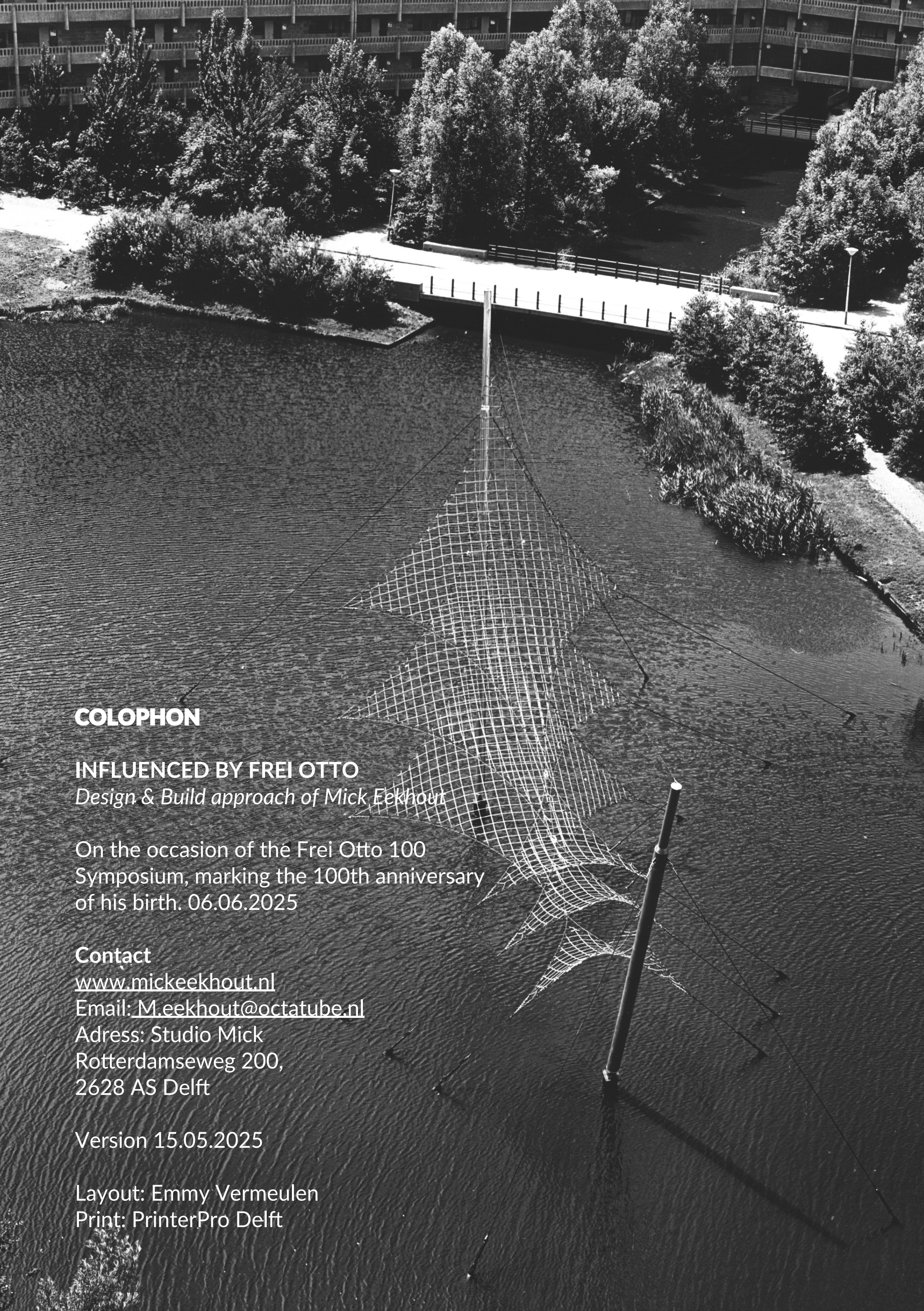
FREI OTTO 100 SYMPOSIUM
STUTTGART, JUNE 2025

INFLUENCED BY FREI OTTO

Design & Build approach of Mick Eekhout



COLOPHON

INFLUENCED BY FREI OTTO
Design & Build approach of Mick Eekhout

On the occasion of the Frei Otto 100 Symposium, marking the 100th anniversary of his birth. 06.06.2025

Contact
www.mickeekhout.nl
Email: M.eekhout@octatube.nl
Adress: Studio Mick
Rotterdamseweg 200,
2628 AS Delft

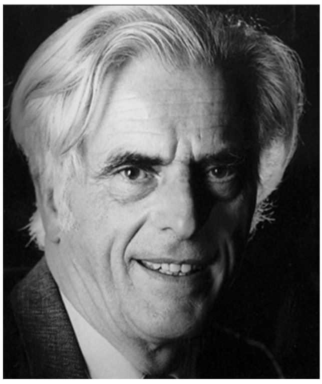
Version 15.05.2025

Layout: Emmy Vermeulen
Print: PrinterPro Delft

DESIGN & BUILD APPROACH
PART 1

1.1 INTRODUCTION

The Institute für Leichte Flächentragwerke in Stuttgart was founded by prof.dr. Frei Otto (1925-2025). As a young Dutch student architecture I, Mick Eekhout (1950), collaborated from February up to May 1970 in a team led by Robert Krier (1938-2023) and Bodo Rasch (1943) to make an alternative mobile membrane roof for the large football stadium planned for the 1972 Olympic Games in Munich. The institute itself was built as a prototype for the German cable net pavilion in Montreal (1967). In 1969 the institute exploded from five engineers to fifty-five architects and engineers from as much as fifty countries. It was a beehive of international architectural interest. Frei Otto and his day-and-night working engineering team, soldering the Munich models in two daily shifts could not prevent that the inaccuracy of modelmaking versus the large scale (1 to 125) appeared not to be accurate enough for realisation. Halfway the engineering was taken over by geodesic, aerospace and structural civil engineering parties that could cope with more exact computerisation. Actually, the large scale of the Munich design compared with the previous projects was an experimentation where none of the participants had any experience. Due to this project and later the Israeli hostage and killing of eleven athletes, ('the Munich Massacre') the cable net structures did not get ample interest. However, the intrepidity by which this experimental technical development process was engaged, was very inspirational for me. The warning was to better take a number of small staps instead of large jump into an unknown ambition. During my entire professional career I used an incremental approach for innovations using a multitude of inventions en and developments for that goal.



This booklet has been written on 40 years of experiences of designing, developing, experimenting, certification, production and realization of structures in architecture in my company Octatube in Delft, where I functioned as the pioneer, general director and main designer for most of the projects. My attitude is an architect's attitude of looking for new compositions, in this case not formal compositions but technical compositions. This ambition finds its origin in the time I spent as a student in the institute of Lightweight Structures [IL] of Frei Otto in Stuttgart and of the Building Workshop of Renzo Piano in Genova in 1970. Both Otto and Piano are my lifelong heroes. Renzo asked me to write my first article of 60 pages in the Italian architecture magazine 'Zodiac 21' (No ISBN) on the Olympic Games cable net roofs in 1971. In 2011 we celebrated the 40 years of writing on architecture with the first handover of 'Tubular Structures in Architecture' (ISBN 978-94-90-675-011) in Genova. Between 2012 and 2014 we collaborated on the design engineering of the Centro di Arte Botin in Santander.

1.2 HIGH TECH ARCHITECTURE STRUCTURES

So I spent my time in designing structural systems, developing new components and designing new material connections, in all (what is called nowadays) 'innovative' technical solutions. It brought me lifelong adventures which I had never dreamt of in the early period (1975-1983) I had my own architect's office in Delft. As a conventional architect one has much of a distance to materialization. Not one architect has his own office at the building site, except Howard Roark in the book 'The Fountainhead' (ISBN 978-90-245-0633-0). Offices are always off-site. In Octatube I combined from the beginning onwards the thinking and the making: the architect's and engineering office in the same place as the factory where the components were made. Steel was cut and welded, aluminium was cut and machined. All metal components were assembled after coating for shipment. More important is that a big part of the factory is devoted to experiments, the Octatube Laboratory is used for mock-ups and test rigs where materials and performances are tested up to the level of certification.

So in one company we can cope with the crazy ideas and wild dreams thanks to the later precise engineering and production of components up to the certification as trustworthy components to be applied on site in projects without any worry for the client. For many visiting architects the factory is a dream world. Like 'Charlie in the Chocolate Factory' (ISBN 978-0-14-310633-3) as written by Roald Dahl. My house was built directly behind the factory. So many times a day I walked from office to home through the factory and the laboratory, always wondering what can we do more or better. This is inspiration from materials and components to make new technical compositions. Seeing and touching materials brought me many 'Eureka' moments. In the office a multi material example of a bicycle suspended from the ceiling is a piece of art. Regularly I wrote books on technical designs such as the books 'Glass Design Innovations in Architecture' (ISBN 978-94-6208-6722) and the forementioned 'Tubular Structures in Architecture'.

1.3 ANSWER IS A 'DESIGN & BUILD' APPROACH

This love for materials and components was accelerated at the very start of my professorship when Thijs Asselbergs introduced in a cultural dialogue the term 'Zappi' as an intellectual ambition to develop a new transparent structural material. 'Zappi' was introduced in 1992 as the yet unknown, fully transparent, structural reliable material for safe structural design in architecture. Thijs Asselbergs, then town-architect of Haarlem and later one of my colleague professors at TU Delft, faculty of Architecture, launched the word 'Zappi' for an ideal, new and unrealistic material in future attractive enough to be invented and developed.

In the Chair of Product Development staff and students have worked at long intervals on this topic between 1992 and 2015, up to my retirement. In Octatube, a stream of experimental structures was developed between 1975 and 2025. In my company structural engineers did material research on glass, detail research on the connections of glass and steel structures. New structural designs were developed, leading to many actual and realised innovations.

1.4 FROM TENSILE STRUCTURES TO FREE FORM DESIGNS

Two decades ago the challenge of ‘Free Form Designs’ , ‘Liquid Designs’ or ‘Blob Designs’ came up and confused the building industry, not only in the international architectural magazines but also in realistic projects challenged to the company Octatube. The gap between architects with new digital skills and refined 3D-computer programs on the one hand and the building industry with its traditional orthogonal building systems and material processing on the other hand widened progressively in the last decades. The Octatube company was challenged to solve geometrical component problems on project base. The TU Delft was challenged to close the gap by developing new technologies, methods and approaches to realize these ‘Free Form Designs’. Up to then the building industry saw them as ‘Fluid Design Nightmares’. The geometry of the components was non-rectilinear and not flat. The building industry did not have any experience in making 3D curved panels, not as load bearing structures nor as cladding constructions. It seemed wise to start a transfer of technology from the nautical and aeronautical engineering industries, where fluid forms always have been very functional. We concluded that transfer of technology alone was not enough. Architecture appeared to be a special domain with specific characteristics, like its large dimensions and relative large freedom in design, like ‘Free Form Technology from Delft’ (ISBN 978-1-61499-553-1) . After a ‘Transfer of Technology’ further ‘Adaptation of Technology’ is necessary to progress technically for applications in architecture. On the Rabin Center with its Composite Free Form Roofs a book has been written: ‘Lord of the Wings’, (ISBN 978-1-61499-594-4).

1.5 ACADEMIC INVENTIONS LEADING TO INDUSTRIAL INNOVATIONS

The quest for innovative technology has been stimulated by a careful and incremental research and development approach. This was partly based on dreams, wild ideas, bold designs, ingenious innovations, entrepreneurship, projects and willing clients on the company site. On the academic side it was based on wider contemplations, academic philosophy, more theoretical research and long term development work and methodological thinking at the university. Practice inspires Theory. Academia inspires Industry as it stretches the foundations for further inventions and innovations in the Industry. Both seen from the academic world as well as from the building industry, it is unique that the two worlds could be closely connected in order to boost up new inventions, innovations, mock-ups, experimental 'zero-series' and even real projects. It shows that collaboration between Industry & Academia can lead to a complete new vocabulary in building technology.

It is imperative to follow this line of mutual stimulant. This dual incremental approach is partly due to the Small Business Enterprise character (SME) of my company. In my company it was accelerated by a constant flow of projects in practice with real world deadlines. Fundamental research in architectural technology in my Chair of Product Development on TU Delft was initiated and connected to experiences from the practical world. But most of all a personal innovation challenge was nurtured which led to a continuous drive to improve technology at two sources in Delft: Industry & Academia.

1.6 MORE PROGRESS IN ACADEMIA WITH PRACTICAL EXPERIENCES

This booklet contains realistic short-term design & development Octatube projects and some longer term research & development projects undertaken in the Chair of Product development in Architecture. All to give a picture of the very personal simultaneous research, development & design of the quest for architectural design innovations. Without the devoted crews of Octatube and the TU Delft chair these results would not have been possible, of course.

In 1991 entering the academic world seemed attractive to me. It was necessary to enlarge the up to then restricted scope of discussions on inventions and innovations. Adventures all over the world were experienced in Octatube, but there was hardly an intellectual debate. Now, after almost 35 years as a full professor at TU Delft the wider scope of a worldwide operating designer is seen compared to that of university researchers. Architects do see wider and are concerned with societal needs above their direct building tasks, which clients normally do not reward, but it makes the profession cultural. Architects are beta-engineers, but also aware of alpha- and gamma-aspects in societies before their designs are applied and accepted as successful.

Based on the earlier experiences of my architectural office ‘Architect Mick Eekhout’ the design & build company of Octatube was started in 1983 to prove that the architectural designs were realistic, although not a single contractor was prepared to realize them. So my position as a designer changed from a pure architect to an inventor-designer & entrepreneur. I never regretted this jump, although this design & build position did not bring the heroism of high-ranking architects. But the portfolio of five decades of innovative architectural designs satisfies and is worthwhile showing, with the most satisfying core of designing the inventions and innovations. The continuous support of the team collaborators at Octatube and of the staff members at TU Delft ensured the velocity of developments. Both teams accommodated to undertake the quest.

Professor Zygmunt Makowski (1922-2005), the world guru of space structures at the time and dean of the Civil Engineering faculty of the University of Surrey, confided to me as a young student when he saw a group of students while designing a roof for the Feyenoord soccer stadium in Rotterdam in the fourth study year (1972):“Mr. Eekhout, please never go into research, always remain a designer”. In 2002 indeed he still was so impressed with the realized results of his former student that he awarded him the prestigious ‘Pioneer’s Award in Spatial Structures’ of the University of Surrey. In 1986 he was invited to open the factory and office of Octatube in Delft.

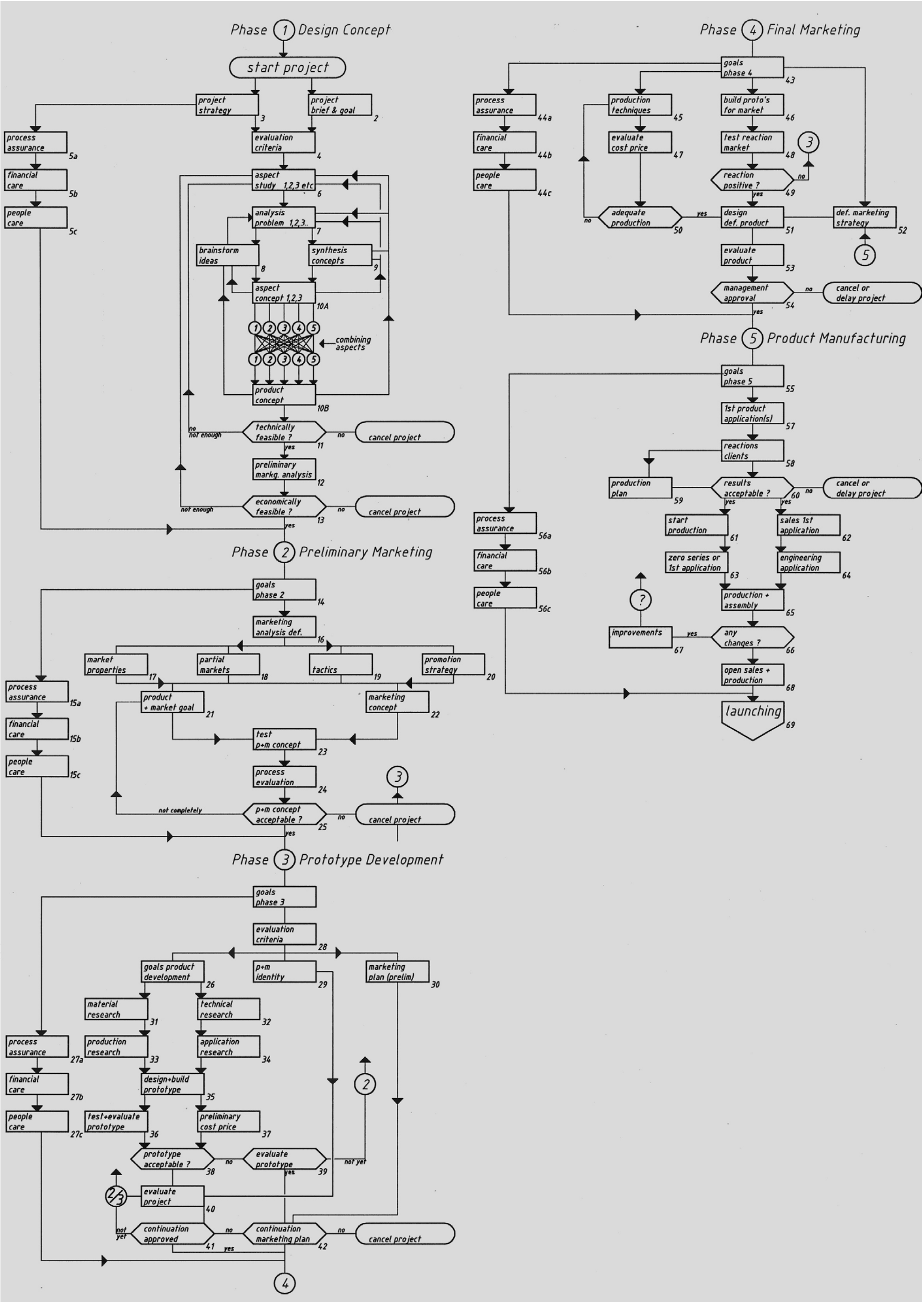
1.7 THE JOY OF DESIGN AND REWARDS OF RESEARCH & DEVELOPMENT

The joy of design is always around. Design can surprise and astonish, can impress as an intellectual solution for a complicated problem. Research is used to cover unknown areas of knowledge. Research is also a path of discoveries with smaller and longer jumps. But when it comes to solutions, the force of design is favoured above the process of research. This enforces to advocate a stronger design component in academic research, called 'Research by Design', using a disciplinary process methodology nurtured during a life long professional designing. In this booklet a short explanation of the virtues of design development methodology is given, referring to one of my books on this subject of Methodology. (fig. 'Methodology of Product Development in Architecture' (ISBN 978-1-58603-965-3) See scheme of development of building products (page 10).

Some of the dreams came true after a life long designing, engineering, producing and building, while other dreams still have to be conquered. It has always been my dream to leave footprints on earth in the form of realized designs in architecture. It became a dreamy reality to lead a group of enthusiastic young people into a new future: at Octatube, at the foundation Delft Design (since 1988), at foundation of Booosting (since 1989), at the Chair of Product Development (1992-2015), at the group of Dutch confederation 3TU.Building Research; to write about creative designs, contemplations and adventures; to combine brains & hands, to combine academia & industry to boost innovations; to have adventures with challenges to be conquered; to think about the future of society and to interfere positively.

1.8 THE OCTATUBE PROTOTYPE LABORATORY

The dualism between designing and building, between thinking and doing dates back to the relation between my father Jan Eekhout who was a building contractor while I, as the eldest son became an architect. The symbiosis of designing & building can generate inventions to become real innovations. From the inspiring contractor's power to realize plans this is how the design & engineering office Octatube was organized officially from 1983 onwards. In order to realize extraordinary designs (stretched membranes and space frames) the start was made to make structures by hand for artists like Krijn Giezen and Loes van der Horst. Already in 1975 the first design and build project was the artwork


Phase 1 Design Concept
start project
project strategy 3
project brief & goal 2
process assurance 5a
financial care 5b
people care 5c
evaluation criteria 4
aspect study 1,2,3 etc 6
analysis problem 1,2,3.. 7
brainstorm ideas 8
synthesis concepts 9
aspect concept 1,2,3 10A
combining aspects
product concept 10B
technically feasible ? 11
no not enough
no
cancel project
yes
preliminary markg. analysis 12
economically feasible ? 13
not enough
no
cancel project
yes
Phase 2 Preliminary Marketing
goals phase 2 14
marketing analysis def. 16
market properties 17
partial markets 18
tactics 19
promotion strategy 20
process assurance 15a
financial care 15b
people care 15c
product + market goal 21
marketing concept 22
test p+m concept 23
process evaluation 24
p+m concept acceptable ? 25
not completely
no
cancel project
3
yes
Phase 3 Prototype Development
goals phase 3
evaluation criteria 28
goals product development 26
p+m identity 29
marketing plan (prelim) 30
material research 31
technical research 32
process assurance 27a
financial care 27b
people care 27c
production research 33
application research 34
design+build prototype 35
test+evaluate prototype 36
preliminary cost price 37
prototype acceptable ? 38
no
evaluate prototype 39
not yet
yes
2
2/3
evaluate project 40
not yet
continuation approved 41
no
yes
continuation marketing plan 42
no
cancel project
4
Phase 4 Final Marketing
goals phase 4 43
process assurance 44a
financial care 44b
people care 44c
production techniques 45
build proto's for market 46
evaluate cost price 47
test reaction market 48
3
reaction positive ? 49
no
yes
adequate production 50
no
yes
design def. product 51
def. marketing strategy 52
5
evaluate product 53
management approval 54
no
cancel or delay project
yes
Phase 5 Product Manufacturing
goals phase 5 55
1st product application(s) 57
reactions clients 58
production plan 59
results acceptable ? 60
no
cancel or delay project
yes
yes
process assurance 56a
financial care 56b
people care 56c
start production 61
sales 1st application 62
zero series or 1st application 63
engineering application 64
?
production + assembly 65
improvements 67
yes
any changes ? 66
open sales + production 68
launching 69

‘Bijlmobiel’, in Amsterdam. Later the model laboratory became a small work shop. And the small workshop became a prototype factory. A few years later a complete factory in Delft was realised. The design office became a medium design & build company of 40 to 60 staff, working over the whole world. (Currently in 2025 the Octatube company had been taken over by son Nils-Jan Eekhout and has a doubled factory of 120 fte staff). The design & build attitude facilitated any ‘wild & crazy ideas’ from the design concepts to be developed & researched, to be certified and to be built as prototypes in projects. And these design concepts were applied in zero series for many lightweight structures and constructions for roofs and façades in architecture.
The design & build company Octatube became the guarantee that colleague-architects could come and trust a quick development of their design ideas in an intelligent thinking-and-doing environment. Architects loved it, as they saw it as their own laboratory during a collaborative project. From this example others could follow, but only few took this extreme step. Knowing the power of Renzo Piano’s Building Workshop, in which designing, developing and engineering of new constructions in new materials coincide with prototyping, the real making was a step further. After a life full of adventures in design and realizations over the entire world, a transition is felt between knowledge & material of the busy early life and the insight & overview of the more contemplative years.

1.9 INNOVATIONS IN ARCHITECTURE ARE STIMULATED BY A ‘DESIGN & BUILD‘ APPROACH

This booklet has been written to give an selection of the tensile designs that originate from my design & build company Octatube and the academic thinking as a professor at TU Delft. The combination of the two worlds, Practice and Theory, enabled developments that are impossible in a single world. This is a message for the world.

Nowadays there is a 40 years long tradition of continuous technical developments and innovations, even outside of the usual material program. Examples are the glass fibre reinforced

composite shell wings of the Rabin Center in Tel Aviv with architect Moshe Safdie. But also the 30 m cardboard dome with architect Shigeru Ban in Amsterdam.
It led in 1995 to the installation of the Prototype Laboratory of the Chair at TU Delft, where more than 1.500 students had to engineer, produce and build a material prototype according to their own design. See 'The Delft Prototype Laboratory' (ISBN 978-1-61499-545-6). This laboratory is now in the capable hands of dr. Marcel Bilow and is called 'The Bucky Lab'.

1.10 INCREMENTAL STEPS AHEAD IS BETTER THAN ONE BIG AND RISKY EXPERIMENT

The hands-on Octatube Prototype Laboratory proved to be very stimulating, for example in case of glued glass connections and of cold twisted glass. Both innovations had their origin in the easy handling of present materials in an unconventional way. Both of them started nightly dreams and wild ideas, they were globally tested in different ways in the laboratory, proven as a concept by the Octatube engineers, further developed and engineered, fully tested and certified and brought into practice in the first project and later repeated many times in following projects. In case of the cold twisting of glass the theory was developed after the first project was completed. Normally a theory I will proceed the practice, but in case of my laboratory it has occurred also the other way around. Anyway, a living connection between Academia and Industry is very worthwhile for continuous technical innovations.

TENSEGRITY STRUCTURES
PART 2

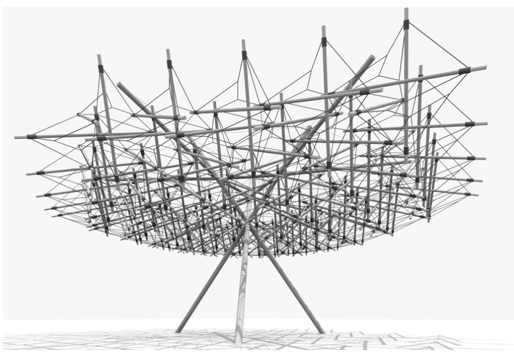
My earliest experiences with tensile structures are from 1970 when I was employed at the IL at Stuttgart and learned extensively on design and development of tensile structures. Forty years later I was engaged in a similar complicated development process.

2.1. THE TENSEGRITY CHANDELIER IN THE HAGUE

In 2013 the engineering, production and building of a number of 'tensegrity' chandeliers was tendered by the city of The Hague in The Netherlands. The architect had won a design competition some 5 years before. The idea behind the urban redesign of one of the busiest shopping streets in town, was to change this street into a giant family living room, with three large suspended chandeliers. The architect worked on the design for more than 4 years. She hired Arup in Amsterdam to do a sample engineering. She had the staff members and students at TU Eindhoven made a model and prepared her tendering package. The client, the Hague municipality went for an official European tendering. In May 2013 the tendering process started after a pre-qualification process (see fig. 1).

Shortly after the start of the tendering process the Municipal Aesthetics & Monuments Commission judged the design as undesirable and aborted the design after 5 years of design and engineering. It was a blessing in disguise as Octatube, as one of the most experienced tensegrity designers and builders in Europe, discovered quite fast that the tensegrity structure was not buildable at all in the situation of a busy shopping street where life had to go on. Yet the challenge how to realize this type of complicated tensegrity structures remains and is interesting enough to be revealed in this article and to be discussed in an international forum.

| FIGURE 1



2.2. TENSEGRITY STRUCTURES AS ARTWORK

A tensegrity structure is a structure which is composed of linear compression elements and linear tension elements, where all compression elements are only connected by means of cables. Not one compression element (usually a tube) touches another one directly. The name dates from the time that student Kenneth Snelson (1927-2016) worked together with tutor Richard Buckminster Fuller (1895-1981) in the late 1940s to make new types of structures. Snelson claims he had thought out the concept, though 'Bucky' was so quick to adopt it as his finding. Long letters have been written since that time. Buckminster Fuller surely tried to adopt these structures in the experimental designs of his domes and cupolas.

The artist Kenneth Snelson has been known worldwide because of his sculptures in stainless steel and aluminum and stainless steel cables which he built on numerous places and exhibitions. His structures are quite elegant and abstract in its detailing.

The Snelson Tower is a 30 m high tensegrity tower made by Kenneth Snelson and his studio in the Kröller-Müller park in Hoenderloo, NL. It has one flaw, however. The pre-stress in the cables is not high enough to keep the structure upright through the stormy autumn season. The flaw is in the way the pre-stress is applied and partly is also reduced during final assembly. The tensegrity tower of Snelson has fallen several times in autumn during storms and is stabilized by guying cables in winter or demounted and laid flat on the ground in winter.

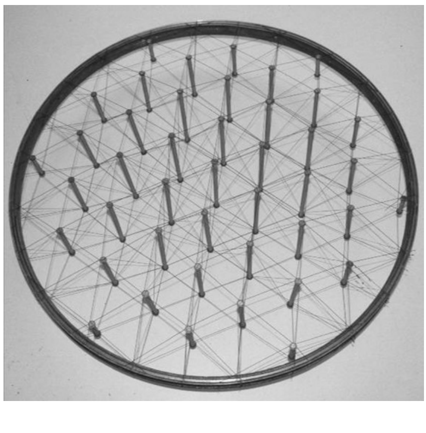
The Snelson structures were popular amongst architects when I was a student in the late 60s and early 70s. In fact they were regarded as the highest class of structural designs at the TU Delft faculty of architecture. I was a student-assistant of the late professor Dick Dicke (1924 – 2003) at the Chair of Mechanical Engineering, who introduced out-of-the-box thinking on new materials and new structures. He gave lectures how to make a reliable structure with unfit material, even with candy, or with 'Zappi', unknown materials with unrealistic properties that forced the students to think clever and not on the automat. I organized two seminars with tensegrity structures in 1972 of 2 weeks with 20 students. One of these students, Dirk Sijmons, even remembered this seminar in his inaugural speech as a landscape professor 40 years later. We made tensegrity structures in the rim of a bicycle wheel (fig.3). Indeed it was quite difficult to solder these models evenly pre-stressed. It was for most of us the last design exercise before starting with our final studies. We kept to designing and building models, soldering mostly. But tensegrities were difficult.

2.3 SANTANDER TENSIGRITY ROOF IN MADRID

In my early years of Octatube, in the 90s, I would develop a whole generation of tensegrity structures for stabilization of glass facades and glass roofs. The bicycle wheel tensegrity structures from my student's time were realized around 35 years later as the 30 m circular roof for the Santander

| FIGURE 2

| FIGURE 3



Bank in Madrid, as designed by American architect Kevin Roche (See fig 4).

We designed a circular ring of RHS 350 x 350 mm as a bicycle wheel structure of pre-stressed upper cables and lower cables, distanced by vertical steel posts at regular distances. This collection of vertical studs kept the upper and lower cables stable. The cables were pre-stressed stainless steel rods. The vertical compression studs were made in stainless steel tubes, but were prepared as glass tubes as an alternative 'Plan B' during the tender stage. The bicycle system is a prototype of a 'closed' system: a closed entity of compression and tension components. There are other systems that are called 'open systems'.
In those cases the compression elements and tension elements are connected, but the edges are fixed on outer structures, like the concrete structure of a building. The edges of open systems are always anchored on outdoor building structures.

FIGURE 4

2.4 OPEN SYSTEM FOR TENSEGRITY FAÇADES

For the OZ Building in Tel Aviv, designed by Avram Yaski, a vertical façade was designed and built in 1995 with a width of 16 m and a height of 52 m. This glass surface was stabilized by horizontal tensegrity trusses of 16 m span on each floor height at 3.6 m distance (See fig. 4). Each horizontal truss is composed of two pre-stressed cables kept at proper distance by compression tubes, perpendicular on the glass surface. The inward curved cable takes care of wind compression on the façade, the outward curve takes care of wind suction. In fact these trusses are open trusses (reaction forces to be generated by the building are high), leading to an extremely efficient tensile tensegrity structure.

2.5 SQUARE TENSEGRITY GRIDS FOR ROOFS

In a series of structures in The Netherlands, square roof modules of 8 x 8 m were realized by 16 glass panels of 2 x 2 m, which were connected by Quattro nodes on compression tubes each 2 x 2 m. The tubes are stabilized in two directions by a system of upward and downward directed cables, leading to the square CHS grid of 8 x 8 m. All of these structures are closed structures, as they are surrounded by a tubular compression grid at 8 m distance. So Octatube has ample experience with all kind of tensegrity structures, (see fig. 5, 6).

2.6 CABLE-STAYED GLASS FAÇADES FOR MARKET HALL

The 'Markthal' or Market Hall in Rotterdam as designed by architect Winy Maas of MVRDV, consists of an envelope in cylindrical form wrapped around an atrium, in which a daily vegetable market is located. The building accommodates 228 apartments. Needless

| FIGURE 5

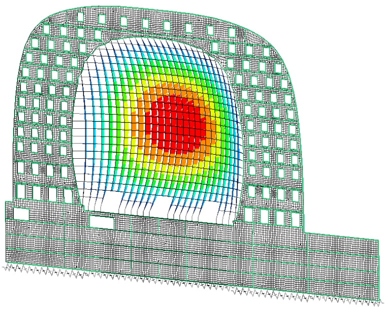
| FIGURE 6

| FIGURE 7

to say, only the lower 3 m of the 35 m height of the inside hall can be used by people. As a sign of the vegetable market the inner walls and ceiling are decorated by giant colorful fruits and vegeta-

| FIGURE 8

| FIGURE 9



bles, so that the function of the cathedral-like space cannot be easily ignored. The two façades on the front and rear end of the cylinder are the largest windows in The Netherlands. From the inside looking out they give a spectacular view over Rotterdam, towards the 'Blaak' side and the town side.

Technical basis
The cylindrical apartment building was closed off on both sides by a vertical glass façade, the largest in The Netherlands: 42 m wide and 35 m high. The loadbearing structure is a single-layer steel cable net structure, highly pre-stressed and provided with laminated glass panels to create an extremely slender and transparent glass façade. The module of the cable net dictates the size of the glass panels. In this project the cable net with all of its design considerations and engineering analysis is far more intriguing than the glass panels.

The two glass façades at either ends of the cylindrical space are surrounded by a 300 mm thick reinforced concrete façade structure in the same plane acting as an arch. Piling into the sand layers below has to be as deep as 30 m. Actually, the soil is not particularly suited for high-rise buildings. One of the basic problems is creep of freshly poured concrete. It is a well-known engineering fact that reinforced concrete creeps mainly for the first two years after its pouring. What would happen when the cable net was pre-stressed in the concrete frame, thus enlarging the creep phenomenon, while after two years the fully installed cable net structure with the glass panels would be released a bit due to the concrete creep? The pre-stressing targeted was high enough to allow for a 2 % relaxation due to creep. The glass panels are not deformable, of course. The deformation has to come from the sealant zones, which in this case are not the usual 10-12 mm, but slightly larger: 12-16 mm. The choice of sealant allows permanent deformation due to creep.

Entrances in a flexible Cable Net Structure Facade

The introduction of three portal frames around the rotating doors complicated the bottom of the cable net façade. These are the entrance doors to the market hall, also functioning as emergency exits in case of fire inside the market hall. The technology used is that of portal frames which can rotate inside and out, following the movement of the cables at all times. The upper rafter of the portal frame moves with the deformations of the cable net, while the two columns stay in the same position. The revolving doors, of course, stay vertical to allow entrance or exit by visitors and marketers. The portal frames and the turning doors are connected by a flexible collar to allow for the deformation of the cable net while letting the doors function properly.

When subjected to the highest wind load, a total elongation of 37 mm was calculated for the central cables, which results in a horizontal deformation in the centre of the cable net of 700 mm inward or outward (Fig 9).

The largest deformations on an individual glass panel sized 1,485 × 1,485 mm is 50 mm. Cleaning of the glass façade has to be done by an outside telescopic crane and on the inside by an overhead crane rail.

The erection of the cable net glass façade was completed in the spring of 2014. The cables were pre-stretched. The steel boxes were cast in concrete and the contractor assessed the misplacement tolerances. They were within the tolerances foreseen by the detailing of the boxes due to the later drilling of the face plates. The concrete roof of the cylinder was the last part to be poured into position, after a curing time of three months. Only after that the anchoring of the vertical cables and later the horizontal cables could be undertaken. It was assumed that the extra silicone sealant width of 16 mm compared to the regular 10–12 mm would give enough room when creep occurs above expectations. The flat cable net structure goes in complete contradiction to what I learned for Frei Otto with the counter stabilizing upward and downward cables, leading to his characteristic saddle shaped tensile surfaces.

2.7 DUTCH TENSEGRITY ARTWORKS

In the past I designed and built several tensegrity structures. The first of the experiments were artworks designed, developed and realized with the artist Loes van der Horst (1919-2012) and Krijn Giezen (1939-2011) as tensegrity structures, combined with membranes which made them more heavily loaded as structures.
The first tensile structure I made in 1975. Loes van der Horst was an artist weaving tapestries. Together we designed and developed the ‘Bijlmobiel’, a structure of 2 masts and 6 cable nets spanned between the masts, situated in the Bijlmermeer of Amsterdam (fig. 10).

A later artwork (see fig. 11& 12) was a real tensegrity artwork, won in an art design competition. It was made of 6 masts, 4 booms and 3 compression studs. These were all steel compression tubes stabilized by 105 cables. The roof planes were made by 3 membranes with the associated wind and snow loads on the tensegrity structure. The structural calculations were rather difficult. It was

1978. The Ices Strudl computer program still was operating with punch cards. The 1 to 20 scaled model proved to be more helpful than the more than 50 computer runs with large deformations with which the computer program could not cope. The sculpture was built in three weeks time, although the planning was only 3 days. It appeared extremely complicated to establish the exact geometry with the analyzed pre-stresses.

In those times I had a discussion with Peter Rice in 1991 at the Amsterdam Architecture Academy, whether he would know exactly how high the pre-stresses in the cable structure in the Louvre Pyramid were. I did not get a satisfactory answer. Most probably the builders stopped pre-stressing when the glass panels were visually seen as flat. This all added to the mystery of tensegrity structures.
In 1985 I made a sculpture in the inner court yard of the Amsterdam Maritime Museum with Krijn Giezen. It existed of 4 twisted masts stabilized by 12 cables, fixed on 4 foot points with

| FIGURE 10

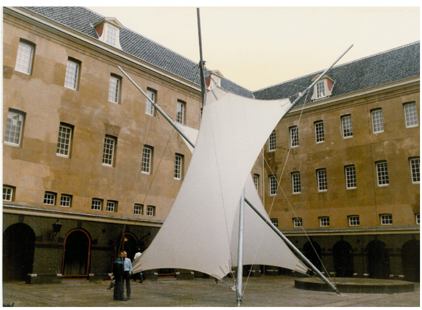
| FIGURE 11

| FIGURE 12

two large twisted sails (fig. 13). People were afraid of the masts falling down, they walked around the sculpture instead of walking through it, as was the logical way. Which was quite visible in the winter snow. The sculpture was removed 15 years ago to enable the inner courtyard to be covered by a glass roof.

So, from our experiences we learned that complicated tensegrity structures were highly indeterminate as structures. Once one single cable is stressed, all other cables will be influenced in their stresses. The tensegrity structure at Hemweg had 13 tubes and 105 cables. It took 5 times as long as anticipated to build and yet we found it was not 100% reliable (Fig. 12).

FIGURE 13



2.8 THE HAGUE TENSEGRITY CHANDELIERS

Let us go back to the initial challenge. In the tensegrity clouds of The Hague around 250 tubes of 5 m length were designed, connected by 1500 cables. One can understand that an entity of fixed cables and compression tubes can be analyzed. The real question was how to reach this stage with properly pre-stressed cables? The biggest problem was how to erect, how to install and how to pre-stress to the phase of a fully reliable structure, suspended in 25 tons of deadweight above the shopping street.

This challenge on the desk in 2013 seemed improbable and impossible. Yet the item of tensegrity structures challenged Octatube with its daring structural engineers and architects. So we studied the possibilities seriously. Making tensegrity compression elements is not a challenge. Circular tubes, even in stainless steel, can be made as regular components. Cable elements with two eye ends and turnbuckles for post-stressing can be easily produced. Normally we would look

for prefabrication off-site. But prefabrication in larger units was impossible as the compression components measure around 5 m long and overhead tramway cable lines at 4.5 m height obstruct the traffic of these units. So prefabrication was not an option.
The structure had to be built on an enormous scaffold platform on the street, with free height for pedestrian and cyclist traffic and for the fire brigade. (fig: 1). As per specs the building time was restrained to 3 months only. There was not a single modus, not even in my wildest dreams, I could think of pre-stressing basic tensegrity units and then combine and post-stress them together on the site.

2.9 BUILDABILITY

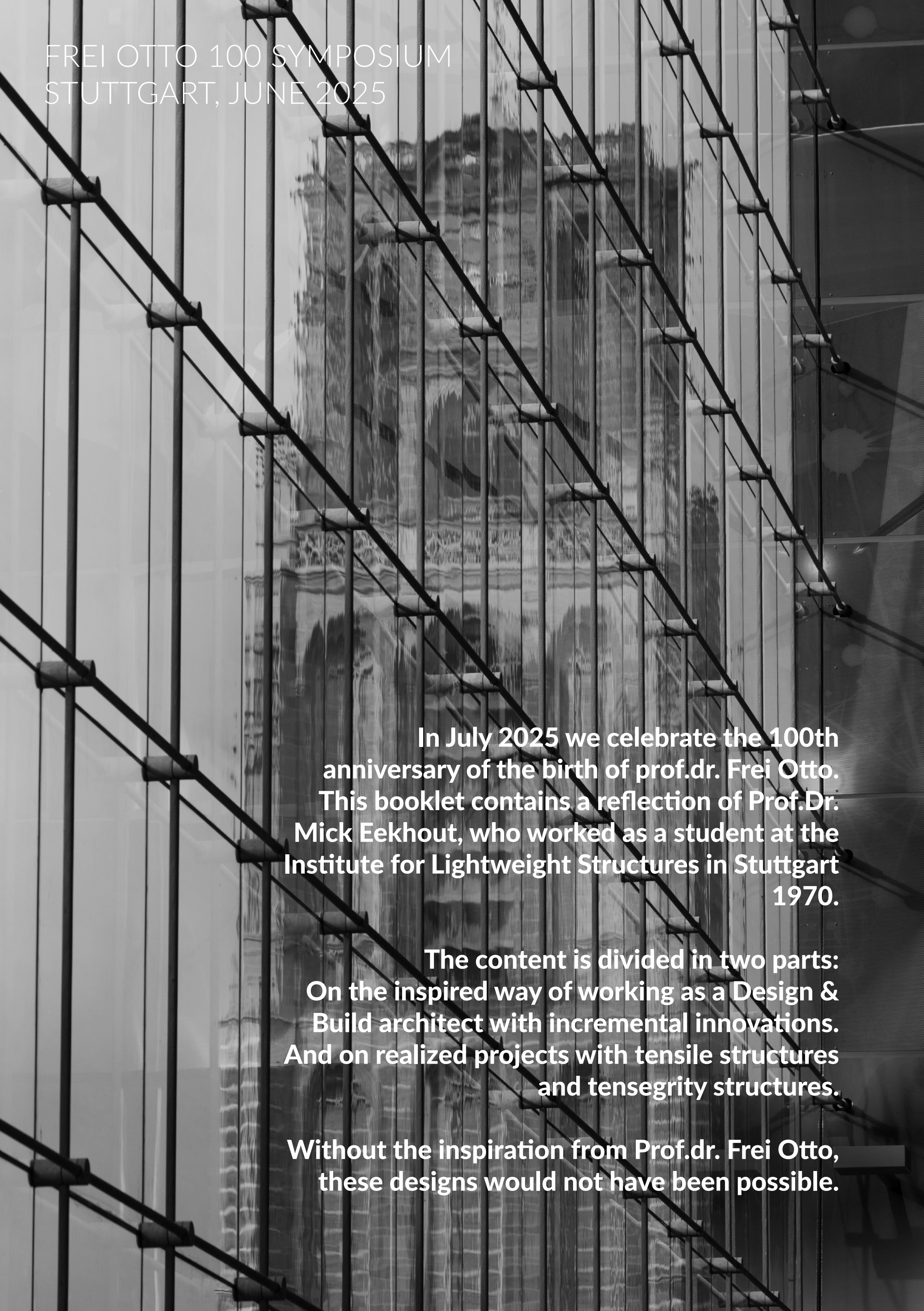
So the basic problem of the tensegrity structure in The Hague was that the buildability of such a complex structure with so many compression tubes and an overwhelming amount of tension cables on top of a busy shopping street in a restricted time, under pressure of a European tender as if it was a normal tender, was impossible. And this claim will stay for another generation, unless more than regular money would be available to take the proper time for experimentation, ample time and computer assisted tension gauges to keep track of the pre-stress process of the individual stresses in the elements and the geometry.
It would have been better to develop a prototype in the mode of project design and learn from this process. And after that tender on gained knowledge instead of believing the computer rendering without any practical experience and believing the opinion of the architect. The first prestressed cable net structure in Montreal was precede by a mock-up prototype. Now the ‘tent ‘of the IL. Making a full scale prototype and learning from it, also by testing, makes a better impression than jumping into unknown waters.

REFERENCES

Horst, L. van der, 2009. *Voor de horizon*. ISBN 9789078964445

Snelson, K., 2009. *Forces made visible*. ISBN 978-1555952433

Buckminster Fuller, R., 2008. *Operating Manual for Spaceship Earth*. ISBN 978-3-0377-8126-5



FREI OTTO 100 SYMPOSIUM
STUTTGART, JUNE 2025

In July 2025 we celebrate the 100th anniversary of the birth of prof.dr. Frei Otto. This booklet contains a reflection of Prof.Dr. Mick Eekhout, who worked as a student at the Institute for Lightweight Structures in Stuttgart 1970.

The content is divided in two parts:
On the inspired way of working as a Design & Build architect with incremental innovations.
And on realized projects with tensile structures and tensegrity structures.

Without the inspiration from Prof.dr. Frei Otto, these designs would not have been possible.