# THE DELFT PROTOTYPE LABORATORY

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# THE DELFT PROTOTYPE LABORATORY

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## THE DELFT PROTOTYPE LABORATORY


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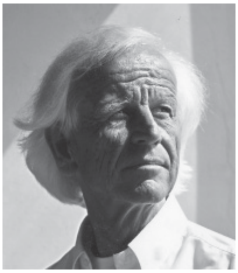
# PREFACE



Hans Ruijssenaars
(© Mark van den Brink)

Somewhat impractical, and lacking any real experience in building, I begun studying Architecture in Delft in 1962. I was skilled in drawing and painting, loved paper, ink, pencils and paint. The unruliness of materials with which I had drawn and painted was a continuous challenge to overcome. It was only after many years in Delft that I was able to grasp some understanding of materials. A lasting impression on me was made through the practice of metalworking and welding and through the early studies of wood, where we had to transform a timber block into a piece of art. This was in fact a crash course in material science, even though our efforts, as I later found out, became firewood for our teacher's open fire. Until this day, 50 years later, I am still benefitting from these exercises. Craft, the taste of making, discovering the limitations of materials and the great admiration for craftsmen are all indebted to my experiences at Delft. Since graduating, I have continued to fill the gaps in my knowledge of materials through attending metal, tile and concrete courses. The fascination for the materials themselves, as well as the interaction between them,their coherence in a building structure, is now more alive than ever.

The computer had not yet entered the world of building when, in 1968, I travelled with several students and professor Bakema, to visit Frei Otto at his studio in Berlin. He had just finished the design for the tent-like roof for the stadium in Munich. It was impossible to calculate how much the main tension cable would sag under the weight of the roof combined with additional snow load. Varying inputs from the brightest engineers in the world gave results from "flat on the ground" to 2 cm maximum. Frei Otto had only tested a small model with imposed scale loads and from there concluded that it was quite all right. Quite remarkably, in reality the roof best matched the expectations that had been predicted in the model! The prototype followed the same laws of gravity and material!

At the end of the sixties, after my graduation, I went to study for a further year with Louis Kahn and Robert le Ricolais in America. Three afternoons a week Kahn held his 'studio' with the almost ever-present Le Ricolais as a fellow teacher. Le Ricolais, 'the father of space structures', was an extraordinary French engineer, autonomous in his way of thinking.
Kahn and Le Ricolais had great respect for each other and enjoyed each other's thoughts and responses. Kahn was continuously working on a greater understanding of materials. In the beginning of his career this involved natural stone of course, then later on concrete and bricks ('what does a brick want to be…."), wood, mostly as a surface material, and in 1950 the sparse use of steel. Much later he 'rediscovered' the enormous potential of steel and it came back, albeit on small scale, into his building designs. For Le Ricolais however, steel was his first material of choice! In his laboratory where I was able to experiment for a year, we built models and competed in bridging 60 cm spans as efficiently as possible. The loading to dead weight ratio of the structure rose to a factor 60!

We did tests with bubble shapes in small spatial wire structures and made the automorphism visible: the cubic bubble within the cubic wire model. In 1969 we made models for a Rapid Transit System running from Boston to Washington. It was 30 meters above the ground and travelled at speeds of up to 300 km/h as it had to compete with the aeroplane (including airport waiting times). We developed an 'automorphic-tube' through which a train raced (electromagnetically!), suspended from cables which slid over the supports, enabling it to benefit from the stiffness in the tube of the subsequent span. Later a helium filled closed tube was introduced to reduce air resistance. We performed scaled loading tests (like Frei Otto) and based on the results we stretched the span between supports from 60 to 90 metres, all under the nonconformist supervision of Le Ricolais: a true prototype laboratory at its best. What a fantastic manner in which to test and practice with one's own hands, the juncture between mechanics and calculation. The sense and understanding of materials, with all their unruly quirks is of continued educational value to me.

In 1992 when I received an assignment to design a cardboard theatre in Apeldoorn's 'paper-city' to celebrate its 1200*th* year, the prototype-lab-sense came strongly back to life. The amazing properties of corrugated cardboard led to a theatre for 200 people that weighed less than 1500 kg, which was protected from being blown away by a tent canvas that secured the structure to the ground with pegs. The entry ticket was an easy to assemble cardboard chair which you could take home after the show. Despite moisture from the air creeping into the cardboard it just managed to survive the required 6 weeks…

If anything has become clear to me in my long and fulfilled career as an architect, it's that building, for architects the designing and developing of buildings, cannot be seen as separate from matter. There is a need and obligation to develop an understanding of materials, which is endless. Computer technology forms a barrier between thinking and making. With traditional drawing methods, there is still a material bond between the graphite and the paper. Computer technologies and modern rendering capabilities raise this barrier further. Of all our senses, only the visual is triggered.

But with matter there is more. Feeling, smelling, hearing and even tasting forms an unbreakable bond with the visual. The coherence, mutual exchange and respect for matter in it's incredible diversity keeps on being a part of our existence.
Also in new materials, new production techniques, like 3D-printing, there is much to discover.

In this book it is wonderful to see how the Delft Prototype laboratory, founded by Mick Eekhout in 1995, is practising with a diverse range of materials, how materials compliment one another and searching for the boundaries of the prototype and how this is becoming part of the DNA of upcoming architects. In that DNA materials interconnect with cerebral design activity. Thus preventing the visual 'rendering' being disconnected from what we ultimately must understand; real materials, gravity and daylight. The Delft Prototype Laboratory is an extremely valuable place.

Hans Ruijssenaars

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# ABSTRACT

In architectural education increasing digitalization leads to de-materialization, to abstraction and to the 'lawlessness' of free form architecture. The lack of practice experience in the study time and the sudden surprises at the start of the practice time of young alumni makes it necessary to prepare architecture and engineering students in order to restore their balance between abstraction and materialization. The experienced generation has ample overview with materialization, be it that continuously new products and techniques are developed for buildings of which they should have knowledge. The coming generation has only its imagination and fast learning intellect, but large omissions in practical building experience. So the students are sometimes brilliant but usually lack practice and experience of professionally working with their hands. Buildings stay longer than the lifetime of the creators. Materials and material techniques are very important to chose the suitable materials and develop the correct details to connect the materials, elements and components together. And yet they lack the inspiration from that materialization. It also influences their faith in their own abilities. As all designers they try to see their dreams realized. In order to open the possibilities of making material prototypes and to get rid of cold feet for young designers a special prototype course and a laboratory / workplace for prototypes was developed and implemented by the Chair of Product Development. For these reasons the Prototype Laboratory at TU Delft was installed in 1995.

Combining creativity and surprising out-of-the-box thinking with the initiative to materialize design concepts for building components can lead to new product concepts for building components. Revolutionary, continuous or even incremental innovation in industrialization and prefabrication with new technologies in the development of building components stimulates the state-of-the-art of technical architecture. It keeps architecture in material respect alive and up-to-date with societal progress. Educating prototyping distinct the department of Building Technology TU Delft from the education of architectural engineers and building technology designers of many other universities. And it works. The amount of foreign students in the prototype semester is almost 50% in 2012. But the experience of prototyping came from practice.

This book also relates prototyping to the position of a practical designing professor at the Chair of Product Development who regards his private design & build office as his research laboratory as it were outsourced from the TU Delft , on the results and processes of which he contemplates in his scientific research publications. He even goes to the extreme of theoretical publications for example on the topic of methodology, but always this knowledge and insights are gained from practice. Being a practical designing architectural engineer as well as a university professor enables him to combine his positions in two separate domains of industry and academia. Experimenting and prototyping play an important role in order to increase knowledge and insight by continuous engaging inventions into innovations.

The Prototype laboratory worked ever since 3 times or 2 times a year with a group of maximum 25 students, a provisional staff in a former workshop in Mechanical Engineering. The collection of 18 years of full-scale material prototyping provided more than 900 graduates with this very valuable experience of design & build innovation. The knowledge of and the hands-on experience in getting any technical design or 'dream design' into reality controlling the material properties and available production techniques equipped these graduates eminently as technical and innovative designers in the realm of architecture.

In education of this type of architectural engineers it is no use to design and prototype the usual, the familiar. Instead the invention and innovation with the risk of failure is far more instructive. To get the stronger effect in the desired education students in small groups are prototyping their own design ideas. The development of the education in the Master tracks of Architecture is showing how groups of students work on prototyping in quite innovative designs in a short span of time.

It goes without saying that the costs of these material educational exercises are often a multitude of normal design and engineering courses. In the more than 18 years of its existence there was a continuous battle to get faculty funding. Originally the Chair had ample means, but after a rigorous slandering of its size due to unforeseen and ad hoc new management rules, the extra over funds came from the department, not any more from the faculty. To keep such a facility going means commitment from the department and the faculty, which really had to be forced in 1995, but later was never actually doubted as a goal. Getting the proper financial means for prototyping, however, is a continuous battle, in which many SME companies are involved, informed and challenged by the students. Many companies have donated small amounts of money to these students or materials, elements and components.

Most of the Delft Architecture alumni have stated that the experience with this design & build process of prototyping opened their mind for an technically inventive and innovative way of thinking for the first time in their architectural education, which is such an important element in the toolbox of the architectural and technical engineer. For this type of architectural engineer the aesthetics of a building or a building component is in a reciprocal relation to the materialization. The architectural engineer or technical architect is the contemporary variant of the architectural hero-to-be that students wanted to become a decade ago.

# INTRODUCTION

Prototyping building components, if at all, is a rare phenomenon in the building industry. Architects see every building itself traditionally as a full-scale prototype. Architects are even proud of the phenomenon that they are designing prototype  buildings. In the sense that each following building is another prototype. This concerns the building as a technical artefact, a composition of selected, coordinated and integrated materials, elements and components. In the world of building components prototyping proves the correctness of the design & engineering process or enables structural tests to be done on the prototype. It goes further. Innovative industrially prefabricated important building components like façades, however, inevitably demand an intelligent design & engineering process to prevent failure in the design & build arrangement and by that prevent complicated post-process claims. Alas the amount of lawyers increases while the amount of architects and technical engineers decreases.

In design & build contracts of new innovative building components the necessity of full-scale prototyping is an essential part of the game. Innovation without prototypes is impossible or only bluff. The complexity of bringing new technologies in the process of product development cannot do without the trial and error character of full-scale prototyping. Reasoning and even 3D computation is not realistic enough.

The wish of failure prevention in the design, engineering, production & assembly process is a motif for introducing prototyping into the design & build product development of building components. But there are  also  the benefits for the speed of the process as a whole. The trial and error character of material prototyping shows possibilities and impossibilities much faster than a process that is based and sketching and computer drawing exclusively. Every technical designer has experienced the reciprocal relation between hand and mind. The hand stimulates the thinking and the thinking stimulates the hand caressing and fantasizing materials. Sometimes the handling of material shows new possibilities to the open mind just as the mind brings the hand to new ways to handle material.

Clearly industrialization, prefabrication and innovation necessitates prototyping as an important part of the curriculum in the education of architectural engineers. The importance of knowledge of and experience in full-scale material prototyping cannot be overestimated.

However important this knowledge and experience is, any graduate of the Delft Master track Architectural Engineering or the Master track Building Technology, has to experience at least once in his education the 'hell of materialization'. The confrontation between the esthetics of technical design with the brutal world of material, tolerances and of production techniques properties is a must have experience for any technical designer. What looks so beautiful and easy in any drawing could be very difficult to materialize. In a way, a drawing is like a 'Fata Morgana', it looks so beautiful but this destiny is never to be reached without blood, sweat and tears.

This book treats the role and function of prototypes in the building industry, actually in the science of Component Design and Product Development. It has been divided in two parts: the first one about prototypes in practice, in the process of design, development, research and engineering of new or renewed products and components. The second part deals about the actual student prototype thinking and results.

The distance between theoretical research & development on the one side and the practical search for an innovative concept on the other side. In general the building industry is known as very conservative, not innovative at all. Innovation yes, but not in my own project. Luckily enough there are also heroes of product innovation, like Frei Otto and Renzo Piano. The Chair of Product Development holds an ambition for continuous innovation.

The two extremes are fundamental research on the one side and free artistic design on the other side. Yet the relationship between these two extreme domain entails the technical domains in between. It shows that there is a relationship between the neighboring domains, be it in the application direction or in the opposite fundamental direction.

In architecture prototypes are known on different scale levels, like urban design, architectural design and building technical design. In this book we concentrate on prototypes in buildings technical design. The newness and innovations will sometimes lead to patent applications, if sufficient newness in the invention is present. It does not count for a new composition of known or existing elements and components.

For a successful company in continuous innovation, it is wise to lead both the design & engineering phase as well as the production & building phase. Design & build companies have more mastership over their motivations, process management and hence results. Examples are given from the practice of Mick Eekhout's Octatube company at Delft, a medium sized (80 plus staff) design & build company working in The Netherlands and all over the world for more than 30 years. Incremental innovation in product development results in positive innovations over the years within one company. This could also be applied in the ambitions of a private architect, an architectural designer or a building technical designer.

In our time of increasing digitalization material prototypes are giving a counter balance against the increasing mode of abstract design, unaware and non-experienced in material design and development. Prototypes can be used, after the making, including the tolerances problem of assembly, to test the performance of the product as a totality. For structural artifacts there are the structural tests, for construction artifacts there is the water tightening for facades, for example, the aesthetics of the modus operandus of assembly.

The Chair of Product Development was installed in 1992 to educate and research in new product development, specialized in the view of the chair holder, professor Mick Eekhout, in lightweight materials and high tech thinking. Towards the extreme potentials of materials. The Chair has initiated in 1995 a fully equipped laboratory for prototypes for preparing and making of prototypes by students. They had to learn making shop drawings, learn about tolerances, integrate different components for assembly made by different sources. The were taught machining of metals, welding of steel, even if only in a rude grade. With these skills they tried to make a prototype out of their own design dreams.

The chair of Product Development has been terminated with the retirement of professor Mick Eekhout on June 22nd 2015. The Bucky Lab supervised by dr. Marcel Bilow is continued in the section Architectural Engineering.

# 01 PRACTICAL PROTOTYPES

## 01.01 THEORETICAL RESEARCH AND PRACTICAL DESIGN

The Chair of Product Development (and Design of Components) acknowledged the importance of material prototyping in the education of technical oriented architectural designers. Speaking from the experience of 30 years of component design in many experimental projects prototyping is essential in the technical innovative product development of building components. Eekhout learned this in his father's carpenter workplace. But also in the (IL) Institute for lightweight Structures of Frei Otto in Stuttgart and in the Studio of Renzo Piano in Genova, while working there as a student. These pioneers and their works have always inspired and do this still.

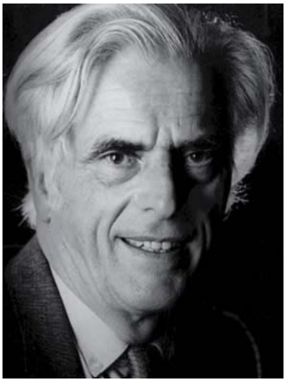

FIG. 01 Frei Otto (1925-2015)

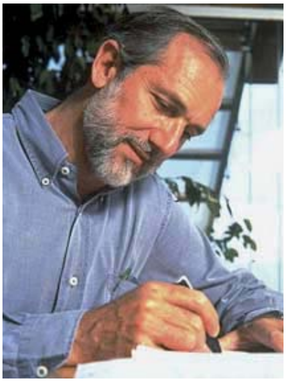

FIG. 02 Renzo Piano (1937 )

Prototypes help designers to be better in their technical designs. Designers need prototypes as they are the materialization of a dream they think of, but are never done before. Some say designers are liars as they speak of a future that has never been before.

Prototypes make an end to a lie. The lie becomes reality. So material prototypes are important for designers. They confirm or rectify their dream. Which becomes reality. They show their own responsibility. Designers are discovering new futures that are not logical or not probable to others. They are the discoverers of new possibilities, new potentials. According to TU Delft colleague prof.dr.ir. Taeke de Jong [Ref.1] architects as designers should be looking for a desirable future, a *possible* future but also an *improbable* future. The probable future will happen any way. For the probable future you do not need designers as it will happen anyway. No wonder that the improbable or surprising factor in Dutch architecture is highly valued. In many countries around the Netherlands the bureaucracy and the norms  and rules are killing dreams before an architect dares to show them as designs. This is the domain of the possible / impossible future.

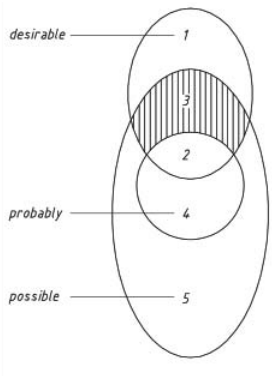


FIG. 03 Taeke de Jong: Designers are pursuing a desirable future, a possible future but also an improbable future.

Scientific Design in Architecture knows many methods, see *'Ways to Study and Research'* edited by Taeke de Jong and Theo van der Voordt [Ref.1]. Eekhout's personal contribution in design methodology has been described in the yellow book *'Methodology for Product Development in Architecture'* [Ref.2]. This is a theoretical philosophy from the practical background of designing, experimenting, prototyping and building of the technical design proposals. Theory distilled from practice. Traditionally the building faculties at the former Dutch Polytechnics in Delft, Eindhoven and Twente were very material-based, before they became Technical Universities in the 1980s. Since then also the phenomenon of academic research, quite independent from practice came up, in imitation of the science-based faculties of the technical universities and of the general universities. At the Dutch faculties of Architecture in Delft and Eindhoven only a small part of research is truly academic and scientific, done usually by full-time professors and researchers, devoting their time in long term, fundamental and academic research. They usually have only light connections with the building sector. But their advantage is to go into a full depth of fundamental research.

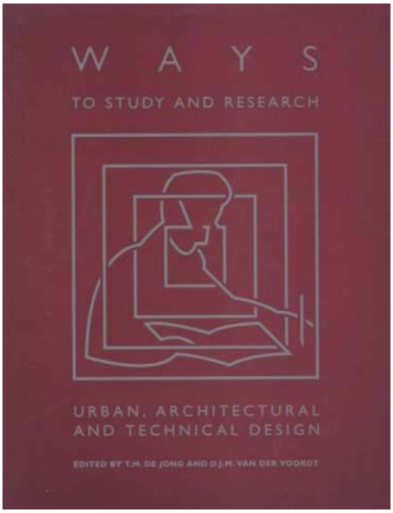


FIG. 04 Front cover of 'Ways to Study and Research'

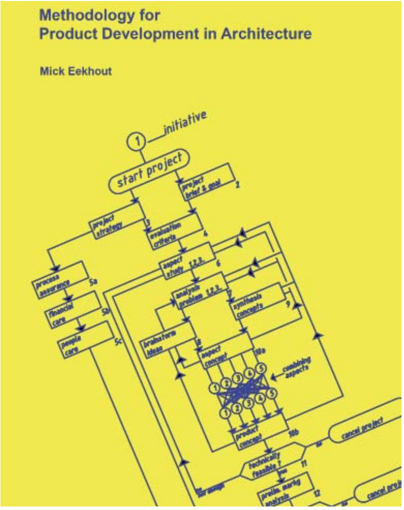


FIG. 05 Front cover of 'Methodology for Product Development in Architecture'

While the majority (90%) of the professors are only part-time engaged to the universities and more design & engineering directed. These practice professors devote the majority of their time in their own design and engineering practices. Usually they are engaged to the university for 0,2 to 0,4 fte only: one or two days a week. Usually they devote their time to education, more than to research. These practice professors (in Dutch 'praktijkhoogleraren') regard their work done in their offices as their laboratory research, on which they contemplate and philosophise at the university and also publish. Their research is outsourced as it were from TU Delft to their offices or laboratories. This attitude has been illustrated by famous architects-professors from the 1960s and 1970s post-war reconstruction (in Dutch: 'Wederopbouw') generation of architects like Hans van den Broek, Jaap Bakema, Aldo van Eyck and Herman Hertzberger. This generation was not known for their research publications, in contrast to the contemporary  expectations of practice professors. They became famous because of their design projects and overviewing lectures which were attended by many students. Always a full house of students. At which occasions they contemplated verbally on their work and the broader scope of the context in which their designs had to be positioned. They inspired students and prepared them for practice.

In the last decades the attitude at the technical universities has changed and drifted more towards theorizing. The professors are expected to be leading both in education and in research in their fields of expertise. Eekhout regards himself as a practice professor, with his main domain in his design & build company Octatube in Delft, contemplating at the Technical University of Delft on the findings and processes of his projects and publishing on this in academia. This book defences that position. Each professor is by law also responsible for valorisation and has to attract collaborations with external parties in the building industry, affiliated parties and consortiums.

## 01.02 KINSHIP BETWEEN FUNDAMENTAL RESEARCH AND FREE DESIGN

In each of the three Dutch TU's the faculties can be divided in 3 main types:

- **Sciences** [at TU Delft: Applied Sciences; Electrical Engineering, Mathematics and Computer Sciences];
- **Engineering** [at TU Delft: Civil Engineering; Aerospace Engineering; Mechanical, Maritime & Materials Engineering];
- **Designing** [at TU Delft: Architecture; Industrial Design Engineering; Technology, Policy & Management].

The habits of the three main types of faculties are different. The markets are different, the players are different and people in these three types of faculties usually do not understand each other quite well as they are not accustomed to each others language, methods and strategies. They have different goals. Yet when one overlooks the total playing field of the all the faculties of the technical university in each research project there are fundamental aspects, technology aspects and design aspects. So in case of a Babel-like confusion there will be a loss of integration and as a result a possible level of quality. Knowing each others specialization, appreciating each other, asking each others assistance and collaborating with each others influence could make better research results. Inspired by a scheme of emeritus prof. Guus Berkhout which he made in his former function as the vice president research of the TU Delft the author has derived a scheme to show the mutual relationship or rather 'kinship' between 6 major different types of researchers at the technical universities, see figure 6.
The scheme shows that each ring-shaped domain has a core of activities that is principally different from its neighbour. Usually the players are different, the language is different, the playing rules are different: these are very different arenas. Yet they have something in common which relates them. Each domain looks to the left hand domain as its more fundamental relative; while looking to the right one sees the more application-directed relative. Fundamental technical research is the most fundamental science available at the technical university. They have a more ('purely') fundamental relative at the general universities, who see them in return as applied fundamentalists. They regard the fundamental technical research on their right hand side as applied playing field that is filled with the principles they have invented and researched and forms them into a wider, broader technology. In their turn these fundamental technical researchers will see their right hand neighbour as developments of principal engineering systems.

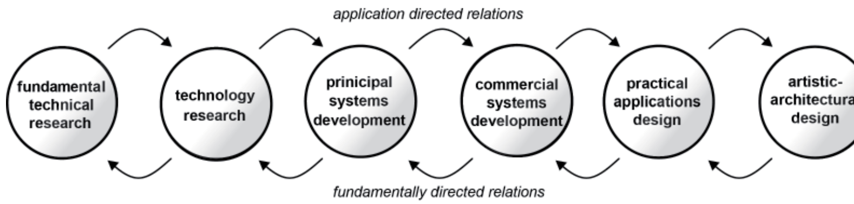


FIG. 06 Relationship between the extremes of fundamental technical research and free artistic design.

In their turn these principal systems look to the right and see commercial systems, made on the basis of their principal systems, but ready to be applied in practice. These commercial and or societal systems looking for applications will find that they need their neighbours, the application designers to bring their results to the markets. The most creative of these designers do not mind restrictions or any systems: they are free thinkers.

Within one project a scientist can also experience that, although his home base is technology development of application design, he would need to go to the fundamental side first to develop new principles or have new principles developed, before he sees how these new principles could lead to an adaptation of the technology, to new system principles and to new commercial systems, that can potentially be realized: Applicable systems. Before he can look for an application environment and apply the new system over there. Maybe, with enough freedom in his head the composition in itself also has a degree of surprising and unexpected newness. So for example a temporary structure out of cardboard would need an in-depth study of the paper or wood from which the layers are made and the glue that bonds the paper, layers study of the structural characteristics of paper tubes in the sense of strength, stiff ness and stability, and of the outer layer protecting the paper tube against his proto-enemy 'humidity'. Having found a new formula for the basic material and the bonding plus an improvement of processing this material industrially, he can go back to structural design technology. Think of the best ways in which improved cardboard tubes can be used to build a structure with certain characteristics. Finally he could look for a challenging application and an application, like a paper dome for a temporary building in IJburg/ Leidscherijn after global design of the Japanese architect Shigeru Ban from Paris. See figures 7, 8. Cardboard structures are very popular amongst students as the basic materials is very cheap. The material in itself is not trustworthy to be applied as load bearing components in a structure, so an engineering process has to be undertaken to ensure a reliable structure in cardboard. Students often use cardboard for their prototypes.

FIG. 07 Outside view of a 3m diameter cardboard dome in Leidscherijn, Utrecht NL

FIG. 08 inside view

Being able to jump around on the 6 ring scheme means that one is able to go deep in research at one moment, be responsible in the width of technology and at another time be creative and original enough to compose with new principles and a new technology a surprising new design that astonishes the world. It is only the very few that is able to do the fundamental research themselves, be responsible technology engineers and do an extremely surprising design composition as well. One tone down we could also be satisfied with realizing these different domains, different playing fields. And to connect oneself to the best brains on the extreme domains when one is not able to perform it himself. This does not change the validity of the scheme: going through it or jumping over it is both possible as long as the different domains are recognized and respected. And the scheme is a principle scheme, not to be taken too literally.

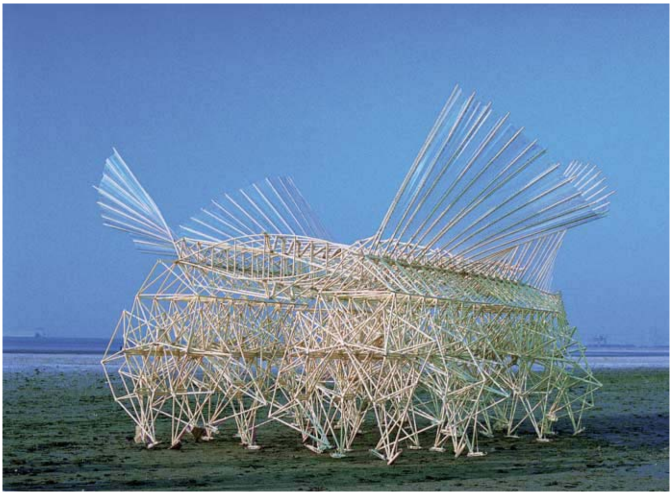

FIG. 09 Theo Jansen's 'beach animals' of PVC tubes 'Animaris Currens Ventosa'

A clear example is a crazy designer like the Delft artist Theo Janssen with his beach animals (he calls them 'animari') that almost walk on the beach against the wind, thanks to the energy impulses from the wind, see figure 9 [Boekman 58/59, Ref.4]

Prof.dr. Rutger van Santen, previous rector of TU Eindhoven mentions 5 criteria for scientific design in his lecture on 04.11.2009 for the Research School Bouw [Ref. 7]:

- Publications;
- Societal impact;
- Development of new knowledge;
- External stakeholders;
- Reputation.

How do prototypes fit in this list? They are carriers of new knowledge and insight in a material form. Without publications or an extensive description on the prototype this proto does not spread the knowledge. In the Octatube laboratory in Delft a number of prototypes are built as segments of a building structure that, after an extensive process of design, development, research and engineering were built to be a proof of the developed quality. One prototype is the façade segment for the Finnsbury Pavement project in London. See figure 10 to 12.

The Finnsbury Pavement façade was designed by Sheppard Robson and engineered by Arup extensively but needed more materialization before it was built. A number of alterations and necessary improvements were made. The costs of such a mock-up are considerable, but noting compared with a site improvement of a built error.

FIG. 10 Finnsbury Pavement façade segment in the Octatube laboratory

FIG. 11 Realised glass façade in London

FIG. 12 Detail of façade

Another row of examples are the different prototypes of wing segments we made for the Rabin Centre, which showed different modes of construction for the Rabin wings, so that we could convene with the architect which way to proceed. These prototypes convinced the designers and engineers of the different possibilities and finally in the discussion with the client, architect Moshe Safdie from Boston, the most attractive mode was chosen on the grounds of elaborate arguments. See fig 15, 16, 17. [Ref. 10] 'Lord of the Wings', Mick Eekhout, Sieb Wichers, IOS Press 2015, ISBN 9781614995494.

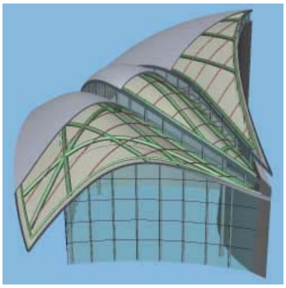

FIG. 13 Overview over the GRP roofs of the Great Hall of the Yithzak Rabin Center in Tel Aviv as a tubular steel srtucture with a thin composite skin

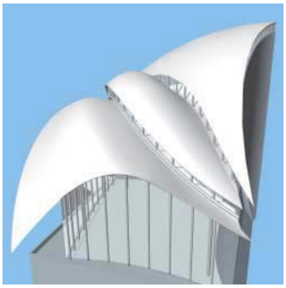

FIG. 14 Alternative in GRP sandwich shells

FIG. 15 Three different modes of segment prototype  for the Rabin roofs traditional with separate membrane skin

FIG. 16 Traditional with prefab GRP

FIG. 17 Sandwich GRP composition

## 01.03 SCALE OF PROTOTYPE DESIGNS IN ARCHITECTURE

Buildings and architecture objects are so big in scale and size that they cannot be made as development prototypes and having them tested and build the real object later as this is too costly an affair. But parts of buildings: i.e. building technology knows smaller scale building products, building systems and special components. They often can be isolated as prototype components of restricted scale. Real material prototyping and testing can be performed and have to be performed as systems often have large repetition in production. A solitary building, even repetitive houses or apartments, is too large to be built, tested, evaluated and built again.

So due to the even larger scale in town planning and architecture material and real scale prototyping is not affordable, usually not done and hence the final building or the urban design is the prototype (in direct realization), the prototype artefact itself to be used by the client or by society.

In building technology, where the artefact is the technical composition of a building made of elements and components, experimentation with prototypes often improves knowledge and insight and produces feed backs by technical testing and human acceptance and usage. This book emphasizes the use of experimentation by the making of prototypes of parts of the building technical products or systems. Prototyping is done in the form of the total composition of the building technical product or a building technical system. If necessary or otherwise unavoidable to see the building technical artefact of the building as a prototype. Goal in order to gain knowledge and insight is to see how one would progress from there.

## 01.04 BUILDING PART, A BUILDING OR A TOWN DESIGN AS A PROTOTYPE

Material scale models, paper scale models (i.e. drawings) or digital scale models (2D-drawings, 3D-drawings or even a 3D-model of the designed artefact) are all scale representations of a prototype. They are proof of scientific designs when a certain level of newness is contained in them, but they would need an extensive description of the process and the result to be regarded as a outcome of scientific design or research by design.

The glass fibre reinforced polyester roofs of the Rabin Center in Tel Aviv are developed as a prototype of a new generation of roof construction. The process and the end result have been published extensively, for example in the Delft Science in Design 2 Congress of 2007, [Ref. 6]. The roofs are a proof of building technical invention and innovation with this extensive description [Ref. 10].

FIG. 18 Test building of 3 sandwich segments of the Library roof in Lelystad

The Mercedes Museum in Stuttgart, designed by Ben van Berkel / UN Studio is a complex building where the Möbius geometry represents the endlessness of the engineering and production cycle at Mercedes. The building's geometry proved to be extremely complex. Yet the building has been realized in the planned time, which makes the building a wondrous combination of architectural concept, co-engineering collaborations, complex management and professional quality level. An extensive treatise was written on the subject [ref.7]. The combination of this all could be presented by Ben van Berkel as a work of scientific design, if he would have been a professor at one of the 3 TU's in the Netherlands, see fig. 19. And the 3TU could regard UN Studio as their lab. Now the same is done by prof. Michiel Riedijk and prof. Kees Kaan.

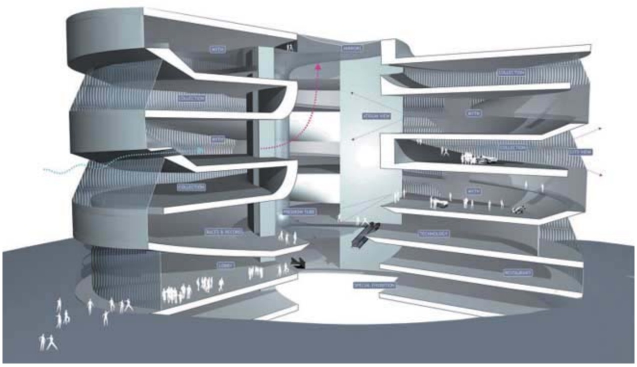

FIG. 19 Isometry of the Mercedes Museum, courtesy UNStudio

The urban design scale is even larger than buildings. The velocity of realisation if weeks for a building component and months or a few years for a building can be decades for an urban plan. Both in scale and in realisation period urban design distinguishes itself from the architectural scale. The design prototype, if materialized can only be a scale model, but by then the details are not present any more. An urban designer can present a scientific design of a part of a new town, for example Almere Pampus in paper drawings or in a 3D-model where the larger scale and the smaller scale details are all included and can be zoomed in and out. In the urban design the architecture of buildings and constructions have a smaller scale and can be prototyped. The most inventiveness usually is done on the scale of the building part. Architecture often is an assembly of well known components, which have been experimented long ago and are only composed in the desired order.

## 01.05 HYPERBODY ROBOTIC LAB (2012-15)

Colleague Prof. Kas Oosterhuis has his Hyperbody Laboratory focussed on digital production, which is worth mentioning here.

The workshop Scalable Porosity (2014) focused on developing design to production methods for introducing porosities at different scales, ranging from micro levels, as material systems, to macro levels as spatial and architectural configurations. The aim was to develop material patterns that by additive layering will generate variable porosities. In principle, these patterns may address a range of scales, where voids may vary in ranges of, to the building scale, where voids may vary in ranges of meter, indicating inhabitable spaces. Due to production process constraints within this exercise, the focus has been on porosity ranges from millimetres to centimetres achieved by means of robotic material deposition.

The Hyperbody Robotic Lab has been established 2012 at RDM in Rotterdam with two large ABB robots and since 2014 has moved back to BK and operates with one ABB demo robot and one KUKA robot. In these period of time two relevant projects have been implemented: The Scalable Porosity project (fig. 20), which was produced by additive manufacturing (2014-15) and the Vault project (fig. 21) which employed wire cutting (2012-13).
The Scalable Porosity project has been supported by 3TU, Delft Robotics Institute (DRI), 100% Research, AE&T, KUKA, and ABB.

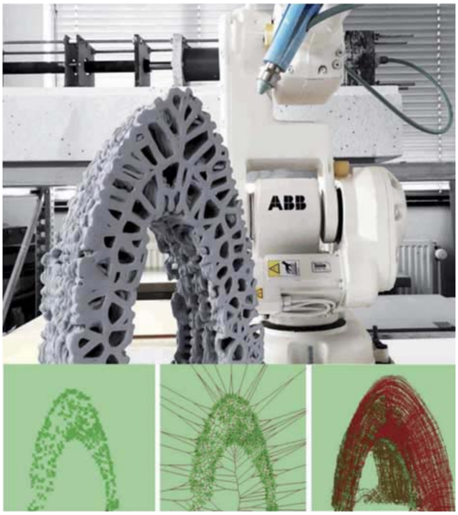


FIG. 20 Fragment of urban furniture (1:1 scale) structurally optimized robotically 3D printed at Hyperbody (2014-15)

The initial experiments with robotic subtractive manufacturing (fig. 21) where followed up by additive robotic production (fig. 20), which implied linking design to materialisation by integrating all functionalities (from structural strength, to thermal insulation and climate control) in the design of building components. This was implemented by employing novel multi-performative D2P strategies: New materials were developed for the robotic production of multi-material building components and novel robotic production and assembly tools were deployed for testing the blueprint of future robotic building.

Teams of presented projects are dr. Henriette Bier, S. Mostafavi, A. Anton, S. Bodea, and MSc 3 Students (Scalable Porosity 2014-15) and J. Feringa, M. Rippmann, S. Oesterle and MSc 2 students (Vault, 2012-13).

FIG. 21 Prototype developed by means of robotic fabrication implemented with two large ABB robots operating wire-cutting tools (2012)

## 01.06 PHD'S ON DESIGN AND PROTOTYPES

The focus of this contribution is on the function and possibilities of experimental material prototypes of different sorts in the process of design and the improvement of knowledge and insight in the process of design research gained by prototyping. Finally this book advocates that prototypes be recognized as feats of scientific quality in the scientific evaluation of design research, but with proper descriptions of the process and its results as prototypes in publications.

Since 1905 according to the Dutch Law of Higher Education it is possible to obtain a PhD degree in Science on the basis of a design. The lettering of the description refers to a machine, according to the logical world of the 19*th* century industrial revolution. But the contemporary interpretation of this working object is also a 'designed object'. In the faculties of Architecture there are three sorts of material design:

- Urban Design;
- Architectural Design;
- Building Technical Design.

It implies for Urban Design that there will always be a scale model of some sort and some scale involved; for a building or architecture a scale model or scale representation is natural and logical; for building technical design, the scale model could also be a real size model, according to the size of the element, component or assembly involved. In all cases the Law of Higher Education expects that aside of the 'designed object' a description of the functional working of the designed object is added. This description is not a conventional dissertation, but could be a shorted variation, depending of the subject. Now we are arriving at the level of the prototype.

The prototype is always a designed and realised object. The prototype would need a description of its functional working and a scientific description and motivation of the design and development process would suffice for such purposes.

The prototype as the designed object has a scientific value when it has ample newness, that is the scale of newness should be beyond the environment of the author, of the university, of the country, for the world. As a symbol of that newness there should be an approval on newness according to the accompanying PhD committee which is per definition collected from the best brains available on the specific field. Newness could lead to inventions, but these are usually seen as material inventions, while progress in science can also be made in immaterial newness. Depending of the position of the PhD candidate in the 6 rings from fundamental researcher to free designer, the subject of the prototype could be fundamental, technical or designed. The extremes can range from the discovery or development of new principles to the composition of a work of art, provided there is enough reasoning, process description and newness in this writing to be found. Preferably a scientific process description should be added.

Likewise, when a designed object is good enough for a PhD dissertation, a designed object in the form of a realized designed artefact, should also have scientific value, provided it is accompanied with extensive functional working description of a process scription of adequate quality. This is also asked of students doing their prototype semester in a lower level of quality.

This means that practice professors who claim to have their 'off-shored' laboratory in their engineering offices can contribute to the building science when a high quality or an adequate description is added to the prototype. It also includes that exhibition models and representations, if provided with an in-depth description, have scientific value. When these descriptions on prototypes are presented as results of 'research by design' the personal involvement of the scientist should be obvious. Design has its gravity outside the university and it is in design offices that design usually is performed in practice, in larger than one person companies. In these cases the designer has to prove or convince that his personal involvement is large enough to regard it as a personal project.

Up to now a number of technical architects have made a successful PhD on design, like Mick Eekhout: Architecture in Space Structures [Ref. 11] (1989), Karel Vollers: Twist & Build [Ref. 12] (2001) and Charlotte Lelieveld: Smart materials for the realization of an adaptive building component [Ref. 13] (2013), see references, but as yet not one PhD student on a prototype for architectural technology, although this domain lends itself excellently for this.

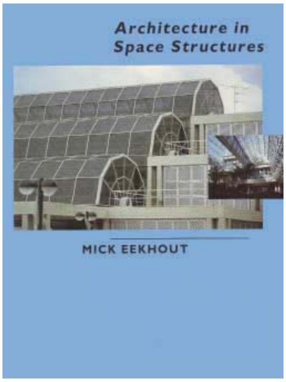


FIG. 22 Dissertation Mick Eekhout 'Architecture in Space Structures' [1989]


FIG. 23 Dissertation Karel Vollers 'Twist & Build' [2001]

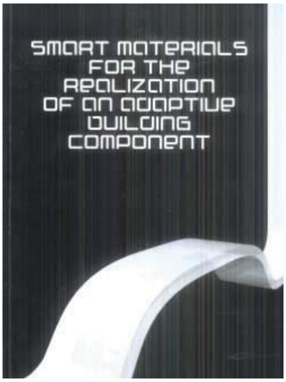


FIG. 24 Dissertation Charlotte Lelieveld 'Smart materials' [2013]

Mick Eekhout wrote his PhD dissertation 'Architecture in Space Structures' [ISBN 90-6450-080-0] [Ref. 11] on his own design & built portfolio of spatial structures and space frames, with the conclusion that glass claddings show the elegance of space structures and hence that in the future more emphasis should be laid on glass, glazings and structural glass and glass structures. After publication in 1989 the emphasis in the work in his design & build company changed indeed from space structures to glass structures.

Karel Vollers published his dissertation 'Twist & Build, creating non-orthogonal architecture' in 010 Publishers, Rotterdam, 2001 [ISBN 9064504105] [Ref. 12] in which he reasoned from urban scale to architecture and via building technology to material technology, after which he composed concepts for components of twisted buildings, proposed an adapted twisted technology and did proposals for buildings in an urban situation. He published the results of his research widely. After this date many architects have chosen twisted buildings in high rise to design slender and geometrically charming high rise buildings like Santiago Calatrava in Malmo, Sweden.

Charlotte Lelieveld finished her dissertation for the realisation of an adaptive building component in 2013, 'Smart materials for the realisation of an adaptive building component', TU Delft [ISBN 9789461861146] [Ref. 13].

## 01.07 NEWNESS AND PATENT APPLICATIONS

The newness as a proof of invention as one of the prerogatives of scientific design and development knows a paper form for society: the patent. This starts as a patent application, in which the newness in regard to the state-of-the-art is documented. In architecture it is not a custom to apply for a patent on newness in the design, be it a composition, or as an technical invention, as there is usually no repetition effect in the prototype mode of design. Also when a design is tendered in the sub-tendering phase main-contractors usually do not like the sub-contractors waving with patent rights. Patents mean a certain degree of monopoly and higher costs. This is not desirable in the building industry with its low thresholds and usual traditional competitive building products. Patents are a token of newness in scientific respect, but are seldom used in the building sector. Patents challenge the more traditional low cost replacement substitutes in building teams or main contractors.

However students are encouraged during their study to describe a patent on their ideas, giving them an idea in which area a patent would be applicable and realistic to attain. As a student Eekhout filed a patent application one day before his final presentation of his graduation project, which later became the Octatube space frame system, the base of the later company of Eekhout. He has filed and later was awarded more than 10 patents in his professional career. For architectural engineers knowledge of patents is valuable. Alas the threshold in the building industry is so low that contractors always will find a competitor who has a cheaper product, neglecting the commercial value of patents for the market directly. But indirectly patents are valuable as they allow the authors to continue their work and not to be hindered by others who infringe their findings by claiming that they have a patent on the same finding.

FIG. 25 The Octatube system (left side) was the result of the final studies of student Mick Eekhout and was applied for a patent 1 day before publication.

FIG. 26 The first application of the Tuball system was demanded from the US by I.M.Pei in a project in Singapore: the Raffles City Complex.

## 01.08 DESIGN & BUILD ATTITUDE

Author Eekhout has more than 30 years experience of designing, engineering, experimenting, production and realization of building technical products and systems in his design & build company. Some of the results and philosophies of this design & build portfolio have been included in this book to give working with prototypes in academia also a meaning for industry. Only a very few architects in the Netherlands have stepped over from pure designing to designing and realisation, each in their own way. The Dutch offices examples are Cepezed (Michiel Cohen en Jan Pesman), Octatube (Mick Eekhout) and (ONL) Kas Oosterhuis.

FIG. 27 Textile museum, Tilburg, Cepezed

FIG. 28 Rabin Centre, Tel Aviv, Octatube

FIG. 29 Showroom A2, Utrecht, ONL

The splits in building component design and development between practice and theory, between industry and academia that usually is seen, has also its distinct privileges when both worlds are combined in order to obtain new knowledge and insight and material innovation.

To put it even stronger and more outspoken: in the process of inventions and innovations in building technology, experiments are continuously colouring the development processes. In order to lead these processes to a successful result, the process leader should lead both the design & engineering part as well as the prototyping, productions & realization part of these processes. In the opinion of the author the design & build attitude is the main factor for continuous success in the attained material innovations in his office. For young architects and architectural engineers prototyping opens for them the material world, with inspiration from material, the co-ordination and integration of different materials and elements into larger and more complex components, which could lead to better designs and better architecture.

## 01.09 DESIGNING & BUILDING IN PRACTICE

Larger design firms traditionally have their own small model workshop. Presentation models are used to convince the client or to explain a design for the larger public. It is used for people to overview a presentation in one glance. A model is a better 3D-means for people who cannot read drawings. But in this case the subject is 'the scientific prototype' or 'the prototype used for scientific design'. The prototype should show how the designed object works, how it functions. This is obvious in a real machine or an industrially designed object, where the scale could be 1 to 1, but this differs from all scale models that usually are not mechanical. In building technical design, close to machine engineering, parts, segments, elements or components and their connections could be proven in their function by a model. For building components real scale model in real materials brings also the possibility to test the assembly. For structural purposes also to test the structural components in its structural behaviour. For architects the assembly of all elements co-ordinated in a more complex assembly of a component is the result of co-ordination and integration, but also of knowing the characteristics of the individual elements in their part-function in the entire artefact.

Architect Renzo Piano has an extensive workshop in his office. He sees the connection between the materials and his hands as so important that in fact his entire office is called 'the Renzo Piano Building Workshop'. In all of his exhibitions his prototypes made in his own model workshop are proudly shown as an integral part of his office and indispensable part of his design method. This is an indication on the other hand that many people do not care about materials, about the materialized side of design or in a certain degree have a certain 'fear of materials' or 'fear of prototyping', just like one might have a fear of heights.

FIG. 30 Prototype laboratory in the Renzo Piano Building Workshop, januari 2013

FIG. 31 Model of the Centro de Arte Botin, Santander

From the experience of Eekhout, as a son of a building contractor like Renzo Piano, who, as a designer, wants to build or to have built what he has designed, there is always the enjoyment of the material side of design. Many scale models were made in space frames to show in 3 dimensions how these complicated structures would work. First for the designers, for the engineers, for the clients, for the production staff and sometimes for the erection crew.

Eekhout made a design (with artist Loes van der Horst, for the Hemweg, Amsterdam) for an artwork, a 'tensegrity' structure of masts, tubes, cables and sails that could only be shown in 3D in a model 1 to 20. The year is 1980. We were not able to make accurate and complete drawings at the time, see figure 32. We even brought the model to the site to show the erection crew which elements were to be put on what position. This is an old-fashioned idea from machine engineering like the building of densely serviced artefacts like a submarine. This model was scaled 1 to 20, workshop scale. The employed computer program, Ices Strudl, was in fact not suited for this type of structures with its large deformations. We had to run the computer analysis more than 50 times and in fact were quite unsure of its behaviour. Until we took a loading on the end of a cantilevering beam which resulted in a similar consequence of loadings, compared to the model. On the site we could apply the same sort of loading in scale and after 3 weeks of assembly and pre-stressing the structure behaved generally as the model did. Only then we were assured that we had build the correct geometry. By the way the assumed erection time originally scheduled was only 3 days. It became 3 weeks, thanks to the complexity of the design. This was at that time the impossibility of the designed 'tensegrity' structure.

FIG. 32 Scale 1:20 model of the competition design for the Hemweg artwork, Amsterdam by Mick Eekhout and Loes van der Horst, 1980

FIG. 33 Realised tensegrity structure with streeked membranes as really built

Nine years later the Pyramid of the Louvre in Paris was completed, engineered by the famous Peter Rice of RFR in Paris, architect I.M.Pie. In a discussion at the academy of Architecture in Amsterdam Eekhout and Rice discussed the exactness of the pre-stress of the many different cables and tensegrity studs. Eekhout axiom: "It is impossible that any body in the world knows the exact pre-stress in this tensegrity structure. It has been completed on the eye: as long as the aluminium mullions are straight, the glass panels are straight, one is satisfied." Even the models could not analyse the structure sufficiently.

FIG. 34 The pyramide of the Louvre, Paris, designed by I.M.Pei and engineered by Peter Rice.

FIG. 35 Interiour of the Louvre pyramid

Another type of tensegrity structures, being the highest class of structural design in academia, are the art works of Kenneth Snelson. It is well known that the beautiful tensegrity tower at the Kröller-Möller Museum in Otterloo has collapsed many times. The insight from handling the tensegrity structure of the Hemweg, brought foreward the idea that the problem of the artworks by Kenneth Snelson was in the lack of post-stressing. The artworks are realised in tubes and champagne cork-like connections. It was Eekhout's idea that before putting the corks on the tubes the pre-stress is increased and decreased immediately when the cork enters the tube. Hence the tensegrity structure has not been fully post-stressed as required, and its stress distribution is not as required and can be influenced by external loadings like storms, which lead to over-stressing or under-stressing of certain cables and hence to instability as a consequence of which the tower collapses regularly. Alas the artist design is very abstract and does not allow any post-stressing mechanism in the  ending of the tubes. Artwork is artwork. But these insights of Eekhout were in fact consequences of making models, prototypes, building real constructions and regarding other structures with experienced eyes. This is the purpose of making prototypes. Learn and understand how technology works.

All of these considerations were put on the table at the time of the tender of the large tensegrity chandeliers at the Grote Marktstraat in The Hague (fig. 38). This structure was far too big, too complex and impossible to be post-stressed as a complete structure.

How much simpler is orthogonal architecture like the reconstruction of the Maison d'Artiste as designed in 1923 by Theo van Doesburg and Cor van Eesteren. The black-and-white photographs of the last model were reconstructed as a 3D model, which was built on scale 1 to 5 by students of the Prototype Laboratory in 2003 (fig. 39, 40).

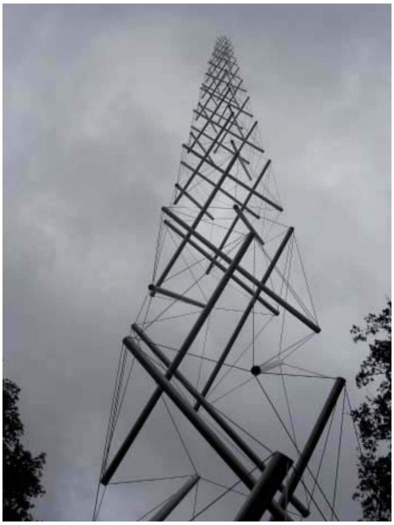

FIG. 36 The Tensegrity Tower designed and built by Kenneth Snelson at the Kröller-Möller museum in Otterlo, NL

FIG. 37 Detail of the foot of the tensegrity

FIG. 38 Design tensegrity chandelier Grote Markstraat, Den Haag proposed by Octatube after model arch. Lana du Croq

FIG. 39  Steel skeletons of 18 cubical volumes, provisionally bolted together

FIG. 40  Maison d'Artiste prototype after the great fire at the Faculty of Architecture [2008] for revision at Octatube

## 01.10 DIGITAL MODELS ARE NOT YET FULL PROTOTYPES

With the aid of 3D modelling programs we are now in the 'tens' of this century, some 20 years after the introduction of the computer aided design and engineering programs. We are able to draw all these material elements and components into one artefact on the computer screen. But even this computer design is to be regarded as a model, a virtual drafting model. Drafting is only half the solution of structures. Structural analysis is the missing other half.

In Eekhout's experience during the design, development, research and engineering process for the roofs of the Yithzak Rabin Center in Tel Aviv the polyester material of the roof shells was defined in its spatial position by one designer, ingenieur Sieb Wichers, who designed all 5 roof wings on his computer and his duo-screens and established the geometry finally for all engineers and co-makers after him, see figure 6. We needed parallel to the digital modelling a material mock-up to fully prove that the digital engineering worked as a full scouting of the GRP roof shells. This engineering work, one of the first BIM models, was absolutely necessary to co-ordinate and integrate all components in this free-form design. The free form geometry required a complete 3D model, worked out in every detail to the millimetre.

However, the simultaneous structural engineering by the structural engineers who took care of the stability, strength and stiffness of the structure  and of the dimensioning of the glass fibre reinforced polyester skins as the upper and lower stressed skins with the central foam core, was absolutely necessary to  make this 3D digital model trustworthy. There still is a grave danger of structural inadequacy in only using the design programs without a proper structural analysis. It is part of a indissoluble twin approach: drawing and structuring.  Material prototyping is the proof of the design concept, like eating is the proof of the pudding.

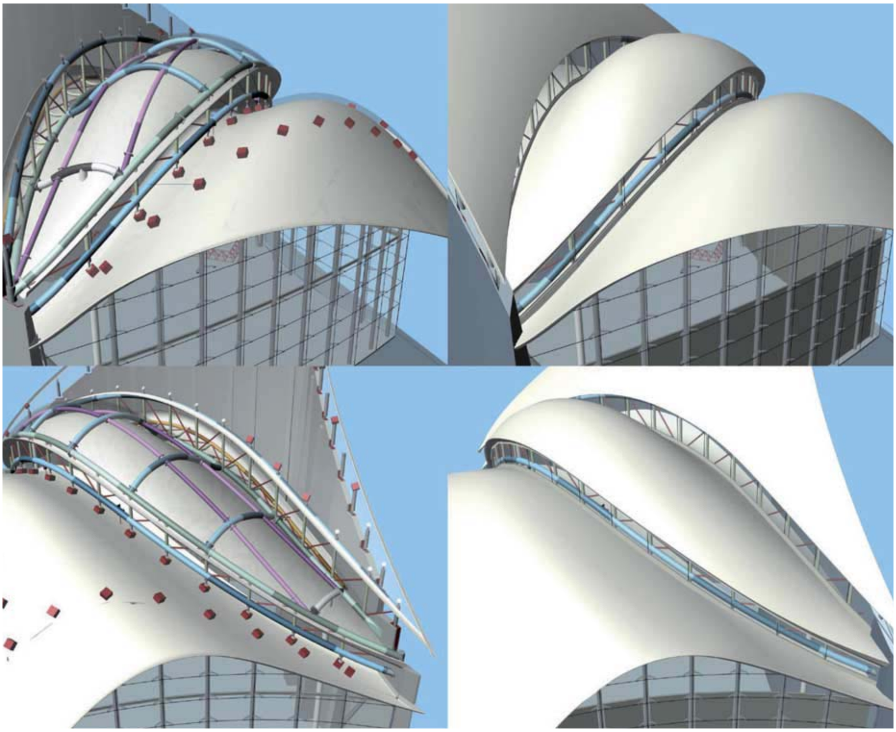

FIG. 41  Engineered 3D models of roofs in Free Form shape for Rabin, (by Sieb Wichers)

## 01.11 THE PROTOTYPE AS A STIMULANT IN THE DESIGN PROCESS

The physical contact between architectural engineer / designer and the material world often stimulates. Material in the hand brings the designer other ideas than he would have in his design studio or research laboratory. In the 30 years of Octatube we were always looking for inspiration from materials, from the processing of materials in connections together (i.e. details), small size but real scale connections. I enjoy the laboratory and workshop. Walking to and from my house at the back of the factory along the metal work being prepared and the glass components being stored, many times gave new ideas. The Tuball sphere in my hand and a cardboard model of the tubes of the space frame gave an 'Eureka' moment when thinking of a solution for the nodes of the Music Dome in Haarlem (fig. 42, 44) and the glazed canopy in Raffles City, Singapore in 1983 (fig. 43). Both were to be executed in the Tuball system but a method of how to insert and screw the internal bolts and to cover the cap of the sphere was lacking. In one moment it came as a brilliant idea. The two projects were after that worked out with ease. This was a fruitful moment of design thinking, accelerated by the prototype in hand.  See drawings and pictures.

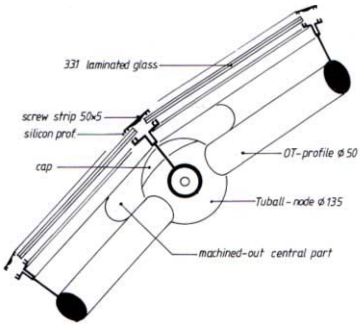


FIG. 42  Tuball-pluas spaceframe detail as developed for the Music Dome (fig. 44)

FIG. 43  Canopy for Raffles City in Singapore

FIG. 44 9m diameter Music dome in the Haarlemmerhout park in Haarlem, as designed by Wiek Röling and Mick Eekhout in 1983, renovated and upgraded in 2005 in its glass detailing.

## 01.12 PROTOTYPE AS A TEST AND EVALUATION LABORATORY

In other cases the prototypes serve as a base for evaluation research, like the Concept House 'Delft' prototype. It was intended, although its size is a full scale apartment, to prove that the designed assembly would work as an energy neutral apartment. So its purpose was to prove a theoretical hypothesis: a real prototype function. This prototype has been designed, developed, produced and build by a consortium of ten SME companies as partners plus 30 sponsors under leadership of the Chair of Product Development TU Delft in 2011/2012. The size of this prototype is that of an average apartment: 7,5 m wide, 15 m long and 3 m high. It is one apartment of 16 in 4 stories, which had to be fully industrialized ('plug & play'), had an extreme low ecological footprint, energy-positive in function, and suitable for medium-rise housing. The newness is in the integration of the building technical components and the service components, to be installed in components in the factory and trucked to site [Ref. 1].

FIG. 45  Exterior of the Concept House Delft prototype (juni 2012)

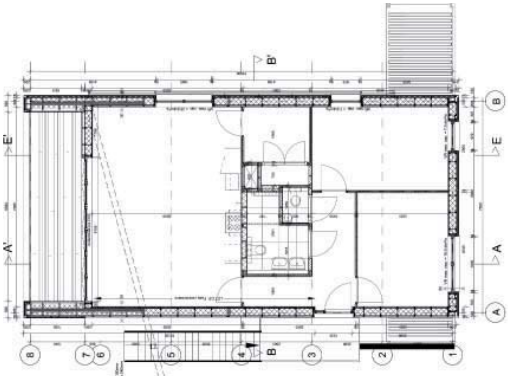

FIG. 46  Plan of the prototype apartement

FIG. 47  Prototype materials .. of wall, floor and roof

FIG. 48  Composition detail of the services cell

FIG. 49 Principle of a building system with prefab components, 2009

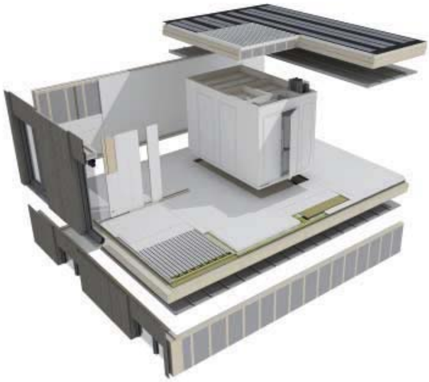

FIG. 50 More complete composition of the same in 2011

The core is the servicing, which has as its axiom that a complex of 16 of such units would form a sustainable building which is energy neutral in operation. Building started in December 2011 and the opening was in October 2012. The evaluation (by measuring and analysing) is to prove that the energy consumption for the period of one year is indeed as per design and engineering, and is to decide whether the inhabitants behave in accordance with the expectations. At the moment of the completion of this book there will be negotiations with the City of Almere to build the Concept House Urban Villa with 16 apartments for the elderly, in an arrangement with 4 other energy positive Urban Villa's under the brand name of 'Barba House, Urban Villa'.

FIG. 51 Concept house as a prototype, possibly placed on the forecourt of the IDE faculty after November 2015 fto provide students with the opportunity to execute real assignments

FIG. 52 Proposal for an Urban Villa of 16 Concept House apartements in 4 stories

# 01.13 FROM THE HISTORY OF THE CHAIR OF PRODUCT DEVELOPMENT

The Chair of Product Development was established in 1992 and focused on design and development of special lightweight building components designed by architects and also, but less, on the development of systems and standard products for the suppliers in the building industry. The chair also focused on the (fundamental) methodology of design, development and research of building components, building products and systems.

The four legs in the Chair of Product Development are:

- Design Methodology (research & education);
- Prototype Laboratory (Education, leading to research);
- Concept House (Research);
- Component Innovation (practice research in off shored laboratory).

All of these 4 legs have publications in the reference list.

The chair started at the end of the High-Tech period in architecture, which started with the Pompidou Centre, Paris, designed by Piano & Rogers in 1976 and culminating in the Kanzai Airport hall, Osaka, designed by Renzo Piano in 1995. In 1996 the Guggenheim Museum was built, designed by Frank O'Gehry, opening the Free Form Architecture period for which technology and dealing with 3D-tolerances would become even more important although architectural designers hardly seem to be aware of, or to acknowledge this shift which has had an enormous impact on the design process.

FIG. 53 Centre Pompidou, designed by Renzo Piano and Richard Rogers (1976)

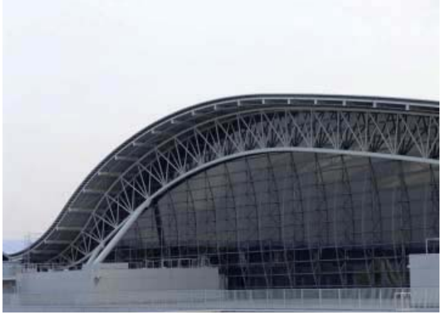

FIG. 54 Kenzai Airport in Osaka designed by Renzo Piano (1995), seen as the beginning and the end of high tech architecture

In 1992, Mick Eekhout immediately introduced the full-scale prototyping into the curriculum based on the before mentioned observations. Every out-of-the-box thinking technical designer needs this experience in his/her education. Innovation in the design of complex building components is speeded up by prototyping and any mature technical industry cannot do without full-scale prototyping.

The Chair however needed three difficult years to convince the Board of the faculty of the necessity to incorporate the materialization into the curriculum and to provide for the extra costs of this expensive type of education. Thanks to the perseverance and zeal of professor Mick Eekhout the Delft faculty of Architecture  is at this moment one of the very few faculties in the world to have an extensive Prototype Laboratory for her students in the Master of Science track of Architectural Engineering and Building Technology, led in the first 18 years by Peter van Swieten and in the latest year by Marcel Bilow.

As the major designer of Octatube of Delft, specialized in designing, developing, engineering, producing and realizing new and innovative structures for roofs and facades, Eekhout is well aware of the importance of material prototyping in any innovation in the building industry. To equip and to staff such a laboratory is however a very expensive excercise, quite apart from the money needed to maintain such a facility and to provide the students with the material needed for the prototyping. The budget needed for the laboratory is much higher than the money that is usually spent on studies with paper and pencil.

The Prototype Lab is pretty much geared to be a reflection of innovative experiences of the past decades, in this case not for production of building components but for the education of young students. Technical innovation lights the inspiration by properties of materials, technical inventions get developed during materialization and for students to get accustomed with the essential tolerances between various different elements and components of a construction or structure and working together in a play role are the four major ingredients that students learn in our Master track.

Many students claim that during their study in the prototype laboratory: *"They saw the light in this course"*. They were amazed by the meaning and the potential of high technology in architecture, technology that they could steer themselves by designing, developing, understanding and production of a full-scale prototype. They are not any more afraid of the materialization phase as other students are but eager to dive into production techniques and material science to realise their design ideas.

The chair of Product Development was terminated with the retirement of prof. Mick Eekhout in June 2015. However the Bucky Lab, as the Laboratory for Product Development is called in 2015, still continues under leadership of dr. Marcel Bilow.

# 02 STUDENT PROTOTYPES

## 02.01 PRODUCT DEVELOPMENT LABORATORY OVER TIME

The Product Development Laboratory at the start in 1995 was a provisionally staffed and rented facility in which a small group of 12 students for the first time in their education got the opportunity to build a façade component. After this small but successful start, in 1998 the laboratory settled in a former machine hall at the Leeghwaterstraat in Delft with a permanent staff under the leadership of Peter van Swieten and Jan van der Woord.

**PO-Lab**

From then on the prototype laboratory has been the main educational focus of the Chair. Right from the beginning Peter van Swieten, the part-time assistant-professor of the Chair, with his education in Industrial Design Engineering at TU Delft and practicing in his Leiden architectural firm, has been responsible, together with Jan van der Woord, for the educational content of the Prototype course. The students are just enough trained with machining, welding and sheet metal handling to build, of course with some help of the staff, their own prototype. A crash course in these production techniques in our prototype Lab used to be managed by Henk Rijgersberg and nowadays Cees Baardolf is responsible for this crash course and later on in the semester for guiding the students in building their prototype.

The Laboratory had to move from this location in 1998 due to the fact that University decided to demolish this building. With this move the laboratory at the same time lost two exceptional results of the design and build effort of the students. The first one was a small office of the instructor Henk Rijgersberg in the machine hall itself. The second one was an elevated colloquium room that seated about 50 people also designed and built by students. This memorable  loss, however, was compensated by the fact that the new facility was in-house at the faculty of Architecture itself. For the first time in the existence of the laboratory all the students and staff of the faculty were confronted with the impressive results of the prototype exercise. This has lead to a more intensive use of the laboratory by every student who wanted *“to make architecture”*. The Laboratory was no longer far away from the faculty, but in full sight.

FIG. 55 Students working in PO lab

### BT Lab

This second phase went with financing from the department instead of the faculty.
The official name was changed from PO-Lab (Laboratorium voor Product Ontwikkkeling / Laboratory for Product Development ) into BT-Lab (Building Technology Laboratory).
In these days attempts were made to rename the Laboratory to Renzo Piano, being the contemporary forerunner of making Prototypes. But his staff was absolute in rejecting this idea. There was only one ' Building Workshop' in the world: Renzo Piano Building Workshop' and no place for a second one. So the name became BT-Lab. The lab also was enriched with a 3D copy machine that could make samples in gypsum material maximum size of 200 x 200 x 200 mm.

### Prototype Lab

May 13th 2008 was the day the Great Fire of Architecture happened, the traumatic burning down of the famous faculty of Architecture building, designed in 1966 by professor Jaap Bakema. It scattered all of the faculty staff and students over the seven other faculties of TU Delft for a few months, after which a renovation plan was realized for the former headquarters of the TU Delft. Alas, although the designer of the two new Glass Houses in the new faculty was professor Mick Eekhout himself, the prototype laboratory was not to be housed in the Architecture faculty, but instead was installed in the Stevin II Hall of Civil Engineering. It has been housed there for 4 years.

FIG. 56 BT Lab in Civil engineering

### Bucky Lab

At the time of writing this book, spring 2013, the fourth generation of the Prototype lab is now working. Out of financial considerations (high rental rates from the faculty of Civil Engineering) the Prototype Laboratory moved out of the Stevin II Laboratory. At the same time the Laboratory's supervision by Peter van Swieten went over to dr. Marcel Bilow after the retirement of the former. Bilow chose another mode: a mobile laboratory, only a few weeks per semester working in a hired space in Delft. This concept has been called 'the Bucky Lab', a tribute for Richard Buckminster Fuller (1895-1981), who made many prototypes in his lifetime.

However, plans are again being developed to house the prototype laboratory for the second time within the premises of the faculty of Architecture. Hopefully this laboratory will soon be back in the faculty of Architecture in a new set-up with a shift from the heavy metal workshop into the modern world of computer aided manufacturing an rapid prototyping which is the future in architectural design. However, the hands-on experience with material properties and production methods will be kept as the most valuable part in the education of our students.

Education and Research are both important but separate elements in any University as it is at the Technical University Delft. Scientific technological research is mostly very complicated and should not be mixed with education in material prototyping. One of the research activities of the chair Product Development (and Design of Components) was initially set up by dr. Fred Veer on the instigation of Eekhout in 1995. This research focused on the realisation of a transparent material with the combined properties of aluminium for strength and glass for transparency. With the start of this project this omnipotent material filled in the illustrious name of 'Zappi' that Eekhout had announced originally in 1992.

Veers research was incorporated into the prototype laboratory during the first 10 years. Graduation students were doing research for Veer: *'Research by Education'*. The research in this period developed from a search for a fundamentally new material into research of the possibilities of a laminate of glass and transparent plastic. For this reason this research migrated from the chair of professor Eekhout to the chair of professor Jan Rots at the faculty of Civil Engineering. Sophisticated research laboratories located at faculties Civil Engineering or Aerospace Engineering are far better equipped for this type of technical research.

## 02.02 THE PROTOTYPE CURRICULUM

In the curriculum of the Master Track Architectural Engineering and the Master track Building Technology students start with the design of a building component, usually the design of a façade. A building façade is selected as the focus for its significance in architecture as well as for its technical complexity. In a short period of three weeks students in this Master track are provided with all basic knowledge in façade design. With this knowledge students design a concept for a new innovative façade, what is called in the curriculum their own 'façade scenario'.

These scenario's are designed by each student individually in two weeks of the semester. Several examples of these scenario's express a specific form in relation to a specific function as is shown in the pictures. After a presentation of the scenario's by the students the best half is selected to be developed to shop drawings for a full scale material prototype. In the next three weeks groups of two students are working together on the shop drawings of a material prototype. In the same period the students get a crash course in production techniques. The instructions are being organized in the Lab and do contain several types of welding, machining, milling and sheet metal forming.

FIG. 57  Façade scenario by student Ann Cowan

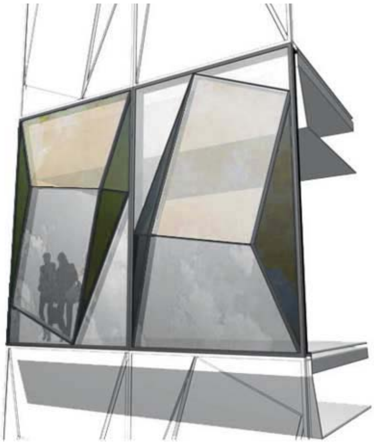

FIG. 58  Façade scenario by student Katarina Doulkari

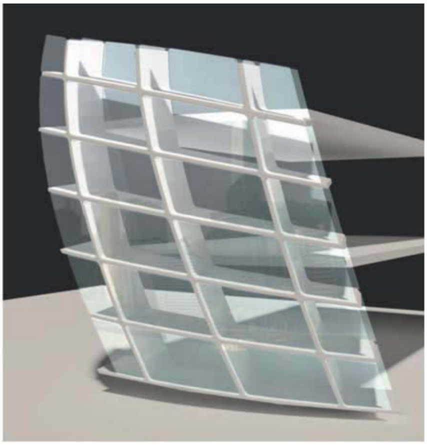

FIG. 59  Façade scenario by Andrea Sollazi

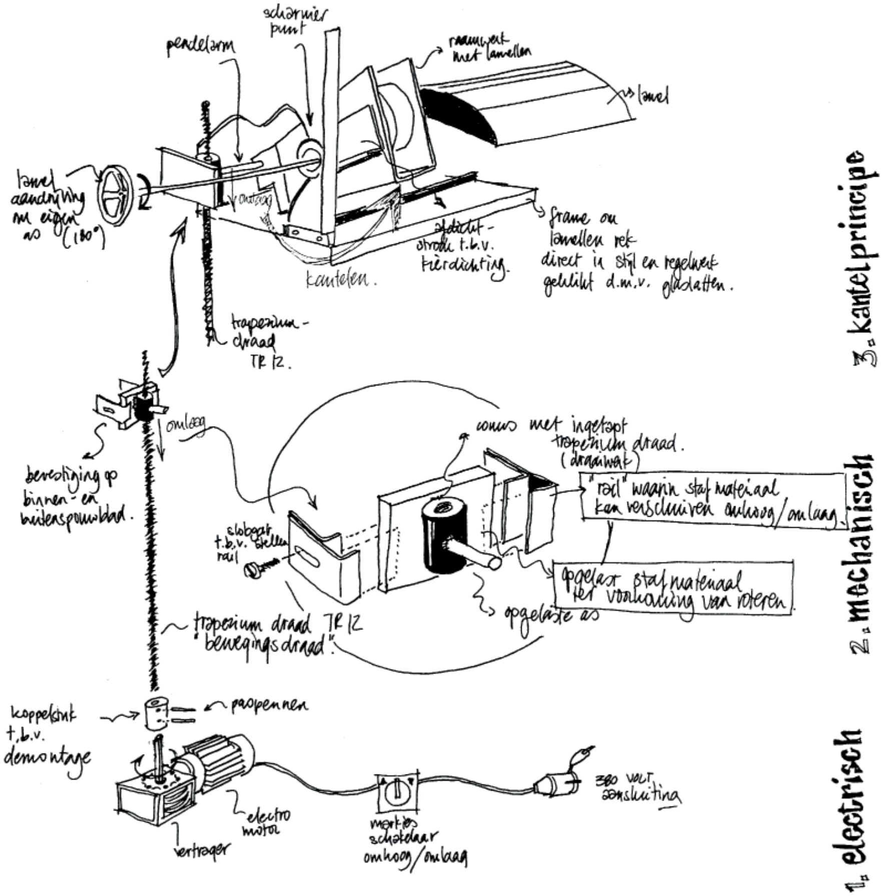

FIG. 60 Research on mechanism at scenario level by students Schreurs

The shop drawings of the material prototype are required to follow European standards, to be clear and to contain all the information needed to manufacture the desired prototype in elements and components. A list of materials is included in the presentation of the shop drawings. The budget for a prototype is usually € 250.00 including VAT. Over-costs had to be compensated by students raising external funding. In a second selection the best of these shop drawings are selected to be built as a prototype. The prototypes are segments mostly at full scale but due to savings on the budget for material prototypes just the most intriguing part of the total façade is built as a prototype. The excellent quality of the concepts and shop drawings in the last years resulted in building all the proposed prototypes in groups of two students.

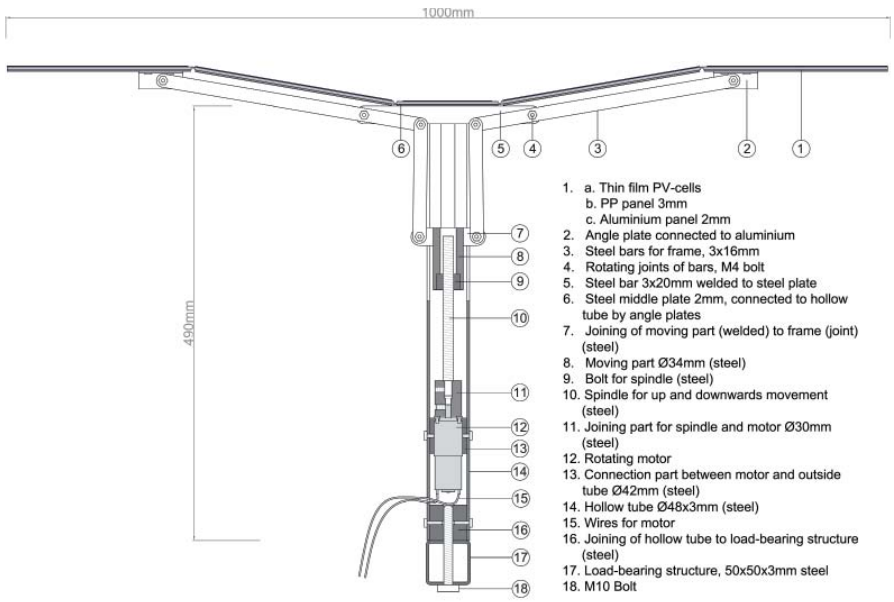


FIG. 61 Foldable PV cell-shop-drawing students Loussos and Kim

FIG. 62 Connection detail

## 02.03 STUDENTS AND PROTOTYPES

Every year from the start in 1995 onwards a number of ten to twenty full-scale prototypes have been built by students in our Prototype Laboratory. Such a production during so many years is of course not without any development and conclusions to be made. In retrospect several important observations can be made as to the role prototyping is playing in the education of our graduates.

The education at the faculty of Architecture from 1992 onwards was organized in a problem-oriented set up in which knowledge is presented to students followed by exercises in which this knowledge can be applied. For this reason the full-scale prototyping is part of a semester in the Master track that combines a design cycle from innovative idea to a final design with lectures about of the design methodology of product development, applied mechanics, material science and computer aided design technology.

Elaborating the scenario until a final design and material prototype the knowledge introduced in the lectures was used interactively in design research in these fields.

For material sciences a computer programme like CES was introduced to the students in such a way the programme could be used in selecting materials for the design they were working at. This of course was guided by lectures about and exams in material sciences by dr. Fred Veer. At the same time for structural analysis the computer programme DIANA was widely used in developing the critical structural elements of the design. And last but not least students were trained in a 3D computer aided design programme like Grasshopper to enhance design decisions of complex geometry and mechanism.

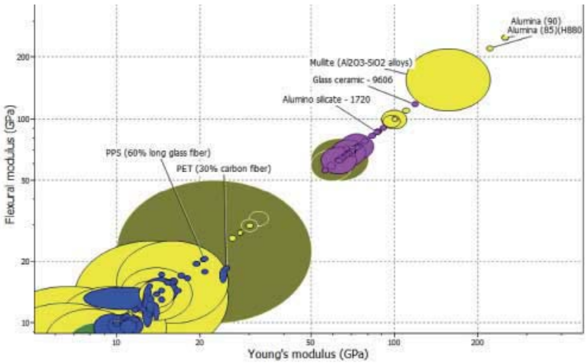


FIG. 63 CES Research results and product development cycle

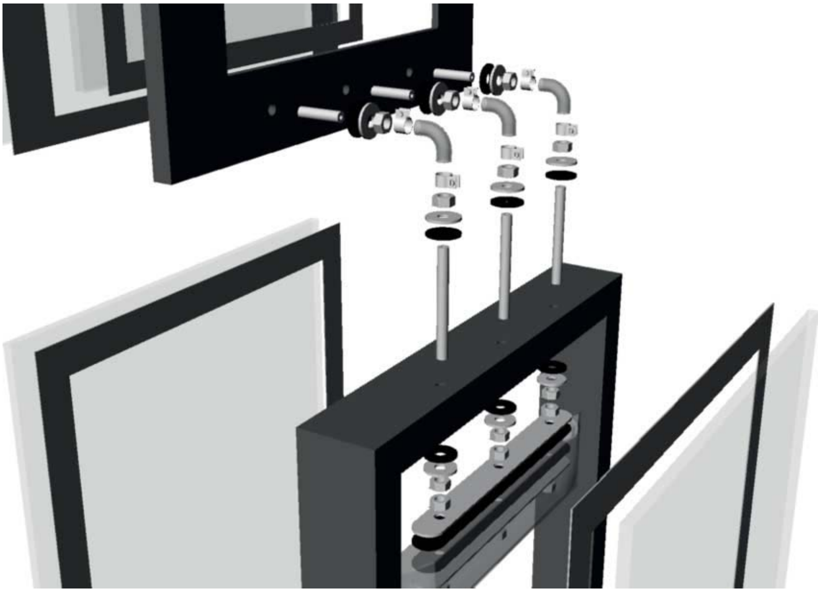

FIG. 64 Exploded view virtual prototype student Katarina Doulkari and Ka Shun Cheung

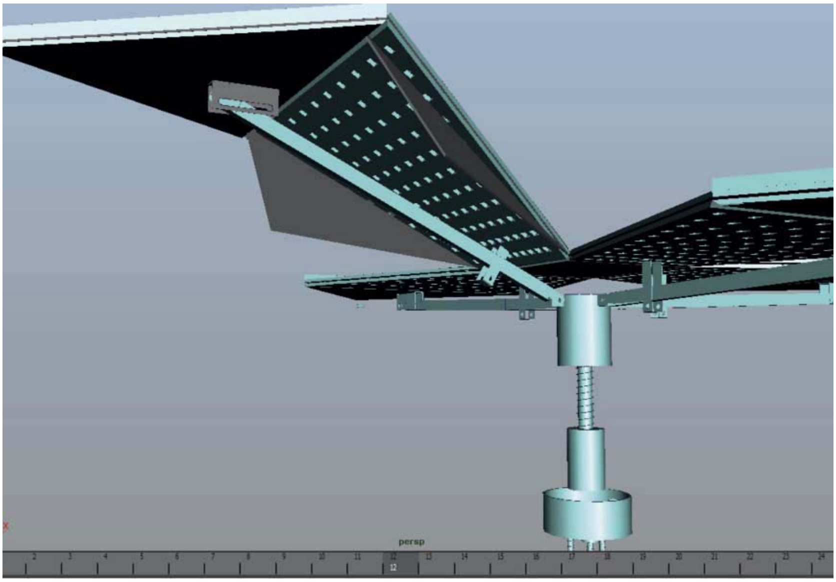


FIG. 65 Maya setup of the solar flower by students Loussos and Kim

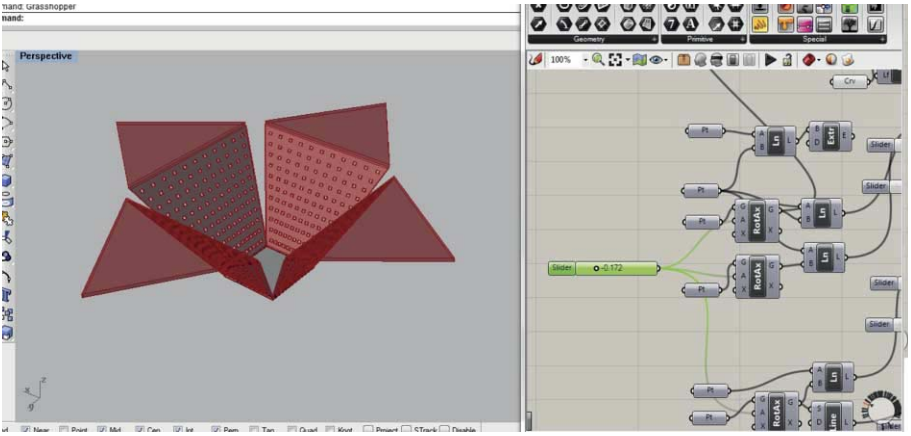


FIG. 66 Grasshopper setup for PV flower cell

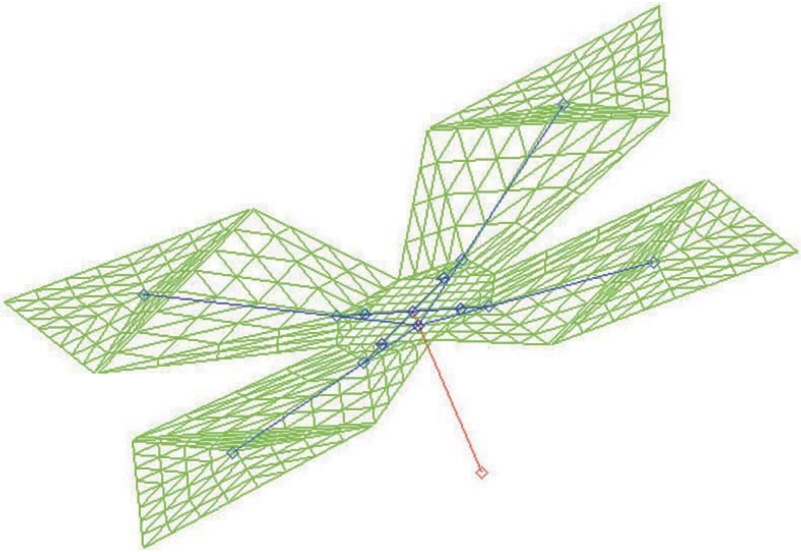

FIG. 67 Diana setup for applied mechanics

FIG. 68  Prototypes in the PO Lab at Leeghwaterstraat

FIG. 69  close up of a chinese fan like sunscreen

FIG. 01 Double floor façade prototype in PO Lab Leeghwaterstraat with in the background the elevated colloquium room

In the early years of the PO Laboratory the prototypes were not yet full scale but for reasons of transportation limited to about 2,1 meter height. Floor height of most office buildings however is usually 3,2 to 3,6 meter so most early prototypes had scale 1:1,6. Students in those years experienced in a limited sense the development of an idea until a final design but important aspects, of which the feel and look of a component is the most noteworthy, were neglected. The assembly for example of a 3,6 m high building component is far more time consuming and complex than one that is limited to 2,1 m height. For a technical designer to get a feeling for the strength of material real dimensions is also very important.

At the moment the design teachers realised the importance of the prototype as marketing tool and product evaluation tool the decision was made to build only real full-scale prototypes, from that time onwards.

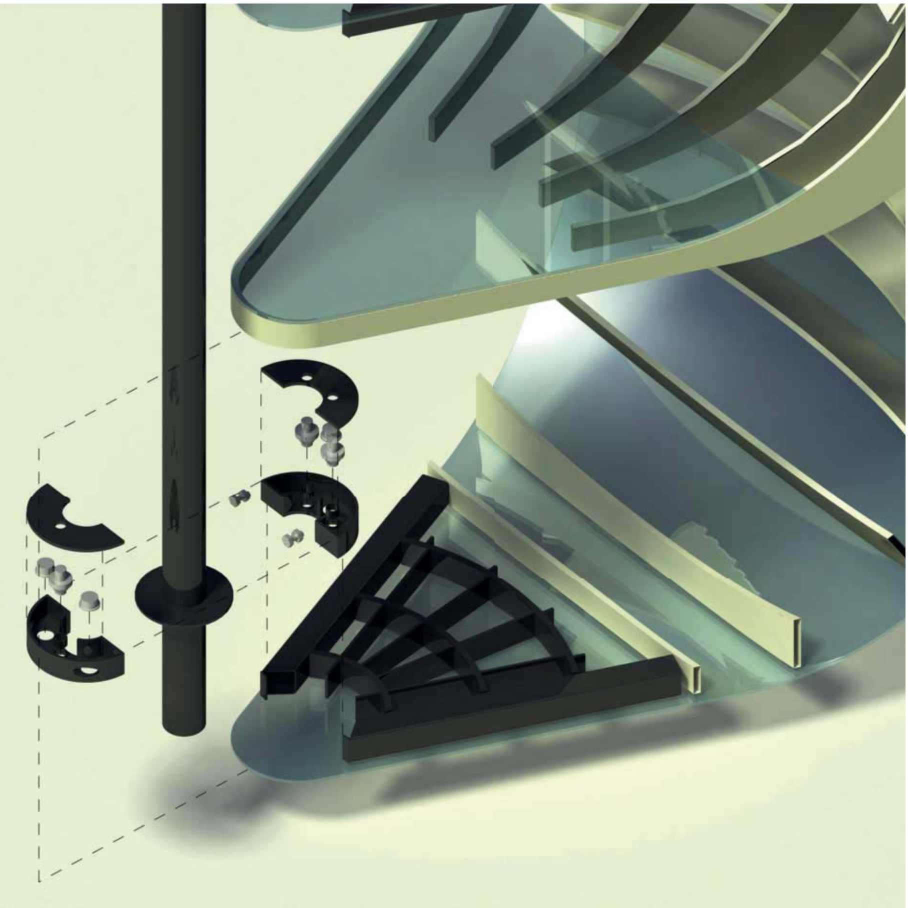

FIG. 71 Exploded view Materialz pavilion By Pieter Stoutjesdijk en Bart van de Water

INNOVATION AND COMPLEXITY

In the mid-nineties of the 20th century the building technological education was organised in three different educational modules of 12 weeks from the development of a scenario to the elaborating in shop-drawings and material prototyping and after testing and evaluation ending in a final design. These modules had carried appropriate titles like 'B2 Scenario', 'B3 Prototype' and 'B4 Laboratory'. B1 at that time was a introductory module in the graduation track of Building technology.

The cycle from first idea, along prototyping to final design was concluded in three different modules with different staff. At that time it was stressed by the teachers for the students to keep close to known practice in order to end with a prototype that could be put to real tests on structural properties, thermal insulation, sound insulation and so on. Knowledge fields like structural engineering, building physics, material properties and production techniques were for that reason integrated in these modules.

The faculty, however, driven by a constant need to lower the expenses, was set to compress the education in Building Technology and Architectural Engineering in a shorter period of time. With this demand the staff started to bring together all the elements of the former separate modules in one semester of 20 weeks. The Building Physics part could no longer be taken in the semester but most of the rest was to be saved. What changed mostly was the shift from product improvement to real innovation and even invention.

The compression of the three separate modules seemed at that time a proper inducement to think freshly about the educational goal of this new semester. The staff concluded that the educational impact would be improved by a set up in which students had even more ownership of the façade scenario. To have the opportunity to design, build and test one's own innovative design idea was expected the students to go to any length to bring about a successful material prototype and in that way to maximise the educational result.

From that time on the groups got smaller to end up with groups of two students and the teachers pushing the students to real innovative ideas with the desired result. In this way the prototyping is at this time more an integrated part of the design education than a mere instrument to incorporate essential knowledge of structural engineering, material properties, production techniques and building physics into the educational programme.

One of the side effects of this pushing to innovative ideas is really a godsend for the teachers in the way the design education every semester had never a dull moment. In all the 20 years of this prototype design education only less than a handful 'scenario's' could be labelled as 'we've done this before'. So for the teachers working with the students was always a joy and a very rewarding job.

The growing complexity of the student prototypes during the lifetime of the laboratory is a second observation. From absolutely static facades with the start in 1995 the prototypes of today often incorporate complex mechanisms for sun shading, multimedia features, energy producing equipment, folding glass second skin and even more idiosyncratic features.

The goal of the prototype laboratory is of course  to integrate even more all this knowledge, to exercise and to obtain insight and overview over production and assembly of technical architecture. Results from the exercises in applied mechanics get immediately used in the search for the appropriate material in for example CES databases. The introduction and use of the computer combined with the possibilities of the Internet in all the excercises, speed the development of the process up in a way that was unconceivable in 1995. This is one of the reasons that the prototyping started with teams of six to eight students and at this moment students are able to develop even more complex prototypes in teams of two students.

Nowadays students are able to test design ideas with considerably more speed than 18 years ago, produce necessary shop drawings of more complex prototypes from the 3D modelling exercise almost immediately and for example acquire information about materials and production techniques on the internet within minutes. So without doubt smaller teams are able at this moment to build more sophisticated prototypes within a shorter period than the students did in 1995.

EXCEPTIONAL PROTOTYPES

With few exceptions the design and build character of this part of the education of our graduates is always focussed on the design of facades of office buildings. The few exceptions are worth mentioning as they concerned the design and build of complete, although small buildings. The first exceptional buildings were two ten meter towers each in four sections of four different materials, from top to bottom respectively in plastic, aluminium, wood and steel. The base of the towers was limited to four $m^2$ and a staircase was to be incorporated in the tower. Two groups of fifteen students designed and built these two towers.

During the lifetime of the prototype laboratory also twice an office for the instructors was designed and built by students, the first one in the former Leeghwaterstraat location and more recently the new office at laboratory at the faculty of Civil Engineering. This last one has a structural frameless glass door with the exceptional dimensions of 3 by 3,5 meter, an elevated floor with a rubber coating and a curved sectioned plastic wall. A team of 26 students was responsible for design, ordering and sponsoring of the materials, assembly and mounting and building of this office.

FIG. 72  Henk Rijgersbergs office

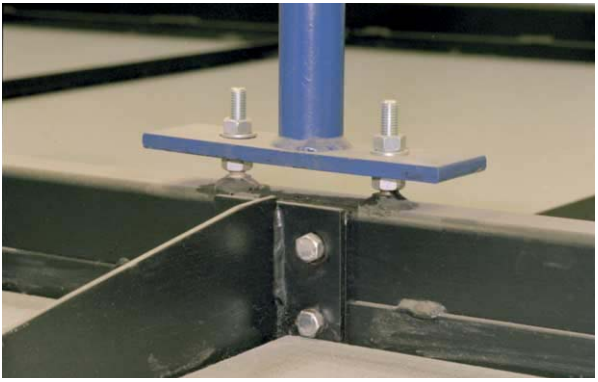

FIG. 73  Close up roof suspension of Henk Rijgersbergs office

FIG. 74  Kantoor Kees Baardolf

FIG. 75 Student designed and built suspend colloquium room in PO Lab Leeghwaterstraat

The most spectacular design and build object that was set up with students focussed on the realisation of a whole new elevated colloquium room in the former laboratory. This was to seat 50 people elevated to the first floor of the adjacent office space and provided with a beautiful curved roof of corrugated aluminium on external curved aluminium tube hangers. This colloquium room however was very short lived due to the decision of the TU Delft board to house the Laboratory at the former faculty building. But the result was there and the main goal to get students acquainted with the design and build process that is in our opinion the essence of the modern product development of building components.

The last exceptional object that was partly designed and built by students worth mentioning concerns the 6 meter all-glass dome that students built together with Jan Wurm. In this very instructive process students guided by Jan Wurm got to the very limit in the connection joints between the separate glass panes. Pictures of this dome, which regrettably was destroyed in the burning down of the faculty, show an exceptional elegant dome. Dr. Wurm is now an established specialist at Arup's for glass and facades.

FIG. 76 Dome Jan Wurm

## 02.04 DESIGN CONCEPT VS PROTOTYPE

The selection of the 50% best scenarios was in the hands of the design teachers and always based on the level of innovation and the feasibility of the proposal mostly in view of basic laws of physics. So, the scenario as design proposal contained 3D sketches along with references to existing well-researched mechanisms and or any kind of calculation.

Even with these basic demands and full confidence of the teachers that the design really could produce a working prototype often at the end it was to be a very narrow escape.

### LIQUID EXTENSION SUNSCREEN

For example, one of the winning prototypes in the 2013 student façade competition was based on the simple physical principle of material heat extension. The principle was used to push up a coloured liquid in the very thin cavity between two glass panes by heating the liquid and in this way offering a 'sun screen'. By using the solar energy for heating a direct connection between sunlight and sun-protection was created.

The scenario contained basic calculations of heat extension of liquids in relation to the possible volume of the cavity that showed that this could work out. But elaborating this scenario proved to be full of obstacles due to demands that only became clear later in the process. Students had a hard time getting around the demand of how the whole system best could be closed. In the first models an open system in a short period of time resulted in a very dirty cavity that could not be cleaned.

At the end the problem was solved with flexible bags below and above the glass panel between which the air in the cavity and the liquid could travel when heated or cooled. But the main educational result of course was that students learned that a very promising design idea or scenario is not even halfway to a final design let alone a final product.

Inexperienced technical designers like the students in this case are not aware of the difficult and winding road between design idea and final design and are apt to sit back and relax satisfied with their first design idea. This of course is no way to do it; students should learn that with a first idea the whole design process only just starts. The second experience they should have is overcoming all the obstacles in elaborating a design idea is very rewarding and great fun.

FIG. 77 The flexible bags below and on top of the double glass pane

FIG. 78 raising the liquid in the cavity by heating up the liquid

FIG. 79 Airtight connection between cavity and flexible bag

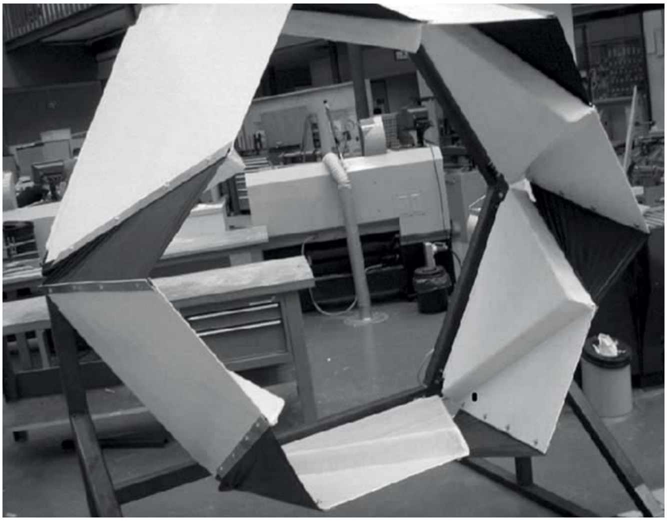

FIG. 80 full-scale model of 'Cracker box' façade

CRACKERBOX

This group of four students was set to develop a second non transparent skin façade that could close the building off at night at the same time operating as a card board sunscreen at daytime.

The concept after an extensive search for alternatives from the beginning was the top part of the famous card board box with crackers, the edible ones that is. The top of a box of crackers is a foldable ring of cardboard that closes in itself with overlapping flaps. The top stays closed when folded because it is pushed a little bit inwards, it takes a little bit of effort to open the box again.

The group did elaborate research with cardboard models the make the transfer from a box to façade component that could be mounted and fitted for use on a building. One of the important issues was the thickness of the foldable elements. The closed elements were supposed to bring thermal insulation to the building. So as is visible in the picture, the insulation is limited to parts of the folding structure, the overlapping parts are as thin as possible.

In this research one important property of the cardboard cracker box, the flexibility of the material was totally overlooked by the group. Setting up the full-scale prototype with the real material sheet aluminium the model proofed to be impossible to close. So while finishing the prototype a solution for this problem had to be developed, either flexible folding parts or some flexibility in the hexagonal ring was needed. Because the whole mechanism was a single motor driven axis with double forked cross connections at the corners flexibility in the hexagonal ring was very difficult. That is why in the end the triangular folding parts in a different stretchable material were put in the prototype.

This example shows really the importance of full-scale material prototypes for testing the concept in the real world, smaller models in cardboard or thin material have an inbuilt flexibility that do not reveal this problem. Virtual reality models in state of the art modelling computer programmes could show the problem but could as well hide it and in a way could lie to the designer and client.

Real full-scale material prototypes never lie, these models are without any mercy and will show immediately all failures to the concept and the design. So it is a real test for the ability and creativity of a designer.

FIG. 81 Prototype of vertical sunscreens with rotating windows

## VERTICAL FAÇADE

The design of a façade with vertical glass elements, rotating on a vertical axis connected with rolling sunscreens originated in a concept in which in east or west orientated façades sunlight could be effectively blocked without losing a bit of the view to the outside.

The main problem in this concept is of course the vertical sunscreens which the design teachers really expected to fail within days. Gravity forces are in this case perpendicular to the movement of the screens and will slowly but surely with winding and rewinding result in lopsided screens and failure in moving them.

The whole system off a big part of the façade is to be moved with only one electrical motor which with one stroke of 150 mm will rotate all the glass panels. The winding of the sunscreens is not separately driven but the result of the movement of the glass panels, springs in the vertical axis of the sunscreen take care of the rewinding.

The group started off with research of possible adequate screen material which had to be easy to wind but on the other hand rather stiff as to prevent unwelcome hanging of the material. The students of the group at the end came across a firm that was just developing such a material a glass fibre reinforced plastic foil with a thin aluminium coating. The design teachers were still a bit sceptical and asked the students to show in the prototype that the material was really suited for this purpose.

In this case the prototype is more than just a show model but just as well a working model. In the days before the final presentation the opening and closing of the screens had been repeated endlessly to demonstrate that the chosen material was right and to show the final design was perfect. The prototype convincingly shows a very transparent second skin façade with storey-high vertical rotating glass panels but has also proven to meet the demands for a mechanical building component.

The design teachers at the end were impressed by the outstanding quality of the research and the set up of the testing of the prototype. This group got the highest grade possible.

FIG. 02 Transparent removable second skin façade

FOLDING SECOND SKIN FAÇADE

In a second skin façade the air in the cavity between the two facades is heated up by sunlight and used inside the building. At the same time the second skin improves the heat insulation of the building. The concept works wonderful on a clear day in winter with still low temperatures outside.

One of the obvious problems with such façade design is the heating up of the air in the cavity between first and second skin in summer in case the outside temperature is not below or even higher than the inside temperature. It is more or less like a winter coat, in summer the winter coat is left at home. One of the solutions is to get rid of the second skin or at least to open it sufficiently in order to remove the cavity.

This group of two students had set themselves to the solution of this problem, to design a very elegant and very transparent second skin façade that could be opened easily and efficiently. Machine driven within minutes and with a wonderful elegant result when opened is a fitting description of what the group had set as a goal.

The picture show a glass square of 2,5 x 2,5 meter with diagonal and half way up hinged folds that enables the second skin to fold into triangular element setting off from the structure of the second skin. The very slender hinges are glued to the glass panes and the bottom U profile is supposed to be lifted by a motor drive scissor mechanism. Unfortunately a suitable motor proved to be too expensive to purchase within the budget and the available motors in the laboratory had to be adapted considerably and this was sadly not possible within the schedule of the semester.

The prototype however convinced as working model notwithstanding the lack of the mechanism and the rather rough use of material. It is easy to imagine that the design in stainless steel and with a mechanism would result in a wonderful building with a very elegeant movable and transparent second skin.

WATER FAÇADE

It looks a bit rough and not quite the façade one would imagine to put on a new building but this prototype is really a wonderful achievement of the group of students involved.

The starting point of the concept is the substantial heat capacity of water that could be of use in any façade to cool in the summer and to heat up in winter like a second skin façade.

The problem with water of course is always the possibility that in a façade it could freeze on winter days with a outside temperature below zero and so damaged the whole façade seriously.

Solutions with anti freeze are often used in these cases, for example water solar cells, mostly in combination with a mechanism that empties the cells when the temperature is falling under minus ten degrees Celsius.

Double-glazing with the possibility to pump water in the capacity for heating or cooling purposes looked promising but to the students but research showed that the use of glass panes is really impossible. The unpredictability of the possible breaking of the glass, the possibility of leakage in combination of the enormous forces on the glass with the weight of the water are serious facts that could not be ignored in designing this kind of façade.

The adoption of weaving techniques with a transparent flexible water hose available in unlimited length was the solution the group in the end came up with. The idea to weave or knit a façade on site with all the traditional techniques that are available in the clothing industry seems something of the future of buildings and is opening up new fields of architectural design.

And moreover the problem of the freezing of water is not as important as with glass, the material is flexible enough to prevent damage in the case of freezing. An extra feature is that the knitted or woven façade when empty has some kind of thermal insulation and can function as a kind of a warm blanket on the building in cold nights.

The presentation of this particular prototype was of course the presentation of a working model in which water was flowing through the prototype to show that it really would be easy to do.

As the presentation was on a hot summer day in a hot laboratory the cooling of water façade was demonstrated very convincingly. The cooling with tap water of about 4 degrees Celsius made for a very comfortable presentation and promised wide possible use for façade like this.

The making of this water hose façade asked of course for special care, the hose can only be bended with a certain radius, otherwise It will close down. The weight of the water in the façade is another matter that has to be taken into account when building a prototype. All this and more will push the designers of such new concepts with great speed and resolution through the preliminary design phase.

All of these examples of built prototypes show very much that with a design concept the design process just starts. In the following design process so many decisions have to be taken that are essential for the end product not just for the technical quality but just as well for the 'looks' of it. Students experiencing this feature of the design process will never forget it in the rest of their design carreer.

## 02.05 MATERIAL VERSUS VIRTUAL PROTOTYPING

With the increasing power of personal computers virtual 3D modelling is becoming a very useful tool in the design process of building components as it is in every field of design. Nowadays walking in and around a new building design in virtual reality is quite possible and is even used for the smallest contracts. This development could raise some doubt about the necessity of using full scale material prototypes in the design process.

As the four main reasons for material prototyping were identified:

- The formal and functional research of the design;
- The speeding up of the design process;
- The use of a material prototype as a marketing tool;
- The use of a prototype for performance testing.

In addition, material prototyping serves a different goal in the Master Course of Building Technology. A technical designer has to have a feeling for material and production methods. The best way to develop this feeling is to gain experience by working with material and production methods. So in our opinion material prototyping should always be a part of the education of graduates of the Master Course of Building Technology.

The inexperienced designers, that students are, are mostly satisfied with a wonderful design idea or concept not realising that the design process just starts with it. In technical design education once to work through the whole design cycle from concept to materialized prototype and not just leave it with a concept is in our opinion essential.

FIG. 85 Wind façade back detail

FIG. 86 Wind façade close up

However, it is not quite certain at this moment in which way virtual prototyping will in the future render material prototyping completely obsolete. The wide spread use of computer aided modelling is bringing designers close to the end product of their efforts and can often be used to get very convincing marketing pictures. So it is an inevitable question for what reason all the effort and the expenses in the production is put into a material prototype.

The first reason is of course the inevitability to materialise the design at the end of the product development process. We are in the business of developing building components of real buildings. The brief usually does not contain the word virtual, the product specifications have to be met in reality and not in virtual reality. So somewhere in the process of designing and developing building components a material try-out makes sense.

As helpful as 3D modelling really is, it is quite impossible to get a grip on every material aspect of the design with this tool. Assembly, for example, of all the elements of a building component into the final product can be much more complicated in reality than it appeared to be on a computer screen. Building and testing a material prototype will usually reveal all kinds of problems, which have to be solved before production can start. The way these problems are solved always influences the design of a building component. And a designer should very much care about this aspect of the product development. In other words, material prototyping is still an unavoidable step in the process of product development within the control of a designer.

The elaborate use of 3D modelling in the process of product development however will push the use of a material prototype more to the end of the process. In 3D modelling the strength, the acoustic and thermal isolation characteristics and even the assembly of the design can be researched in detail. This means that a designer nowadays will get relatively more certain about the characteristics of his design than he or she could get in earlier days.

With all the possibilities of eloquent virtual 3D modelling, like assembly testing, testing of applied mechanics etc., one is likely to be solely dependent on the virtual tool. It seems every aspect of the design can be developed sitting at a computer screen without getting dirty hands at all. But fooling yourself with all the beautiful pictures and virtual analyses is at the same time a real danger to every designer. A material prototype leaves a designer no room for fooling himself, or his client, for that matter. So in our opinion a material model of every design is as necessary as ever despite all the use of virtual 3D modelling.

In our opinion the virtual and material prototyping are complementary to each other and should be part of a design process at the same time. Researching every aspect of a conceptual design will be very useful for the design process and will as a consequence speed up the process.

# 03 CONCLUSIONS

Innovations in technical architecture can be conceived in a designer's head, can be sketched on paper and engineered on the computer, but for the final materialisation and inspiration one still would need material prototypes. Material can also ignite sudden ideas for design concepts. Those ideas are to be worked out in material stage right away and then designed and engineered out in material prototypes again. Both in the industry and in academia the prototype can be a wonder of amazement.

In the process of design, development and research in architecture the prototype is often a very legitimate proof of the content of the design and the process it went through and the decisions taken that resulted in the end result of the designed artefact. If three conditions are met:

- Sufficient newness on world scale;
- Description of the design process;
- Description of the designed artefact,

The prototype, be it material or digital, be it on a real scale or on a smaller scale, is a proof of scientific design and as such is regarded as a part of the scientific world. The realized artefacts in the form of building parts, buildings or urban designs can be seen as prototypes as well and are also proof of scientific design when the above mentioned requirements of newness and description are met.

The Prototype Laboratory is an expensive tool but with exceptional results in the educational progress of students in the Master tracks Architectural Engineering and Building Technology.

The 'Design & Build' process in the  prototype laboratory inspires and motivates students in technical and architectural innovation. Technical knowledge of materials, production techniques, applied mechanics and product development in itself is not enough to get the extensive effect design and build of a material full-scale prototype. Learning the existence of material tolerances for example, without its compensation no technical building would mature.

Most of our alumni have stated that the experience with this design and build process opened their mind to an innovative and technological way of thinking that is so important element in the toolbox of the architectural and technical engineer. Focus of any architectural engineer is of course on the aesthetics of a building or a building component but such an engineer is in an equivalent way focussed on the technology that brings these aesthetics into life.

Prototypes in the architect's and engineer's practice illuminate and accelerate new design concepts. Architects are more sensitive to a prototype approach, as their imagination is fuelled. This is normally not the case at engineering offices, Octatube being an exception.

The two decades of experiences with the Prototype laboratory study modules at the faculty of Architecture of the TU Delft have generated enthusiasm in the education of architects and building technical engineers. Its example has been followed worldwide.

# 04 EPILOGUE

Atto Harsta

The prototype laboratory, nowadays called the ‘Bucky Lab’ did not exist when I started my study on Building Technology at the end of the last century. We were the first (prototype guinea pigs) who had to follow the new curriculum and maybe co-design or amend it as well. The Master study Building Technology was a new phenomenon in the architect’s stronghold of Delft. Thinking about the making of architecture and also really making it was quite a change for many veterans. We, as students, did hardly notice this resistance. We were enjoying the new and the experimental. We felt the positive energy of a number of new professors and supporting teams. The concluding module ‘The building of a prototype’ fitted perfectly in the range from Concept, Research, Testing and Building. It was the jewel in the crown. We started in blue overalls in a rented space to make a prototype scaled 1 to 1, which we had developed and researched in the modules before.

For some of our fellow students this was the first contact with welding and drilling machines. We helped each other to compose in a relative short time something entirely new and fabulous. The feeling of a close collaboration is very stimulating and has to remain as an essential value in the education of engineers. The final presentation was by far the most impressive one during my entire study. It was quite normal to work on day and night before those presentations, but the adrenaline kick was this time very special. If you saw for the first time those scale 1 to 1 models standing together, the pride of the students, the workshop assistants and the supervising teachers was unique. Together with the period of my final studies it was the most intensive and impressive experience of my entire study. Not only because of the materialised design but also because of the educating experience, taking the perfect tone to see the profession of the making of architecture from another perspective.

Peter van Swieten was the ideal person to supervise the students in the process from design up to the making of prototypes. As an industrial designer who later went into architecture he had the perfect mentality and skills to guide us. Apart from a few chairs and the usual cardboard models not much building activities and material experimentation is going on in the faculty of architecture. That is something for the production industries and the building site. We educate designers, who do not have to weld and to operate machines themselves?  The more brilliant it is that Mick Eekhout and Peter van Swieten maintained the climate of making material artefacts in such an architectural climate. Personally I am very thankful to them as I realise the impact it had in my academic development as a designing engineer.

Stimulated by the experiences in the Prototype Laboratory (Bucky Lab) and certainly by Mick Eekhout and Peter van Swieten, I followed the reverse path of education. First Architecture and later Industrial Design Engineering, the last one not finished completely but I followed enough complementing courses to complete my study of Building Technology.

I am writing this epilogue now, knowing I had preferred to craft something, which would have been much more appropriate as a tribute to 18 years of ‘the Making of Architecture’. But Mick loves texts, so I had to put it on paper. Also privately I craft many things with my family. Our soapbox won a second place in the soapbox race; the sleeping bench I made this weekend for my daughter is a tremendous success. If I look around me in the home I live in for 10 years with my family I see many things I constructed myself. It started with the house I transformed from a ruin to a comfortable almost autarkic home.

Making things was not only a private hobby in my life. In the almost 20 years after the prototype laboratory I invented and developed many new building systems and products as a building product designer. Always together with others and almost always accompanied by one or more prototype phases in which we could test our ideas, research and present the feasibility of those designs. The importance of prototyping, which I had to defend so many time at the client’s table when the proposal was to skip some costs in the process.  Afterwards they always agreed that the prototypes were very functional as they realised it had a large impact on the design decision. For me personally it is the most fascinating phase of  the product design development. Whether we are talking extrusion moulding which can be printed very easy as a prototype these days, or a complete and complicated façade panel, material in your hands are very inspiring and you can always improve your design.

In a larger scale I see Living City Labs emerging in analogy with the Prototype Lab. I am engaged with the making of the Floriade 2022 in Almere, NL. We regard the complete process of preparations as one big field experiment. The City as the Prototype Lab and the ‘The Making of’ will be more important than the end result. Essential part of the making of was that we started to raise our own materials (hemp on wastelands which we now integrate in experimental buildings. The first floating building is made with a fine mix of students, who had to fell trees, cut them and make them into trusses. A larger scale that the Prototype Lab but with exactly the same results: to connect young people with materials and to enthuse them.

‘The making of’ has also been claimed by the circular economy. In the USA a serious ‘maker movement’ has emerged with a magazine ‘Make’ in which people share their successes. ‘Sharing’ is going to substitute ‘Owing’ in the circular economy. From that point of view the prototype lab is a sharing experience. After almost 20 years making gets a complete new meaning and a growing interest around it. Do it yourself with endless amounts of examples of your own creation on Youtube. Making it yourself, changing it, repair it in repair café’s are high on the circular ladder of ReFuse, ReUse and ReMake to ReCycle and ReCover. It is a method to keep raw materials longer in function and to maintain the chain or usage. Part of the cycle are the FatLabs running commercially in different cities (like IFabrica in Amsterdam) where everybody can make their own things. Last time I visited them I got the Prototype Lab awareness. The energy, the drive, helping each other, creating collectively, the younger and the elder, all of these items were present. This popular making movement has not been started by Mick and Peter, but has been fed and accelerated.

Let’s make this world together.

Atto Harsta
Aldus Building Innovation

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