water depends on the width of the capillary channels of pores that are interconnected. In most bricks, these are both large and small pores and capillary suction is limited. With a mixture of small and large cavities, the holes on the surface fill with water from the brick over and over again. This seems beneficial for plant growth; however, it is actually bad for frost resistance because brick with holes completely filled with water is more likely to get damaged. Traditional Dutch handform brick is often quite frost-resistant despite its high water absorption because the large pores never get completely filled.
The water absorption and strength of a range of bricks were tested. The final brick choice in the design for the quays was not determined by these tests alone. For the biological receptivity test in which the brick buffered water for plant seeds in the joint, two extremes were used: both a hand-shaped brick favorable for plant growth with much and prolonged continuous absorption and, on the contrary, a relatively hard and dense brick with much less water absorption. Indeed, most seed germination occurred on joints between the water-absorbing brick.

Laboratory phase - the structural joint

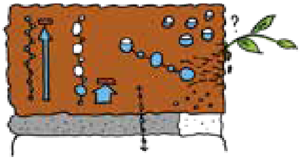
A large number of basic combinations of different “binders” and “aggregates” were made for the mortar in various proportions. Mortar compositions were also made in which some compost or compost water was mixed into the mortar. A precast base mortar was also included for comparison. Of these combinations, 4x4x16 beams were made and tested for compressive and flexural strength, on acidity and for carbonation after 28 days. The water absorption of the mortar samples was also measured.
Not all compositions were useful for the follow-up. For example, adding compost or using only vermiculite without finer sand directly resulted in the mortar becoming much too weak.

Further reading: UIA GreenQuays preliminary rapport D0.0.0





Pore size and distribution that is favorable for plant growth is often unfavorable for frost resistance.



Only channels of fine pores increase capillary pressure. Many large pores increase absorption capacity. With connected large and small pores, the small ones always fill completely with water.

Laboratory phase - bioreceptivity of brick and mortar joint

Based on the properties of brick and mortar, a selection of combination walls of two bricks each with a mortar joint in between and mortar on top was made. Seeds were mixed into the mortar. These little walls were placed in a covered outdoor area and periodically watered and monitored for a year. The germination of the seeds and outgrowth of the plants was considered an initial indication of bioreceptivity.

Some samples were coated with a diluted yogurt mixture as a nutrient for the formation of a thin biofilm. Unfortunately, this yielded mostly fungal growth in practice. Other samples were coated with a highly diluted phosphoric acid. The purpose of this was to speed up the mortar surface becoming less alkaline over time.

The test showed that it was mainly test walls with the water-absorbing brick that showed germination. This usually involved a mortar that had air lime with trass (AT) as a binder. The lowest binder/aggregate ratio of 1:4 scored best here. Some seeds also germinated in a single mortar with natural hydraulic lime.

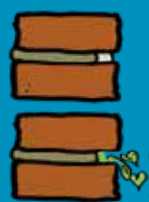
After the standardized 28 days, only mortar samples with a combination of natural hydraulic lime with cement had really high strength. Use of only NHL (with a little seed germination) also produced a mortar that was still sufficiently strong. The growth favorite, air lime with trass seemed acceptable for the mechanical masonry test only in a binder/aggregate ratio of 1:2.

Further reading: UIA GreenQuays preliminary rapport D0.0.0

only weak bedding mortar

The rediscovery of the pointing mortar

The Netherlands has a tradition masonry with pointing mortar. The structural mortar is then scraped out a few centimeters and provided with a tightly cut decorative joint. During the tests, the idea arose that this decorative joint could be the solution to the low strength. Thus, a bioreceptive joint could be created for the plant that could degenerate or gradually be replaced by organic material without compromising the structural strength of the quay wall cladding. In the worst case, the wall is repointed during major maintenance. The most bioreceptive but weak joint ATst4 became our first candidate for such a pointing.



bedding mortar with weak pointing mortar for plants

Above shows that mortar of air lime (A) with trass (T) and standardized sand in a 1:4 ratio, covered with highly diluted phosphoric acid was one of the most successful combinations for seed germination. However, as a structural mortar, this combination was rather weak. Shown below is a large number of test walls after being watered for several months.

Laboratory phase - masonry, strength of combination

The strength of the bond of the bricks plays a major role in absorbing wind loads on the quay wall and in withstanding collision by a boat. In the cavity situation, the brick cladding sheet of brick transfers these forces through the cavity anchors to the supporting structure behind. To do this, it is important that the sheet is strong and rigid enough and that the cavity anchors do not get torn out of the joint.

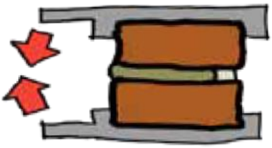
Using a bastard mortar of cement and NHL lime as a reference and a number of more bioreceptive mortars (based on only NHL lime or consisting of air lime with trass) and two different types of brick, this was tested. The first test involved a flexural adhesion test (bond wrench), the second a cavity anchor pull-out test.

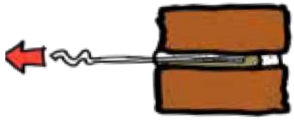
For the laboratory brick with a frog - that is, a dimple in the top surface - bonding was stronger than for a comparable hand-shaped brick. Only application of NHL lime as a binder was found to be as strong in the adhesion test as the "bastard mortar" that also had cement mixed in. (Cement allows for faster brick laying.) In both series of anchor pull tests, it was first and foremost the anchor that became completely deformed before being pulled out. The application of a post pointing mortar joint of weak mortar had little to no effect on strength. With advancing insight and additional research into literature and reference projects, another "best guess" structural variation was devised based on the laboratory experiments. Also, the possibility now presented itself of developing a super bioreceptive post mortar, in which structural strength would play no role whatsoever.

Capillary substrate in a cavity

Water suction from the river only through the brick would probably occur only to a very low height. To achieve high suction up to 1.5 meters, a variant with capillary substrate in the cavity seemed much more promising. In the Groene Kademuren Houthaven project in Amsterdam, cavities filled with different substrates were applied, monitored with moisture sensors and compared. However, this was a trial with plants potted between basalt bricks and not an overgrown masonry cladding. BVB Substrates' ACCAP 7120+ substrate seemed to be the most successful after a year of monitoring and was therefore chosen by GreenQuays in Breda. The material consists of soil with coconut fibers bound with a biological binder. It is important that the material is poured into the cavity at once as wet mud in order to have always some fibers in the vertical direction everywhere.

See also: 18.T0583 Ontwikkeling groene kademuren Houthaven Amsterdam 24-06-2019





Two mechanical tests were performed on composite "couplets" of bricks with selected mortar joints: a brick-mortar bond wrench test and a wall tie pull-out test. These test gave an indication of the strength of brick cladding wall. The influence of working with a structurally very weak pointing mortar was also examined.

Laboratory phase - masonry: the choice of a pointing mortar

Working with an air lime-tras only as a pointing mortar provided an idea for new variants. If no strength was required, a special post applied pointing joint could be developed. That pointing mortar would only need to have sufficient cohesion to suffice as a bioreceptive soil for plant growth for long enough until this joint was replaced by collected organic material, For the Small Scale Pilot it was decided to do use the best planth growth mortar form the laboratory phase and supplement this with another promising pointing mortare consistting of clay and a small amount of lime as a binder and barley straw as “reinforcement” for the strongly shrinking clay. An experiment was done in which different compositions were placed in sun and rain to see how quickly they eroded. Because the amount of NHL lime most affects the alkalinity of the mixture, the goal was to create a mix with as little lime as possible. After a three-month outdoor erosion trial, an extra pointing mortar based on a binder of NHL lime and clay (1:3) and agregate of sand and vermiculite (2:2) was chosen.

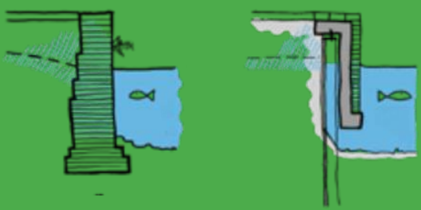
The panels of the Small Scale Pilot had the following mortar compositions:

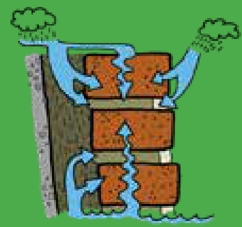
- panel 1: MMmK - structural mortar only: reference mortar MMmK
- panel 2: Hst2 - single structural mortar NHL lime with 2 parts standardized sand
- panel 3: HT2 - only structural mortar lime (55/45%) and 2 parts sand with vermiculite in it (90/10%)
- panel 4: HCst2 & ATst2 - structural bastard mortar of NHL lime and cement, scratched out and filled with 2 cm of pointing morrtar of air lime and tras with 2 parts sand.
- panel 5: HCst2 & HKstvb - structural bastard mortar of NHL lime and cement, scratched out and filled with 2 cm of pointing mortar with a binder of NHL lime and clay (1:3) and agre

Samples of bioreceptive 'fantasy pointing mortar' of different composition were exposed to sun, rain and wind for three months. The sample with the least lime that still had just enough cohesion was used for test panels 5South and 5North. The photo below shows the overgrowth on that seam mortar in the Small Scale Pilot after six months (late October 2020).

Small Scale Pilot - design of masonry testpanels

How do we keep the brick cladding wall moist? Where old brick masonry quay walls are in direct contact with the ground and ground-water, today's cladding structure is separated from it by a steel sheet pile wall and a concrete suspension structure.





The lining on a concrete apron with a half-stone length of thick brick usually remains too dry for lush plant growth. The brick itself is unable to soak up water very high, the porous brick does absorb and buffer some rainwater. In reference embankment projects, capillary substrate had been applied before, but never directly compared to different constructions like with thicker masonry. In the Small Scale Pilot, all panels with different mortar combinations were divided into three vertical strips that do not exchange water between them [6]. On the left half-stone masonry 10cm thick, in the middle half-stone with about 12 centimeters of capillary substrate behind it and on the right full stone masonry 21 cm thick.

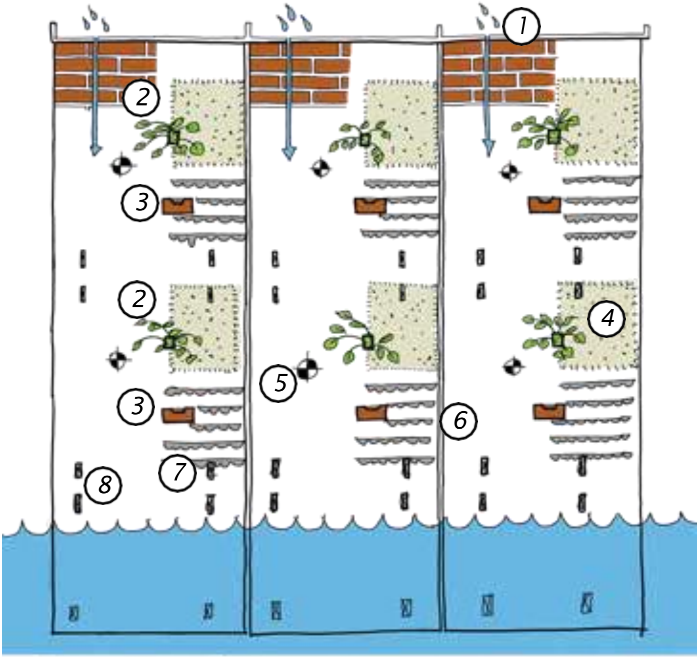
The surface checkerboard

Various experiments were conducted on the approximately 65-cm-wide strips of masonry at different heights. Rainwater that collected on the cover flowed concentrated in one spot over the wall surface [1]. Seeds of wallflower and wall snapdragon were glued on the joints with an adhesive of maisena. At 70 and 160cm from the water surface, small plugs of wallflower and trailing bellflower were planted in a gap of a quarter stone [2]. At about 50 and 140cm from the water surface there were protruding stones with a frog [3]. Pieces were covered with a yogurt-moss mixture to stimulate moss growth [4]. There are also pieces with protruding mortar beds where the mortar 'beards' had not been not been brushed away[7]. At different heights there are open butt joints [8]. One panel has TDR sensors at different heights, capable of measuring mortar moisture independently of salinity. In March 2020, the panels were erected at masonry company Van Leijden in Roelofarendsveen and hung in the water at the Small Scale Pilot site in April. They were monitored until May 2022.

Further reading: UIA GreenQuays D4.4.1 en D 4.4.2 TUD SSP Workplan

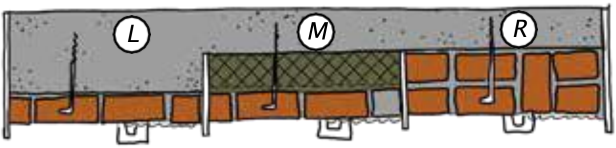
UIA GreenQuays D4.4.2 pointing morter selection annex to D4.4.1 and D4.4.2

UIA GreenQuays rapport D4.3.2



1. rainwater on cover runs concentrated over wall surface; interplanted wall flower and creeping bellflower;
2. locally a brick protrudes with frog container facing up;
3. part covered with yogurt-moss mixture
4. moisture sensors;
5. partition sheet between vertical panel strips;
6. rough protruding mortar counters;
7. open butt joints in masonry

water



L. 10 cm brick
M. + 120 mm substrate
R. 21 cm brick

Small Scale Pilot - monitoring of masonry panels

During the two years of the trial, no structural mortar damage was observed in any of the panels. What became clear very quickly was that capillary substrate behind the masonry was very important in keeping the wall surface moist. Drill samples of the joints at different heights showed this. It was very evident with the survival of Creeping Bellflower and Wall Snapdragon potted in the recesses, but also visible with Wall Flower and Wall Snapdragon germinated from seeds on the joints. On most panels, the survival of those seedlings on the mortar was sparse and mainly limited to open butt joints and crevices. At the junction between brick and the moisture-separating boards between strips, plants often still grew best. With the traditional mortar compositions, most plant growth was on the center strip of panel 4 with the weak grout of 1 part air lime and trass and 4 parts sand. However, everything was far surpassed by panel number 5. With that bioreceptive pointing mortar of lime, clay, sand, vermiculite and straw, the seedlings did so well that it becomes very visible how the different wall construction and height in relation to the water level affects the outgrowth of plants: see the photo below.

Later it also became clear that masonry can also be too moist, leaving too little space for oxygen which plant roots also need. On the middle strip, Wallflowers appeared to disappear again on the bottom 50 centimeters. A follow-up project Delft Quay Wall Garden showed very clearly that different species maintain themselves at different heights: At 1 meter above the water especially the Wallflower, at 50 centimeters precisely the moisture-loving Wall Snapdragon.

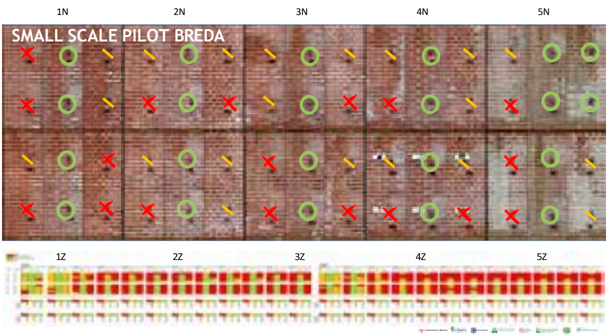
Further reading: UIA GreenQuays D6.2.8 Monitoring van materiaal- en structuurgedrag

UIA GreenQuays D6.2.3_Monitoring planten small scale kademuren

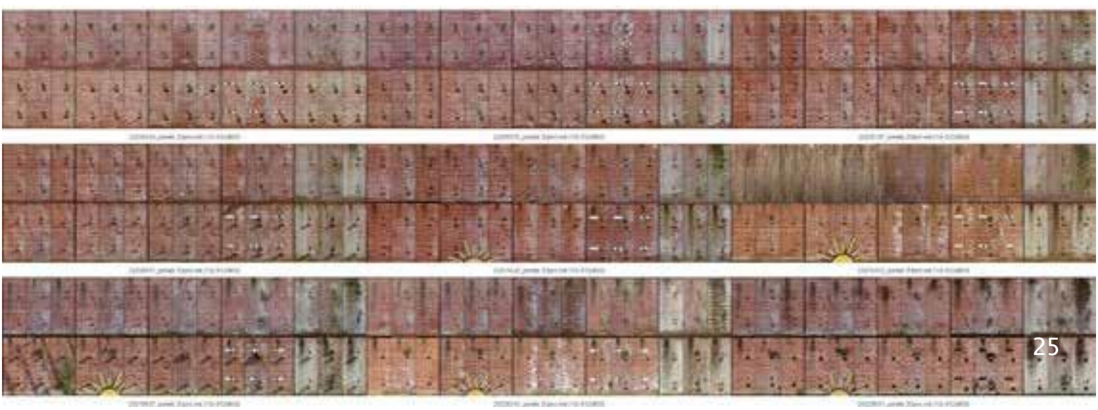
UIA GreenQuays D4.2.2 & D4.2.3 specification construction materials and structural layout

UIA GreenQuays rapport D4.3.2

Vegetation on the most bioreceptive post-joint on top and bottom of panel 5N. It can be clearly seen that there is the most plant growth on the middle strip behind which there is capillary substrate wetting the joint surface. Next, the right panel of stone brick does better than the left panel with only a half-brick cladding.



Monitoring the Small Scale Pilot pilot panels.
Above: the arrangement between Markendaalse Weg and Nieuweweg.
Left: monitoring of the potted plants
Below: normalized photos of vegetation on the test panels from April 2020 to June 2022



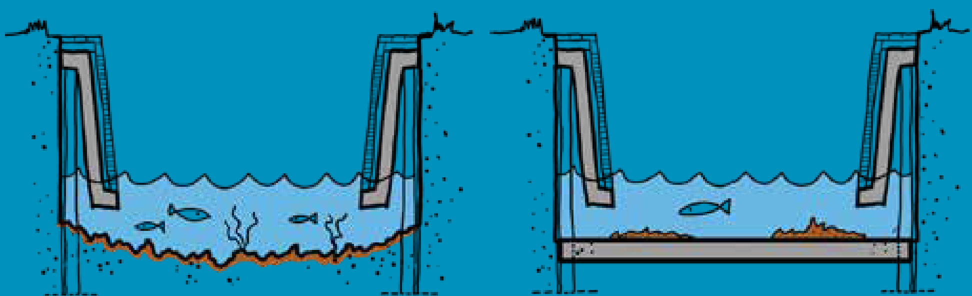
Spatial structures underwater - aquatic plants, rocks, dead wood - are of great importance to fish. They use these to shelter among, search for food and reproduce. Aquatic and riparian plants naturally provide this structure underwater. Because the New Mark will also have an important recreational function, which means, among other things, that it must be navigable, aquatic plants are not desirable everywhere.

Further reading: UIA GreenquaysD.6.2.4. (Nulmonitoring biodiversiteit RLP Nieuwe Mark).

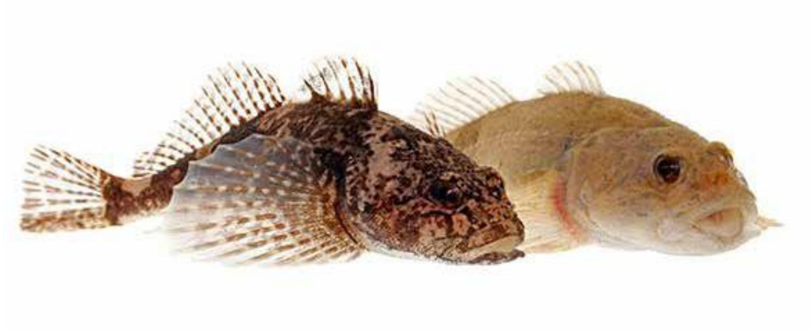
Research into the distribution of fish in the project area and potential source areas from which fish could later colonize the Nieuwe Mark also showed that underwater structures are important for fish. Three types of water were compared: inner-city quay walls without aquatic plants, canals with sheltered banks and aquatic plants and natural banks with a lot of structure in the form of overhanging trees, shrubs and aquatic and riparian plants. In the canals and waters with natural banks, not only were more different fish species caught, but often in higher numbers.

Because of the limited space for aquatic plants, the literature searched for other options for providing structure underwater. The application of floating green structures (rafts), open concrete structures (reef baskets or reef balls) and the introduction of dead wood emerged as potentially promising. From a practical (navigability and safety) and aesthetic (the floating rafts look messy) point of view, the rafts were discarded. The installation of gabions containing substrate under the quay walls proved the most promising.

Further reading: UIA GreenQuays D.4.1.3 (Ecologische randvoorwaarden vissen)
UIA GreenQuays rapport D4.3.2



For nature, a natural soil would have been preferable. But due to structural constraints of the site in combination with nearby buildings, it was not possible to anchor the earth retaining embankment walls only on the shore side, and a concrete bottom holding the walls apart was still necessary.



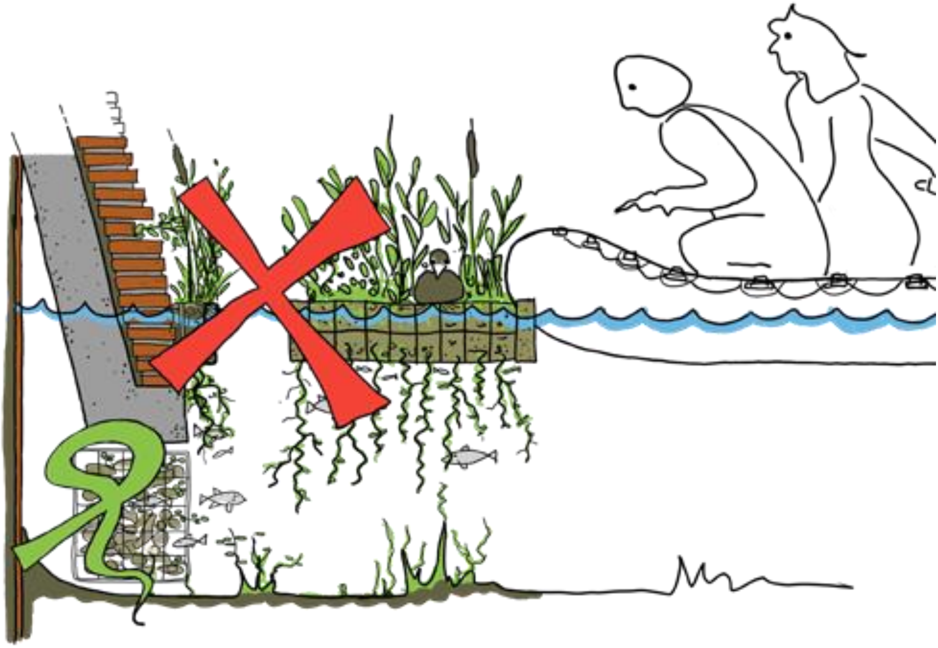
Above: The bullhead is an important target species for the New Mark
Below: Roach with shelter by dead wood and in the river

Small Scale Pilot - artificial shelter for fish

The gabions will soon be installed under the new quay walls. These quay walls do not extend to the water bottom. There is space available under the concrete aprons (about 1 meter high and 40 cm deep) which in principle can be used for the installation of gabions. Because this space is under the quay wall, the gabions do not form an obstacle for boats. Wood was chosen as filling for the gabions. This is because the Mark, as a lowland stream, naturally contains little stone and because it is known that exotic gobies, which also occur in the Mark, flourish on stony substrate. The preliminary study of the ecological boundary conditions also revealed that the target species (young bindweed, bullhead and eel) all use wood for shelter.

To investigate the effect of the gabions filled with wood, a Small Scale Pilot was conducted in which 20 gabions (50x50x200cm) were suspended along a bank lined with sheet piling along the Mark River. The gabions were fitted with different volumes of wood. The gabions were installed in May 2022 and have since been monitored Five fish species have now been found in the gabions, namely: perch, roach, bream, predatory bleak and bindweed. Moreover, more fish were caught near the gabions than along quay walls where gabions were not installed. The duration of the study is still too short to make statements about the desired wood volumes. It is expected that over time the wood will slowly decay, become overgrown with algae and colonized by macrofauna. These algae and macrofauna in turn serve as food for the fish.

Further reading: UIA Greenquays D.4.4.1.Werkplan small scale proefopzet schanskorven



Floating rafts or reeds and other plants behind riser beams are not desirable, but under the embankment wall, however, there is room for gabions filled with them as fish shelter.
Below and left: gabions and set-up for Small Scale Pilot in the flowing river Mark at the location of the Markkade near city park 't Zoet in Breda.

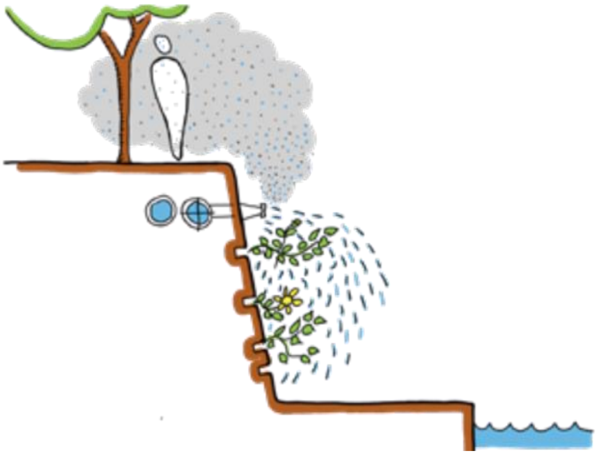
Water misting

Simulation by Wageningen University & Research in the modeling software ENVI-met has shown that the immediate surroundings of narrow canals and rivers can be made cooler by creating more shade with trees, applying natural ventilation and fountains or water mists. Through a Research Through Design process, two virtually alternative design scenarios were explored. These new designs did not replace the preliminary design developed by Breda City Council - they formed parallel variants from which a climate-responsive strategy could be drawn, based on application of the REALCOOL prototypes and the New Mark project. With the design variants with REALCOOL alternatives were tested in terms of shade (significantly more shade with trees near the water), ventilation (allowing air to flow as unobstructed as possible), water evaporation (introducing water fountains and mists close to people), water accessibility (promoting proximity to water and people) were investigated. The effect of long-wave radiation and water infiltration at ground level and on the facades of buildings along the New Mark was also considered. The first alternative scenario examined the on-site effect on a typical heat wave day; the second focused on the wider natural network in surrounding streets.

This modeling revealed that water misting can reduce heat stress on the wharf on heat wave days. With a prevailing southwest wind direction, it was decided to incorporate the nozzles of this misting system into the quay wall so that the upward directed mist will be blown over the adjacent street. By also aiming the nozzle partly at the quay wall, the system also functions as a backup on extremely hot and dry days for wetting the quay wall for the wall plants.
The testing of this has only taken place on a small scale and has not yet been tried on site for an extended period of time.

The dilemma of climate change is whether local species will remain. Water misting reduces the pressure on local species to migrate to cooler regions. Also, favorable growth sites for wall plants have been created precisely on the more damaged southwest side.

Further reading: UIA GreenQuays D5.2.2 Climate responisve design strategy



The principle of water misting on extreme heat wave days, with additional nozzles directed so that wall plants are also additionally wetted. Below the test setup in the laboratory phase.

Real Life Verification - an outlook

At the time of writing, the quay walls of GreenQuays are being built. The ecological results cannot actually be expected immediately when this part of the New Mark is completed, but only when the entire stretch is realized and the New Mark has once again become a flowing river.

Clearly visible are the earth retaining steel sheet pile walls. Unlike in the Small Scale Pilot, the concrete aprons are not prefabricated, but a molding form is constructed shuttered and the concrete then casted on site. On the left one sees the lowered quay of the Nieuweweg, which, when the river soon returns to real flow, will very occasionally get flooded. On the right, the welded tree containers are visible where trees will soon grow horizontally through round portholes through the masonry. At the head, where the Nieuwe Mark will later be extended, a few test panels of the Small Scale Pilot are still touching the water behind the sheet piling.

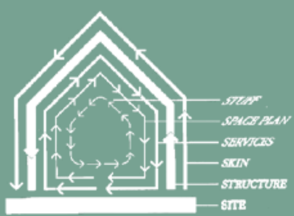
Above: Principle section of the low quay that will flood several times a year during heavy rainfall.
Below: Construction of the GreenQuays Real Life Verification - part of the Nieuwe Mark, April 2023.

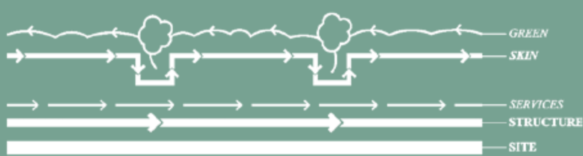
GreenQuays lessons and strategy

There is much to be learned from the GreenQuays project. For example, on how to reconcile structural strength and safety with bioreceptivity.

The context is important: some design choices for the New Mark design transcend GreenQuays research. For example, the structure with steel sheet pile walls with suspended brick-clad concrete aprons attached to them was already decided upon, and the local situation required that a concrete river bottom had to be constructed to anchor the quay walls. The exposed brick cladding in this situation is essentially cosmetic and used primarily for complying to the historical city image. But within that context, additional nature-inclusive functionality for brick cladding is a logical improvement. Thanks to the research, capillary substrate is applied in the cavity. The stone masonry in a header bond has been given plenty of set-back relief and there is an extra-wide joint with a plant-friendly pointing mortar. The trees growing diagonally from the quay also provide additional shade on the surface of the gently sloping, stepped quay wall. The results of the study will feed into the design of the remaining Nieuwe Mark section.

One of the main conclusions is that it makes sense to use that layered structure as a starting point, with nature-inclusiveness being part of the outer ecological shell. Following Stewart Brand's model, this is then a layer that can have different lifespans, or that changes relatively quickly over time. A strong example is of course the pre-hung tree containers, but also application of the pointing mortar joint in masonry, which is bioreceptive, but whose degradation does not compromise the construction of the outer sheet.





Colophon:

This generic description of quay wall construction was written based on our experiences within the UIA GreenQuays project.

Images:

Gemeente Breda
TU Delft
Ravon
Ton van Beek

This guide was written by:

Koen Mulder (TU Delft)
Edwin Dijkhuis (Ravon)
Jeroen den Brok (Van den Berk)
Ton van Beek (BLASt)
Joost Barendrecht (Natuurplein de Baronie)
Roel Klei (Gemeente Breda)

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Gemeente Breda

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