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Intelligent Glass Solutions

Autumn 2015

MARKTHAL – A CARNIVAL OF LAVISH COLOUR IN ROTTERDAM

Complex geometry façades with cold bent glass pt.2

ZAHA'S STYLISH FREEFORM GLASS FAÇADE IN OXFORD

Digital Printing, stars of the screen

INTELLIGENT GLASS SOLUTIONS

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A new interactive domestic hub has been designed and constructed in Rotterdam where local people can live, work, shop and play. Could this innovative multi-functional structure be the model template for densely congested cities around the world?

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Summary

Markthal is part of the new inner city heart of the Laurens Quarter, the original pre-war centre of Rotterdam. The building is a sustainable combination of food, leisure, living and parking, all fully integrated to enhance and make the most of the synergetic possibilities of the different functions. The hall is formed from an arch of privately developed apartments, strategically allowing private investment and initiative to provide a public space. The result is a covered square which acts as a central market hall during the day and, after closing hours remains lively due to restaurants on its first floor. With a total surface of 95.000 m^2, it comprises 96 fresh food stalls and shop units, 20 retail units, restaurants, cafés, a supermarket, an underground parking garage and 228 apartments. The underground car park has a total of 1.200 parking lots. Markthal is an energy efficient building and has been awarded a BREEAM very good rating.

Urban transformation

Markthal is built at a historic site. Around the year 1270, the first settlers built a dam at the river Rotte, from where the city expanded. For centuries, this had been the centre of the city, around the medieval Laurens Church from the late 15th century. In 1870, the river Rotte was diverted to make way for a new elevated rail track that would connect Amsterdam with Belgium.

In 1940, Second World War bombardments destroyed most of the historic city centre. The Laurens Quarter was rebuilt but fell into neglect: the masterplan for the rebuilding of the city from 1941-1946 (Dutch: het Basisplan voor de Wederopbouw van Rotterdam) foresaw the construction of a new commercial centre west of the Laurens Quarter; canals were filled in to serve as new traffic arteries; its northern and southern boundaries were designated as the city's new commercial and business zones, respectively. The elevated rail track marked the eastern boundary beyond which new residential areas were built rapidly in the post-war years. Subjected to fragmented planning and drained of its function and population, the Laurens Quarter found itself isolated from the urban dynamics.

With the ambition to regenerate the historic quarter, the municipality decided in the early 1990s to replace the elevated rail track with the Willemsspoortunnel, as a result of which today's Binnenrotteplein emerged and which since then hosts the largest weekly market of Rotterdam. In the early 2000s, the need for a covered market came about, as stricter EU regulations signified that the open air sale of fresh fish and meat would longer be permitted. Next to this, the municipality decided to augment the number of inhabitants in the city centre in order to create more capacity for the services in the area. In light of the Laurens Quarter regeneration process, a developers competition was launched in 2004 by the city of Rotterdam for a mixed-use building, a combination of market and housing, which was to be a key project that would help the historic city centre become a lively and bustling area once again.

Architecture

The team of Provast developers and MVRDV won the competition from five other teams. The demanded programme – housing, parking and a market hall – asked for an obvious solution: two residential slabs with an economically constructible market hall in-between. Provast and MVRDV had seen in the South of Europe that these kind of market halls are often dark, introverted buildings with little connection to the surrounding urban area. The market hall in Rotterdam however was to be an important impulse in the development of the Laurens Quarter neighbourhood and had to strengthen the Eastern side of the city centre. A highly public, open building with good accessibility was needed. The team decided to just flip the two slabs and market which led to a larger hall with two wide openings towards the city. In order to make the construction more

efficient a curve was chosen that fitted a traditional elevator core. By adding some space to the lower floors for extra retail space the current volume of the arch emerged, 120 meters in length, 40 meters wide and tall, 12 storeys above ground and 4 storeys below.

The building needed to be as open as possible to attract the public and at the same time it had to be closed off due to weather conditions. Keeping the closure as transparent as possible a cable net façade was chosen which needs very few constructive elements. Its principle is comparable to a tennis racket in which the steel cables are used as strings in between which the glass is mounted. This cable net façade is the largest of its kind in Europe. It allows the art piece inside be visible from the outside, its shapes and colours invite the public to enter the building. The exterior of the Markthal is executed in grey natural stone, the same as on the pavements, anchoring the building in the city fabric and putting the emphasis onto the interior.

Besides being open and inviting, the building had to connect to its surrounding on a urban level. Therefore, Markthal is designed as a building without a backside. All four sides of the building are accessible or shop windows. Part of the first underground level is reserved for delivery and loading; it's here where the goods arrive, food is cooled and prepared, and taken up to the hall by means of freight elevators. The entire distribution for the hall, the shops and restaurants is therefore located underground. In this way inhabitants are not hindered by distribution activities that often occur in the early hours of the morning. On the same level is a supermarket and two more shops. The delivery for these stores is organised through an underground tunnel leading to hidden elevators at Binnenrotte square, in this way larger lorries can operate in distance to the hall. An extra storage room for each apartment is also located on the first underground level.

Inhabitants can reach their apartments through six separate entrances leading to elevators and double helix flight stairs. Due to the curve of the structure the elevator hall is gradually - floor by floor – changing in size and location. On the ground floor the elevator is located at the inner façade, on the top floor towards the outer façade. Each elevator hall services a maximum of four apartments. Half the apartments has windows to the market, these windows are triple glazed to avoid sound or smell nuisance. Even though originally intended, these windows cannot be opened for fire safety. Every apartment has an outdoor terrace with views either to the medieval Laurens Church or the river Meuse. There is a broad choice of apartment types, from free layout loft apartments to duplex with multiple bedrooms. The penthouses have their entrances on the tenth floor and inside stairs and room for an elevator to the eleventh floor, in this way the arch of Markthal could be realised without any elevator boxes on the roof.

The interior of the arch is covered by the large art piece "Cornucopia", a multi-coloured image by Rotterdam artists Arno Coenen and Iris Roskam. The art piece is a five layered digital print made with Pixar Animation software depicting a photographic 3D illusion of fresh products such as fruit, fish, bread, flowers and also the tower of adjacent Laurens Church. Cornucopia refers to the great still-life paintings of the Dutch golden century, to the Greek mythology in which Cornucopia is a legendary object and to the tradition of artistic arch decoration known from places such as the Sistine Chapel. The artwork evokes the illusion of laying on your back in a meadow, looking up, right through Markthal towards the sky. The sun in the centre figures as Cornucopia from which the fresh produce falls down to earth.

Cornucopia is one of the largest art pieces of Europe. In total the image consist of 400.000 megapixels, 1.47 TB and is equivalent to the resolution of a glossy magazine. The artwork covers a total surface of 11.000 m^2 which is made of 4,500 individual aluminium panels of 152x152cm. The panels above a height of 8 meters are perforated in order to absorb the noise from the hall. The aluminium panels are attached to acoustic panels, which together achieve a high acoustic performance.

During the excavation, archaeologists found traces and artefacts of the first settlements dating back to 1270. In order to capture the historic importance of the site and exhibit the finds, a small museum has been set up in Markthal, named the 'Time Stair'. It presents the history of Rotterdam in a vertical exhibition alongside the escalator in the centre of Markthal which connects the hall to the four underground levels. The deeper the escalator goes the more in depth the history of Rotterdam is presented in a number of displays with findings and models, accompanied by sound

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and images. Together they tell the story of the beginning of Rotterdam and its history of food.

Sustainability

Markthal received a BREEAM Very Good certificate. The building is connected to city heating and a thermal storage system underneath the building which will also heat and cool a number of adjacent buildings in the surrounding area. The various functions in the building can exchange heat and cold. For the hall itself extensive research was conducted to create a comfortable interior climate with an extremely low energy use. The hall is naturally ventilated, underneath the glass façade fresh air flows in, it rises towards the roof and leaves the hall through ventilation shafts in the roof. This is a thermic system which can function without any installations. A central monitoring system is used to exchange heat and cool between the different programmes, in this way less installations could be used than normal for these programmes. The combination of housing, shopping centre, parking and market hall makes the installation technology more efficient. Inside the market, an information panel illustrates the energy use and CO2 savings of the building. A smart sanitation system is designed to save water.

The tenants of Markthal have signed a so called Green Lease Agreement regarding sustainable performance requirements. This covers the use of water, energy, waste and the use of healthy construction material. In this way the sustainable ambition reaches further than just the cask of the building.

An ecologist was invited to improve the ecological value of the inner city location and advised to create space for bats and swifts. On the western façade of the 11th floor are four large bat stays integrated into the façade, on the northern side of the first floor are ten nests for swifts mounted to the wall.

Markthal Rotterdam

Royal HaskoningDHV
Maurice Hermens MSc,
consulting structural designer

The Markthal in Rotterdam is not only extraordinary in an architectural sense, also the structural design features interesting challenges: the 4 story basement in a kind of 'thick soup', the gigantic roman arch like super structure and the extremely transparent cable net wall.

Picture 1: The Markthal.
Source: Ossip van Duivenbode

Dutch building context

The context of buildings and construction in the Netherlands is rather strict, while the architectural quality of buildings is world famous. Furthermore quality demands for comfort are high, for example the demands for acoustic isolation between apartments. The efficiency of floor plans is extremely high and in particular the structural system's space requirement is very low. Last but not least the total absence of bedrock and the present soft soils in most of the country requires special attention in the structural design.

Two key design drivers

The two main design drivers for the structural system have been first to realize an architectural icon and second to do this within a reasonable budget. Logically also the functionality of the apartments as well as the parking garage had to meet high standards. The main parts of the structural design are the four storey basement, the arch filled with apartments and the two end façades.

Four storey basement in soft soil

The ground water level in Rotterdam, as in the greater part of the Netherlands, is just below ground level. So realizing a basement is like holding down an empty bucket in a water filled bath. But now the bucket has a footprint of 120 x 90 meters and is 13 meters high. Because the Netherlands, thus also Rotterdam, is situated in an old estuary area the ground is composed of soft layers: sand layers are alternated by clay and peat. In this area, again like most part of our country, bedrock cannot be found within the first hundreds of meters deep.

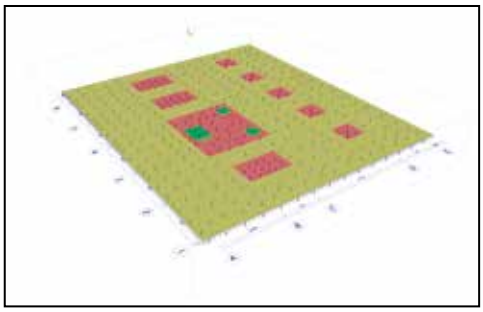
In order to keep the 'bucket' down in the water 2.500 piles were driven into the ground, one on each 2,5 by 2,5 m, plus extra below columns. The excavation was done mainly under water, so the water inside the excavation supported the walls of the future basement. After pouring an underwater concrete layer of 1,35 m connected to the piles, the basement could by pumped empty.

In order to keep the depth of the excavation to the minimum the reinforcement for the pilecaps below the columns was integrated in the underwater concrete. Under water construction workers placed the prefabricated reinforcement cages on top of the piles and around the columns.

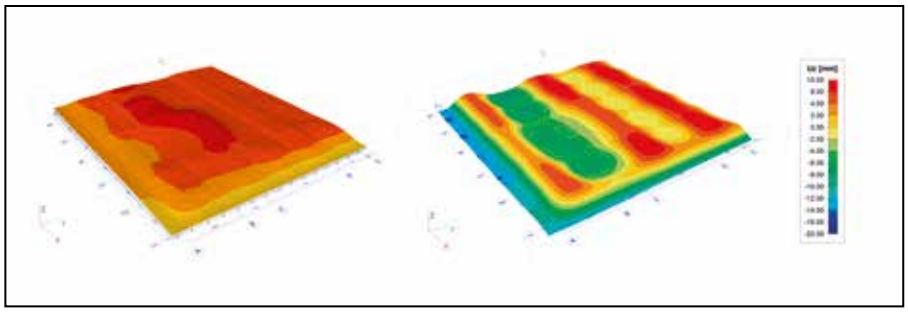
In order to support the basement walls after pouring out the water, a concrete strut frame was designed in the future -1 floor. The beams of this future floor functioned as supports to withstand the gigantic horizontal forces caused by the ground water.

The soft soil is also a structural design challenge in the perspective of realising a water tight basement: the weight of the arches pushes the basement down, with settlements up to 40 mm, while the upward force of the water causes the basement to rise about 20 mm between the arches. These differences in settlements cause bending stresses. In order to keep those stresses and thus cracks in the concrete to a minimum the floor was made as thin as possible: a 500 mm concrete floor withstanding a more than 10 m water pressure. This was made possible by an intelligent placing of piles and reinforcement.

Picture 2 : Integrated concrete strut frame and reinforced underwater concrete. Source: Royal HaskoningDHV



Picture 3a: Quarter part of basement, read areas are high concentrated downward loads in end phase. Source: Royal HaskoningDHV



Picture 3b: Differences in settlements caused by pile deformation, excavation [above] and end phase [below]. Source: Royal HaskoningDHV

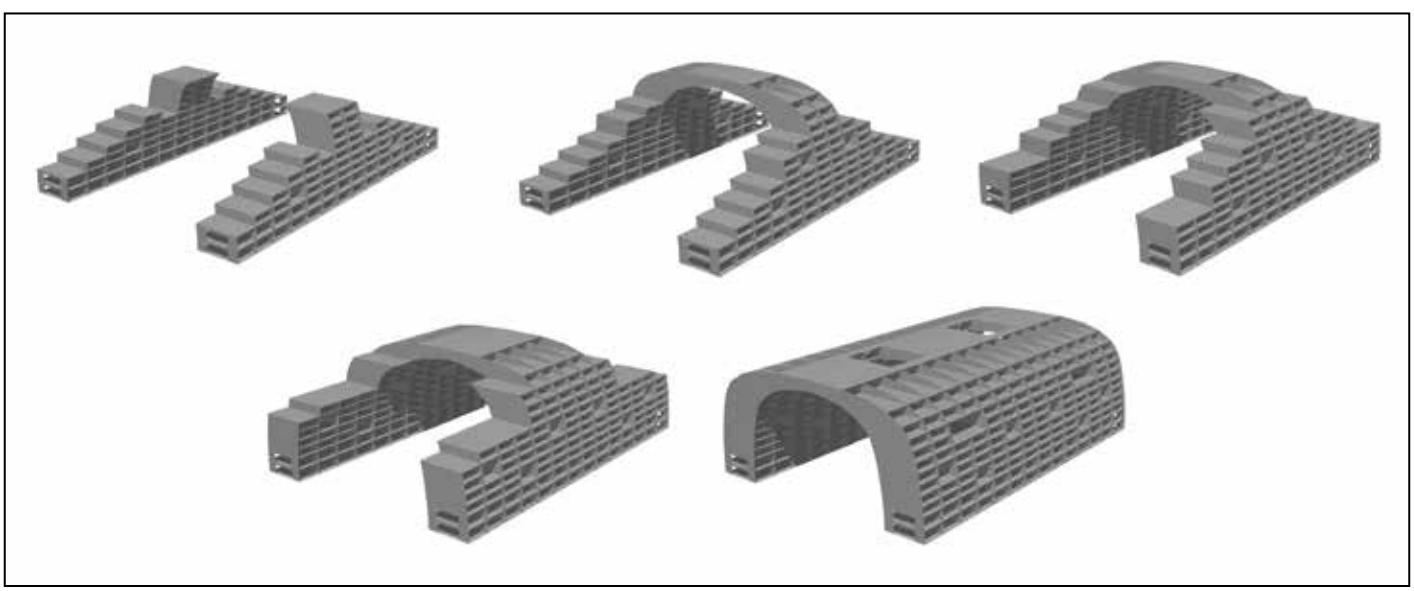
Arch filled with apartments

Already in the earliest competition phase we set the first ideas for the structural design. In order to realize an arch with apartments without extravagant extra costs, standard construction techniques should be used and adapted in order to create the special shape. In the Netherlands apartments are very efficiently built up by cast in situ concrete walls and floors using the so called tunnel-forming method.

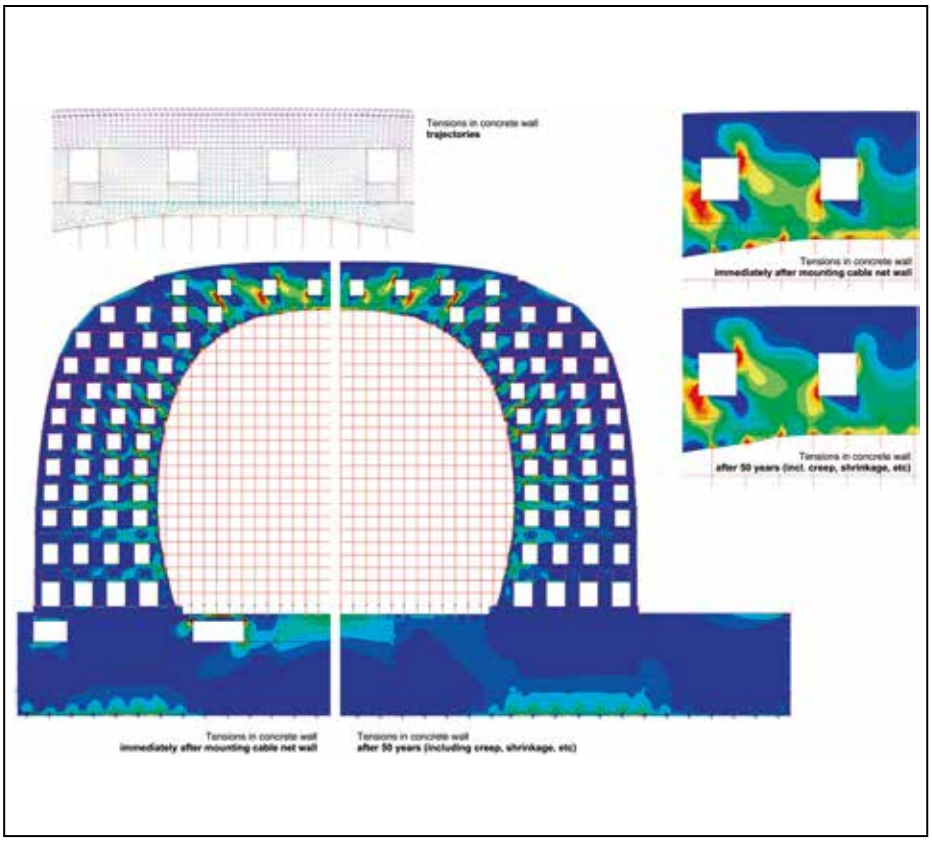
The roman arch like superstructure is the ideal shape to span the 45 meters between the two legs of the arch. However this works only when the arch is completed. During construction a huge scaffolding system could be necessary. In order to avoid this 'temporary building below a building' a smart solution was found: by having the tunnel-forms step towards each other on each floor going upwards, the gap was becoming smaller and smaller. The gap is closed by the so called keystone, in which the floors, walls and roofs form a box like, almost 5 meter high beam, spanning the remaining more than 30 meters. Once the gap was closed, the two parts of the long arch were leaning against each other thus finding a favourable equilibrium.

Cable net walls

The space below the arch filled with market stalls was designed to be a covered outdoor space from building physics point of view. Still rain should be kept out, as well as birds. So the two ends of the long arch were to be closed with a glass façade. We considered all thinkable systems, with (special) trusses, (glass) fins, curved cables, etc. However in a façade with a height of 35 meters and a width of 45 meters the wind load asks for either heavy or special structural systems. In order to keep the transparency as high as possible a special solution was necessary. This was found in a cable net wall: prestressed straight cables vertical and horizontal are combined. Together with the glass they form a kind of sail of glass: the wind load causes the cables together with the glass to bulge. And exactly that curvature is necessary to divert the strong winds to the rest of the building. In that sense the façade can also be compared with a tennis racket: high tension in the strings make it possible to hit the ball with high speed. But to make it work a strong and stiff racket has to hold the stings in place. In the Markthal the racket was already present, formed by the arch together with the concrete walls in the basement.



The deformation of the cables allowed in this case is 1/50 of the height of the façade, so 700 mm for maximum wind load. The elongation of the cables is 1/1000 in that case, so 35 mm. The rotation of the cables at the connection with the concrete is up to 5-6 degrees (1 to 12). However the maximum rotation between two glass panes is only 0,5 degree. Still the glass panes are warped by the wind and also the rotation at the fixations cause bending stresses. To keep those stresses to a minimum it is necessary to keep the glass as thin as possible. Our design together with these preconditions were given to the façade supplier Octatube as a starting point for the detailed engineering and manufacturing.



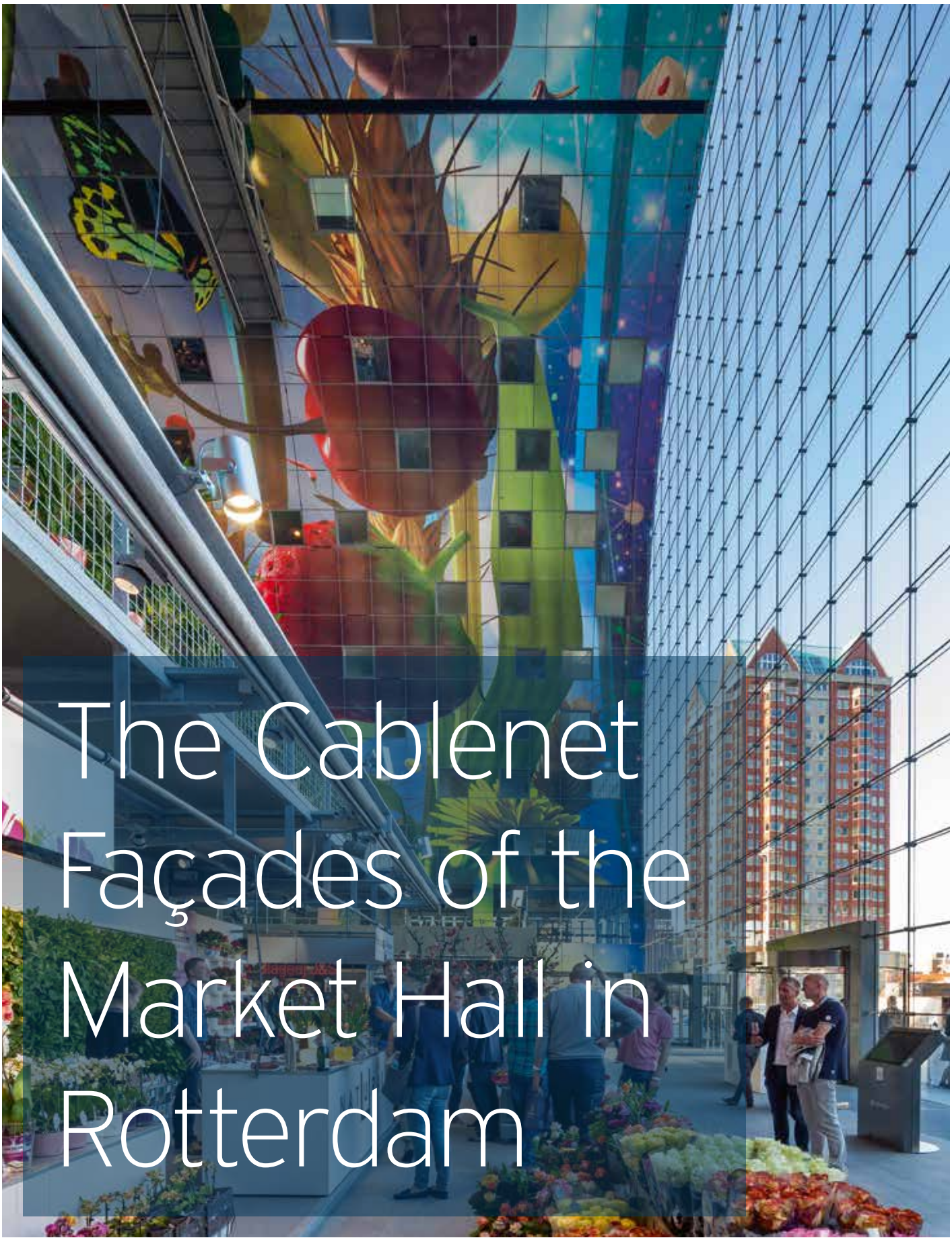
Picture 5: Cable net wall with surrounding concrete structure. Source: Royal HaskoningDHV

Royal HaskoningDHV

Royal HaskoningDHV is an independent, international engineering consultancy providing services for the entire living environment. Our work contributes to the sustainable development of the communities we work in all over the world. We believe meaningful solutions cannot be created without collaboration with our partners, clients and other stakeholders. We enhance society together.

For the Markthal we delivered the structural design and engineering form the earliest competition phase up until the delivery of the building. Our services comprised the excavation and basements, the superstructure and the final design of the cable net walls.

Picture 6: Cable net wall, overview and details. Source: Ossip van Duivenbode



The Cablenet Façades of the Market Hall in Rotterdam

Design
The Market Hall is an architectonic residential project and market hall in Rotterdam, designed by the world-renowned architectural office MVRDV. The concept and typology of the building are readable from the iconic shape. The combination of an apartment building covering a fresh food market with food shops, restaurants, a supermarket and an underground parking is found nowhere else in the world. For the Netherlands the realisation of this new hybrid public building also means the first covered market.

The building needed to be as open as possible to attract the public and at the same time it had to be closed off due to weather conditions. This resulted in a spectacular design covering the front and backside with a flexible suspended glass facade, allowing for maximum transparency and a minimal structure. These transparent cablenet facades have a width of 42 meters and a height of 34 meters, the largest of its kind in Europe.

Octatube has been responsible for the engineering, production and installation of these large glass facades in collaboration with: Provast (Client), JP van Eesteren (Main Contractor), RoyalHaskoningDHV (Structural Designer), MVRDV (Architect) and Inbo (Interior Architect).

Engineering
The glass facade is divided in 26 vertical and 22 horizontal cables. Together they form a suspended net, similar to a tennis racket that functions as a single layered load bearing structure. The cables are pre-stressed between strong (60 mm thick) steel boxes embedded and cast in the concrete walls. The boxes have been designed in such a way that rough concrete tolerances could be transferred into tight tolerances needed to construct a glass facade. The galvanized steel cables run through spherical joints to allow for deformations and prevent material fatigue. All cables have a diameter of 31.3 mm, and their breaking strength is 884 kilonewtons. One of the technical challenges for the structural facades of the Market Hall, is to deal with the high pre-stress forces that have to be transferred to the concrete arch. The cables are prestressed to a maximum of 300 kilonewtons each, of which 50 kilonewtons is in fact surplus capacity to deal with the consequences of creep in the concrete.

A cast steel node (3) is placed where the cables cross each other, allowing the vertical (1) and horizontal (2) cables to intersect while fastening the corners of the glass panels in one single detail. The distance from the horizontal cables to the glass is 150 millimetres and the distance from the vertical cables to the glass is 100 millimetres. Laminated single glass units (4),

with a typical dimension of 1485 by 1485 millimetres, are fixed to the cables by means of circular clamping plates (5).

In the middle, the facade can be exposed to deflections up to 70 centimetres during extreme wind loads. A horizontal deflection of a facade with such tolerances is one of the characteristics of cablenet facades. The deformation causes the cables to elongate and theglass panels to rotate up to 5.4 degrees. In the corners of the facade where 2 sides of the glass panels are more or less fixed, one corner can move inwards and outwards up to 50 millimetres.

The detail of the door portals is also interesting: the portal frames are moving with the facade disconnected from the revolving doors.

Production & Installation
The main structure of the cablenet facades consists of galvanized steel cables, cast clamping nodes and steel plates for the embedded boxes.

All cables in the facade are of the same type, but the theoretically required pretension force is different for each cable. For practical reason the cables' pretension forces have been distributed and grouped per five adjacent cables. In addition, a very specific pretension protocol has been written to gradually and uniformly load the concrete arch.

The cables are - without pretension - too short to fix them directly at both sides. Therefore, the cables have been fixed at one side, while a temporary tension bridge has been used at the opposite side. After installation, the cables have symmetrically been pre-stressed for 50% by means of hydraulic pretensioning, after which a second round of pre-stressing has brought the pre-tension in all cables to 100%. During this operation the cables have all been stretched between 94 and 147 millimetres each. The maximum applied tensile force of 300kN can be compared to 20-25 middle class cars.

The typical glass panel is 1485 by 1485 millimetres, composed of clear heat-strengthened float glass. The single glass units are laminated with two panes of six millimeters. It has been a deliberate choice from the architect not to apply any coating on the glass. The main consideration for this has always been to maximize the sense of openness and transparency. The two facades both have a total glazed area of 1258 square meters.

Realization
The Market Hall was opened on the first of October by Queen Maxima. Ever since the opening the building has attracted ongoing publicity. There are hundreds of favourable reviews from both the international architecture platforms and international media such as The Guardian and The New York Times. The realization of the building has also played an essential role in strengthening the reputation of

the city and the brand of Rotterdam, now named as one of best cities in the world for travellers to visit. In the first few weeks the Market Hall had already attracted one million visitors.

The exterior facade is clad in grey natural stone; the same is used for the market floor and the surrounding public space, in this way the emphasis lays on the colourful interior. The large mural has been rendered in the Pixar Studios and covers the vaulted interior. Especially at night the 11.000 square meter interior painting, called 'Cornucopia' or 'The Horn of Plenty', comes alive. This sensation is enabled by the transparency of the cable facades with only nine kilograms of structural steel per square meter.

The success of the Market Hall may lay in the synthesis of a new urban mixed-use building typology, bold architecture and a spectacular interior artwork. The cable facades facilitate these aspects.

Not only has the building already won several prices, but also the cable facades are awarded with the Dutch Construction Awards 2015 in the category for building materials and – systems. The jury praised the synergy between structure and architecture as well as the guts and intelligence of the engineers.

Together with glass fins, cable structures are an emerging trend in architecture. They are the perfect tool to create very transparent facades of which the Market Hall's cable facades are a prime example. Systems and solutions like these fit perfectly within the scope and working method of Octatube, where all departments are situated in one building. We believe it is essential in our delivery of innovative and dependable results such as the Market Hall.