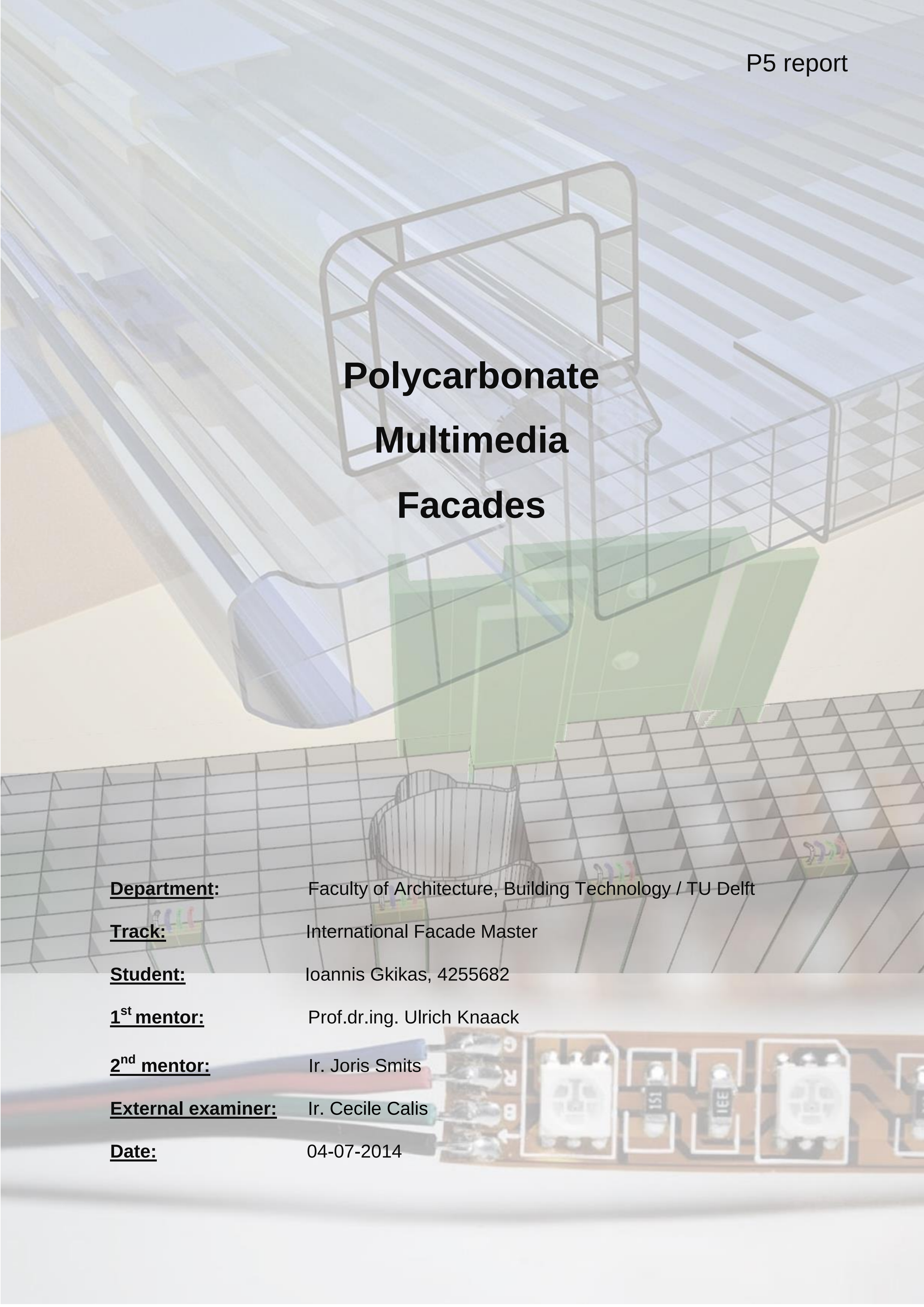


P5 report

Polycarbonate Multimedia Facades

Department: Faculty of Architecture, Building Technology / TU Delft

Track: International Facade Master

Student: Ioannis Gkikas, 4255682

1st mentor: Prof.dr.ing. Ulrich Knaack

2nd mentor: Ir. Joris Smits

External examiner: Ir. Cecile Calis

Date: 04-07-2014

ACKNOWLEDGMENTS

First of all, I would like to express my gratitude to Prof.dr.ing. Ulrich Knaack who has been my main mentor throughout this thesis. In addition my second mentor, Ir. Joris Smits who helped me think deeper by posing me critical questions.

Furthermore, I am grateful to Rollecate Groep who supported me from the beginning of this thesis and gave me the opportunity to get involved with my fascination of media facades. Especially thanks to two members of Rollecate Groep, the product manager Mr. Daniel Nijboer and project leader Mr. Siebe Wassenaar for their constant support throughout my graduation.

Moreover, I would like to thank RODECA for providing me with materials for my final mock up in order to materialise it.

Last but not least, I am grateful to all my people being in the Netherlands, United Kingdom and Greece who contributed with their help for the completion of this master thesis.

Ioannis Gkikas

Delft 04-07-2014

Contents

1. GRADUATION PLAN
1.1 Problem statement

In the late years the media enhanced building envelope has evolved at considerable speed, with the result that we now have to consider a new element in architecture. The world of media facades is rapidly changing given that this kind of facades must keep in pace, as much as it can, with the latest technology of electronic world in the market. In 2009 M. Hank Haeusler had published the first book about media facades including projects which are now already old according to the evolution of new media facades and the future potential of them. In the Netherlands the world of media facades is not as well known as in other developed European countries like Germany or countries in USA. Dutch facade companies decided to take part in this market competition and invest in research of constructing systems for such applications.

One of these companies is Rollecate Groep with which I had cooperation for my graduation thesis. Rollecate is a leading façade construction enterprise specialized in Aluminium, uPVC, steel, composite, glass, maintenance and export divisions with 60 years of experience in the façade industry and employs over 550 people.

Part of my research is focusing on a case study building constructed by Rollecate where the two owners of the company have their offices and they want to integrate an innovative type of media façade element/component. The importance of the media façade is very big given that the office building is facing the A28 highway and the exterior image could be a huge benefit for the enterprise. A new media façade component produced by Rollecate could be the key of success in today's competitive market.

View of the office building heading south on A28

View of the office building heading north on A28

The second part of my research is focusing in logistic buildings and big shopping malls. A common material used for their facades, especially in the Netherlands, is the polycarbonate structural sheets. Such buildings do not require direct sunlight transmission because users are focusing on the interior works and usually these building are used for storing.
Such buildings exist plenty across countries in Western Europe and usually in places where many people are passing by with the car or train. For example, when the train starts to decelerate in many stations in the Netherlands you see buildings across the road made of polycarbonate structural sheets. These facades, although they can be produced with coloured panels and printed graphics on them they seem quite dull and boring. Thus, my idea is to take advantage of this exposition of buildings in such places and improve them in a way that they can add value to the marketing and raise social awareness for people watching the animated media facade by projecting social and cultural topics.

Apeldoorn , Amsterdam (www.rodeca.nl)

De Ark, Hendrik Ido Ambacht (www.rodeca.nl)

Cultural Centre Ranica in Italy (http://openbuildings.com)

1.2 Goal of the research

The goal is to achieve the development of a media facade which can fulfil several requirements for our case study buildings. The challenge of this project is the fact that there are many options of media facade technologies and through the requirements and preconditions analysed we should compare the best solutions in terms of technology and cost effectiveness. The requirements are the following:

The new media facade must be translucent in order to allow natural daylight transmission and because it is better for the interior users to have the feeling of the exterior day and night condition. Moreover, the facade must have the ability of projecting good quality graphic images and animation videos. There are many types of illuminating facades which reproduce shapes, colours and basic elements, but those which are able to support marketing and advertising images and videos are going to be included in this research. In addition, the facade must be designed in order to be visible in day and night time. Not all elements are able to produce intense light for day use.

An additional goal is the comparison of polycarbonate structural sheets with glass. By exploring the possible applications for both of them in a media facade negative and positive statements will occur.

Moreover, nowadays there is a new type of lighting, OLED lights, which have entered the market and we should compare them with the existing LEDs and see the advantages and disadvantages, maintenance, serviceability and life expectancy to get the best applicable solution for the media facade.

All in all this research should contribute firstly as the development of a media facade component for the specific needs we mentioned above and as a consulting for Rollecate which is interested in this product.

1.3 Research question

Which is the best-state of the art- technology to design a multimedia facade and which are the ways to improve it?

This general research question can be subdivided:

- Which is the state of the art technology today?
- Will the media facade component be a separate element mounted outside or will it be integrated to the façade element, or both?
- Could Rollecate detail and construct such an element in order to sell it?
- Are there any clients in the Netherlands to absorb this kind or product in the market?
- What could be the cost of the media facade compared to all the other ones which exist on the market?
- What happens to the facade after the end of polycarbonate's lifespan?

1.4 Methodology of the research

The methodology which is used in the research can be divided in three parts: research, design and evaluation.

Research: The research starts with the available literature study through books, articles, internet and interviews with experts. The aim of this is to establish the knowledge regarding media facades, the way of construction, costs, materialised projects and state of the art examples. The direct contact with Rollecate and other companies involved in the industry is important to get real numbers and feedback in the research. Through research we will be able to collect all information about media facades and used technology, filter the examples which are relevant to our needs and proceed to the design process.

Design: This step is focusing in the design and application of the innovative facade element. It should be functional, economic, easy constructed and mounted, energy efficient and fullfill the requirements given for our case study buildings. It is wise to use exising facade systems constructed by companies like Rollecate and modify them to create the media facade component in order to save energy and money.

Evaluation: The final step of evaluation is the most important because it prooves that the system which is designed meets the requirements or it fails to offer the best solution. Here will be suggestions for improvements of the design according to the evaluation of the drawings and the guidance of experts from the company and university. Ideas for further research are also included in this sector.

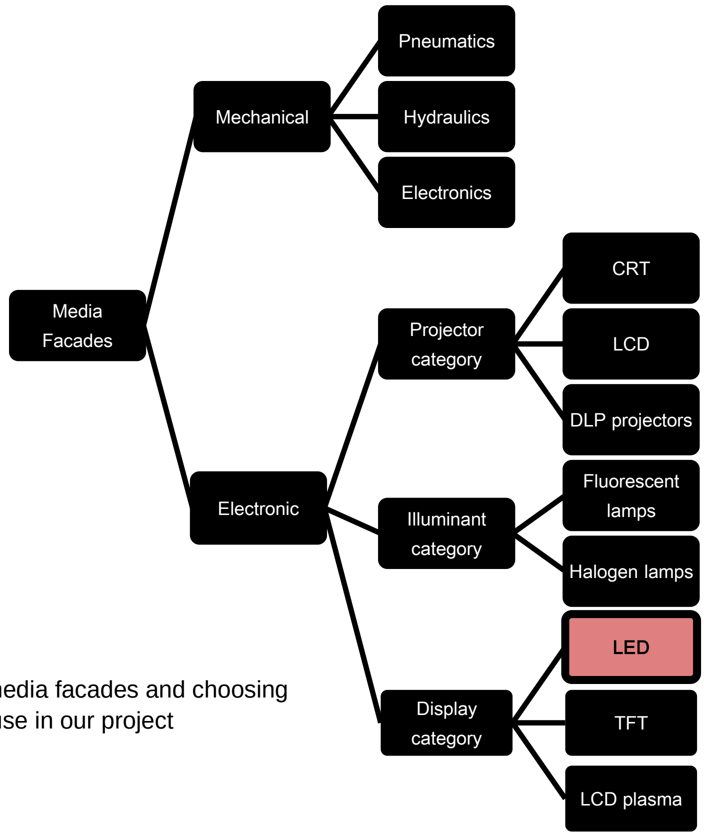


Diagram categorising media facades and choosing the technology we will use in our project

1.5 Scientific contribution of the research

The media facade which is going to be developed is a realistic project asked by Rollecate Groep. The value of the research is directly related to a request of the business market and it will provide critical conclusions for subjects concerning media facade technology, costs and future potentials not only for the company but also for other enterprises. The world of media facades is still under development and as scientists mention LED lighting's 'best years' will be 2013 to 2017(http://optics.org/indepth/3/2/5).

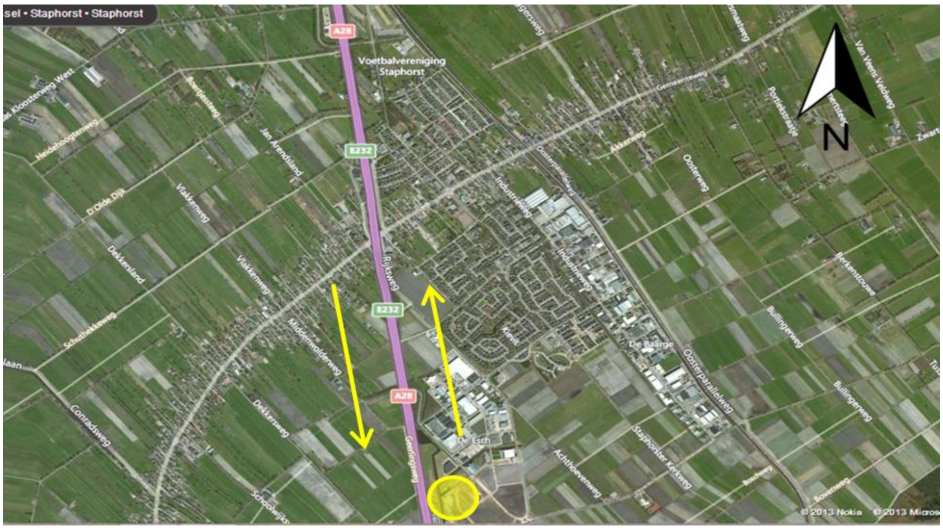
Furthermore, the purpose of this research is to inform deeper people who are involved in the facade industry about the latest technology for media facades, present the world's top media facade designers and provide more technical information compared to the existing few media facade books been published. I was impressed when I searched on TU Delft library files about media facades and only five results came out in the research. One of them is the book I mentioned in the beginning and four are master thesis, one of which is only relevant to a media facade proposed for the new faculty of Architecture in TU Delft. So I am glad to have the opportunity adding my little stone to TU Delft's files.

Finally, when we will reach the design process we hope to succeed in developing a clever system which can be flexible for several applications and end to a product which can be competitive in the market.

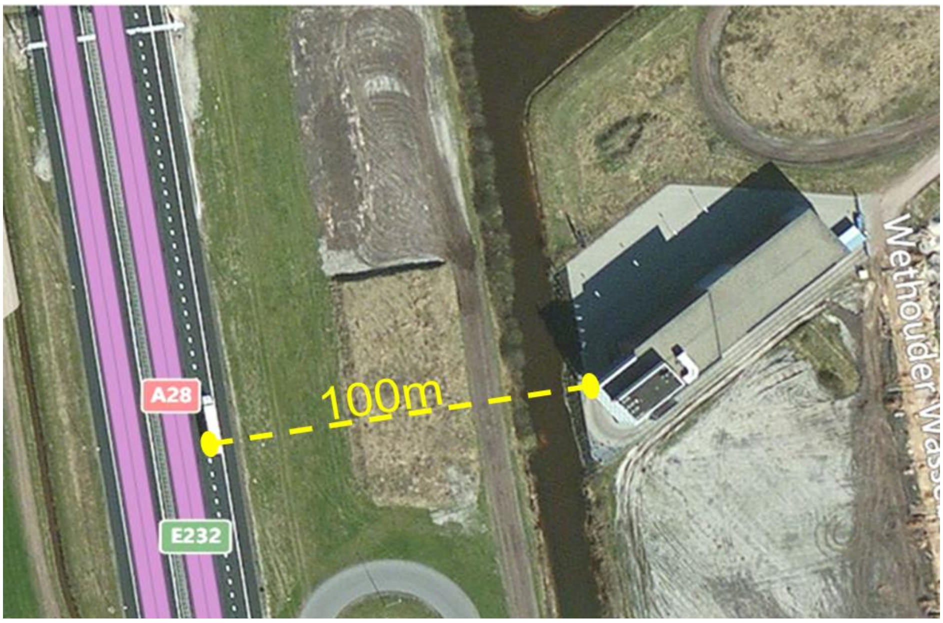
As it will be proved in the research, the construction of a media facade is very costly. Thus, potential cheaper solutions for the marketing world might lead to a new approach to media facades and their use.

1.6 Case study buildings

Rollecate's building is located on the south part of Staphorst, with a distance of 100m from the highway A28. It is a 5 storey glass building with spaces of 4.500 m^2 facing northwest and southwest.



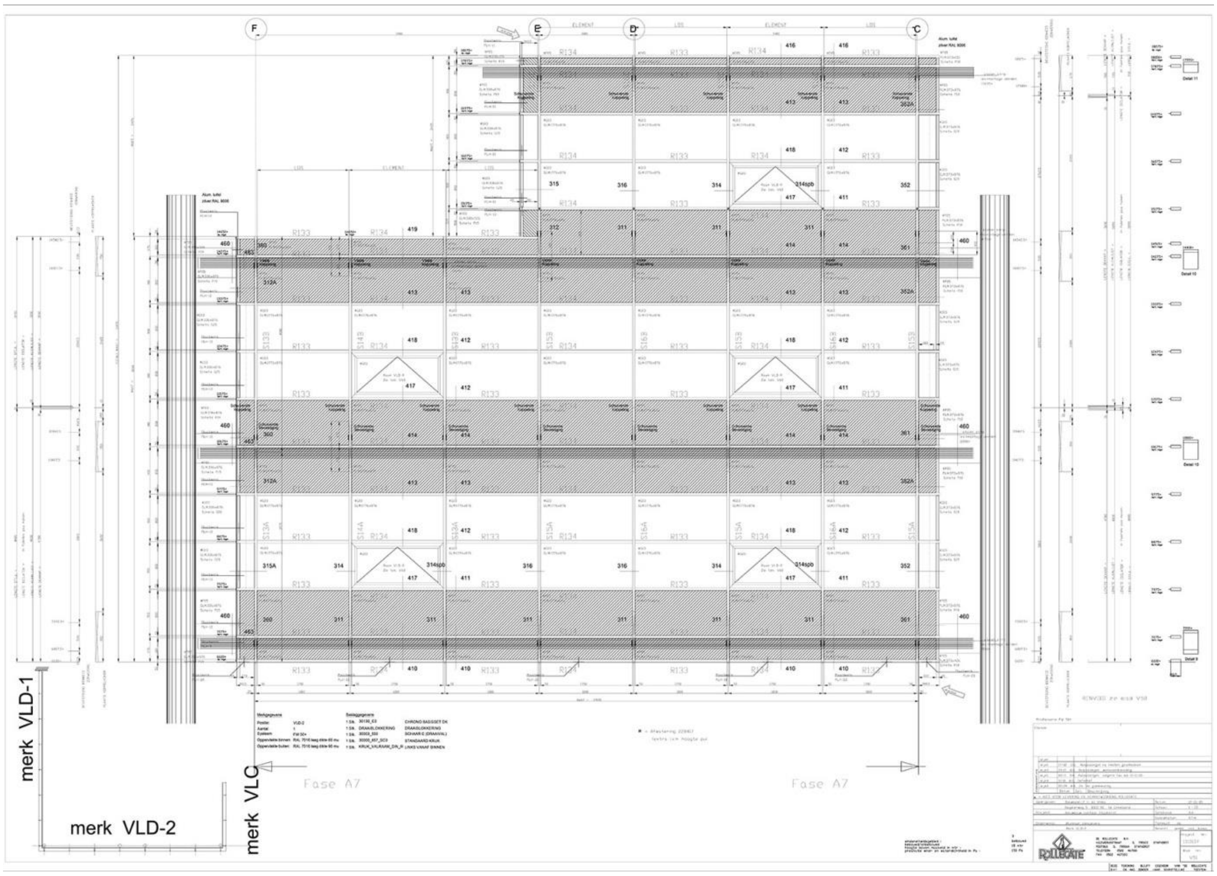
Position of the office building(yellow dot) in the south part of Staphorst



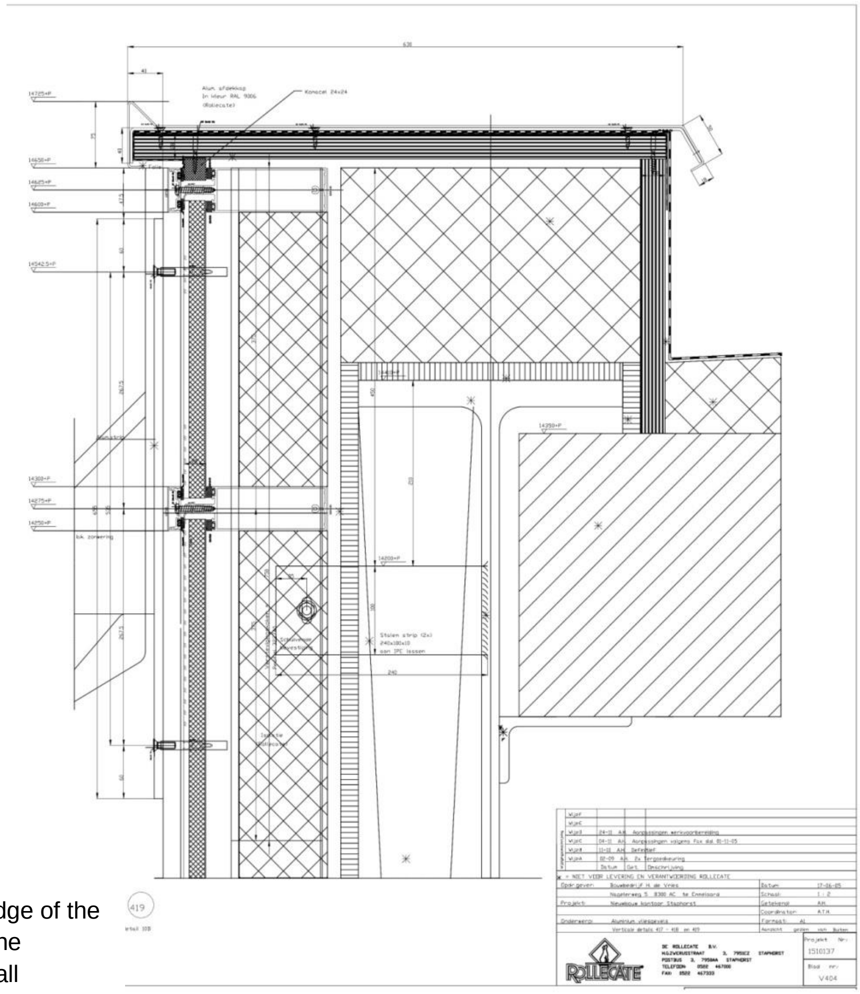
The distance from the highway is 100m, something which should be taken into consideration for choosing the appropriate LED pitch

The facade is a curtain wall system with aluminium profiles and double glazing. This is a system which enables the change of glasses on the facade and gives the opportunity of a good maintenance. It has a height of 11,5 m and a width of 16 m. In some parts there are openable windows for ventilation. In addition, around the facade there are four zones with metallic grills which are used as sunshading.

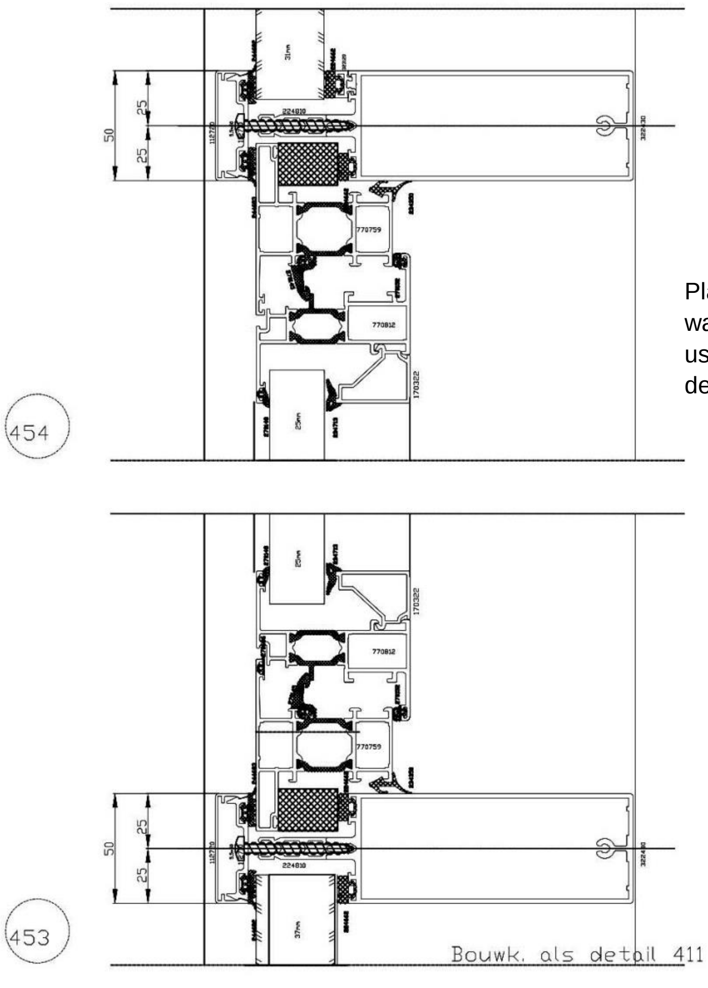
Closer image of the building with the glass facade



Technical elevation with the dimensions of the facade, the openings,
the transparent and translucent parts (Rollecate)



Detail at the edge of the roof showing the connection of all elements (Rollecate)



Plan details of the curtain wall system which can be used as a base for the new design (Rollecate)

Furthermore, the research is focusing in buildings' facades which can be made of polycarbonate and do not have so many requirements as an office building where occupants are working under certain conditions. Such buildings may have different geometries from straight to curved facades. For example, the growing demand for warehousing and logistics management creates the need for modern building requirements. These must serve the needs for economic, fast and safe construction, easy scalability and in height storage. These buildings, often covered with polycarbonate structural sheets are becoming the most common applications in the field of logistics. The advantage of such construction is its competitive price and the ability to avoid a number of bureaucratic procedures and additional fees for the building license.

Common facade of a logistic building covered with PCSS

In addition, the ability of polycarbonate to be cold bended on sight offers the geometry variety in the panels. Curved shapes are mostly used in buildings where aesthetics and exterior appearance is more important, like museums, stadiums and exhibition halls. Polycarbonate sheets and aluminium profiles are almost the same as in the straight occasion with the difference of being curved. These buildings have many visitors and consequently a media facade would be ideal for marketing purposes and interaction with the people.

Museum of Energy in Spain with polycarbonate facade (http://www.archiscene.net/)

Arena in Zagreb covered with polycarbonate panels by Rodeca
(http://housevariety.blogspot.nl/2011/01/arena-zagreb-by-upi-2m.html)

Omnisport in Apeldoorn with polycarbonate facade panels 23 m height
(http://rodeca.nl/)

2. LEDs AND OLEDs

2.1 Light Emitting Diode (LED)

A Light Emitting Diode (LED) is a solid-state semiconductor (*A **semiconductor** is a material which has electrical conductivity to a degree between that of a metal (such as copper) and that of an insulator (such as glass). Semiconductors are the foundation of modern electronics such as LEDs*) device that converts electrical energy directly into light. On its most basic level, the semiconductor is consisted of two regions. The p-region contains positive electrical charges and the n-region contains negative electrical charges. When voltage is applied and current begins to flow, the electrons move across the n-region into the p-region. This process of an electron moving through the p-n junction releases energy. The dispersion of this energy produces photons with visible wavelengths which means light. (http://www.philipslumileds.com/technology/led-glossary)
The construction of a light emitting diode is different from that of a normal signal diode. The p-n junction of a simple LED is surrounded by a transparent, hard plastic epoxy resin hemispherical shaped shell which protects the LED from vibration and shock. A LED junction does not emit much light. The epoxy resin body is constructed in such a way that acts like a lens concentrating the amount of light emitted by the junctions on the dome at the top. This is why the emitted light appears to be brightest at the top of the LED. (http://www.electronics-tutorials.ws/diode/diode_8.html)

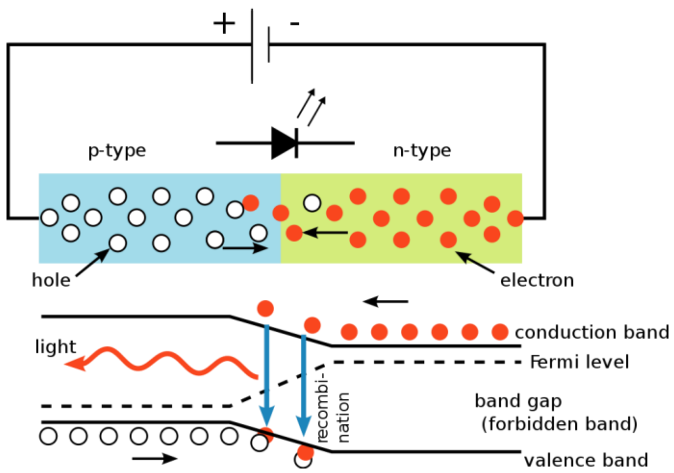
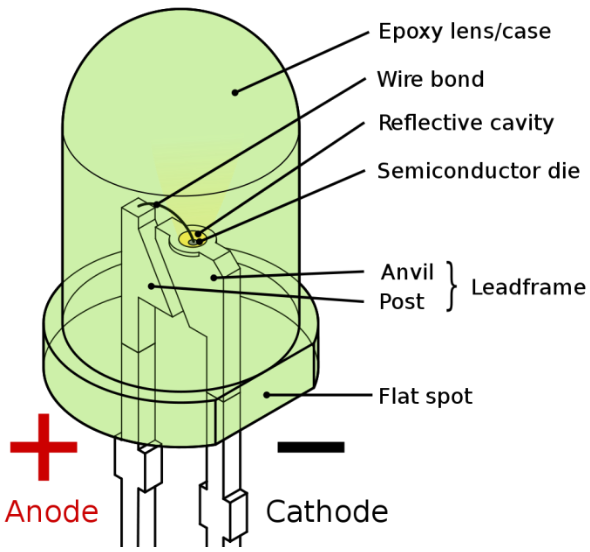


Diagram illustrating the concept of LED lights and how do they produce light (http://en.wikipedia.org/wiki/File:PnJunction-LED-E.svg)



Axonometric image of the anatomy of Led light (http://en.wikipedia.org/wiki/File:LED,_5mm,_green_(en).svg)

The actual colour of a LED depends on the wavelength of the light emitted, which is determined by the semiconductor compound used in forming the p-n junction during manufacture. Consequently, the emitted colour is not determined by the colour of the LED's plastic body. These are coloured to improve the light output and to indicate its colour when it is not illuminated. They are available in a wide range of colours with the most common being red, blue, green, amber and yellow which are widely used as visual indicators and as moving light displays.

A reasonable consequence is that LEDs have limited operation lifespan. Considering their long lifespan they are reliable light sources as indicators and for lighting. For any component or system like LEDs, the MTBF (mean time between failures) is very important to be known. The MTBF is the elapsed time which is predicted between inherent failures of a component or system during operation and for LEDs is calculated as:

MTBF = Hours of operation / Number of failures

(http://en.wikipedia.org/wiki/Mean_time_between_failures). Hostile environments like high temperature and vibrations reduce the MTBF. However, when LEDs are used within their limits they last for a long lifetime but their light intensity is being reduced anyway.

The LED life is the time when the emitted light fades to a certain level. The generally accepted levels are 70% and in some use 50% of the original value. The LED life expectancy is quoted in the format L70 and L50. The L70 value was chosen by a power LED industry group ASSIST (Alliance for Solid-State Illumination Systems and Technologies) which undertook several tests with people who generally did not notice a gradually diminishing LED light output until it had dropped by 30% of its original brightness. So 70% of the initial light output and then this stranded for the L70 figure. Roughly we can say that most LEDs for lighting applications offer L70 values of 50.000 to 100.000 (laboratory tests) hours (up to 12 years if working 24/7, 12 to 16 years working 16 hours/day, 23 to 34 years working 8 hours/day).

(http://www.radio-electronics.com/info/data/semicond/leds-light-emitting-diodes/lifespan-lifetime-expectancy-mtbf.php).

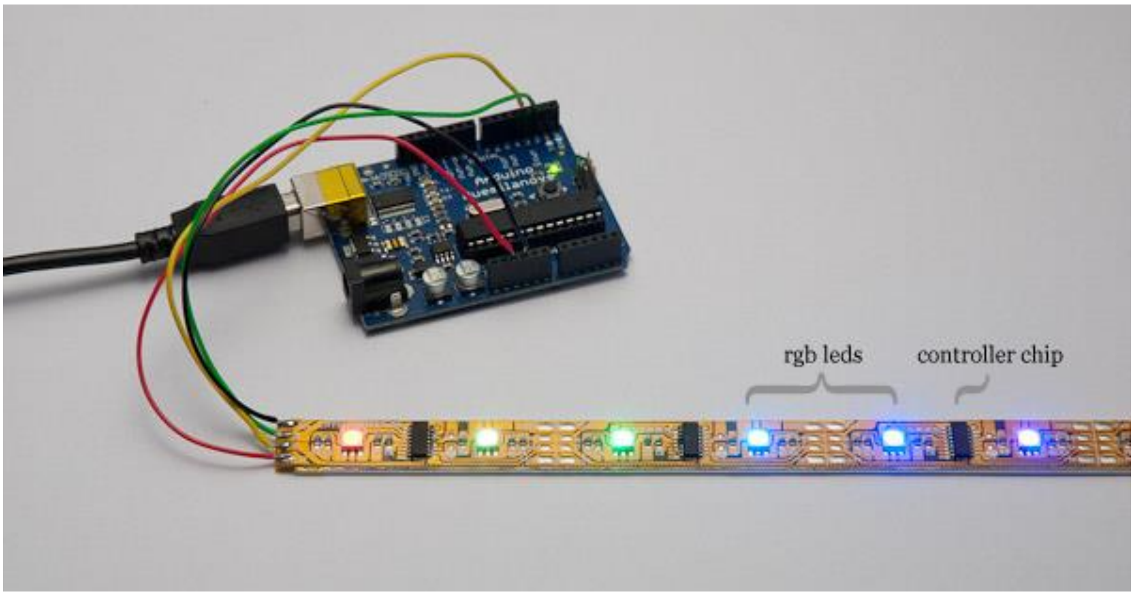
LED is basically a small chip being sealed in the epoxy resin, so it is very small but very bright with a low power consumption. The working voltage of general LED lights is 2 - 3.6 V and the working current is 0.02-0.03 A. This means that the power consumption is less than 0.1 W.

Another type to create lighting with LEDs is by joining them in strips. A LED strip is made of polyimide PI substrate flex circuit as the carrier and through the series-parallel circuit design LED light chips are mounted on the LED flexible light strip. All this system works with a power source and a luminous program controller like Arduino, to achieve more glaring light effects.

The flexible circuit board has good mechanical properties, which makes the LED strip bended easily and can be fixed on arbitrary convex surface. With reasonable design and

welding technology it can reduce the chance that the light bar does not work, as well as avoiding other quality problems to improve product stability.
(http://www.chineselight.com/Led-Strip-Light.html)
The trend of LED integration in facades for purely architectural purposes has produced a number of new products. The most important step towards state of the art media facades was done by Shuji Nakamura who created the first high brightness blue LED and the production started in 1993.
In the 90's, lighting technologies have developed at a phenomenal pace. In the past decade LED technologies have matured to have both proven reliability and longevity with easier installation and control. With the current generation of fixtures from the big suppliers the client can be confident that the equipment specified and installed today will be in fashion in the years to come. The same happens with the lighting designer and the end client.

2.2 RGB Led strips



LPD8806 addressable RGB LED strip hooked up to an Arduino (http://nut-bolt.nl/2012/rgb-led-strips/)

An addressable RGB LED strip is a long flexible strand of LEDs each of which can be individually set to a certain colour. By adjusting the level of red, green and blue per LED many colour combinations can be derived. The chips between the LEDs take commands from a controller. This controller can be an Arduino or a controller specifically designed for LED strips.

The strips are produced in many configurations with different current, distance of LED to LED and number of LEDs. Most of them run on 12V and 5V and split every two or three LEDs. In addition there are different levels of waterproofing for indoor, outdoor, underwater and sandwiched uses.

Depending on the purpose of use the following features help to decide the type of LED strip needed.

- Size or type of LED
- Number of LEDs per meter of the strip
- Colour temperatures of the LEDs
- Flexibility of the strip
- Direction of LEDs on the strip
- Carrying capacity-heavy duty
- IP rating
- Voltage
- Dimmers and controllers

Of all the determining factors mentioned above, the most important is the type and size of the LED included, both of which determine its performance and brightness.

Another important factor of the performance is the number of LEDs in the strip for a meter. The higher this number is the brighter the strip. Extremely high numbers within a meter often require special technologies, like double width strips where the LEDs are placed in two or three rows next to each other.

Triple RGB LED strip (http://www.colorsled.com/?l=en)

The colour range of the LED is almost endless because any colour can be created with RGB technique. There are generally two or three shades of white available: bright or cold white, warm white and the natural white. The temperature of the white colour is measured in Kelvin, and the higher colour temperatures reaching 5.000 K are the cold or whites and the lower ones reaching 2.700 – 3.000 K are the warmer white colours.

Single colour LEDs are available in all colours but the RGB LED strips can emit a large variety of colours. RGB strips operate with a controller and this one decides the colour of the strip being constant or making special effects by changing in a variety. Special pixel RGB strips are able to change the colour in a row creating a run-down effect. The variety of colour changes on the RGB strip depends mainly on the type of the microcontroller.

The flexibility of the LED strips is a determining factor in their application. Usually, strips are flexible to one dimension only.

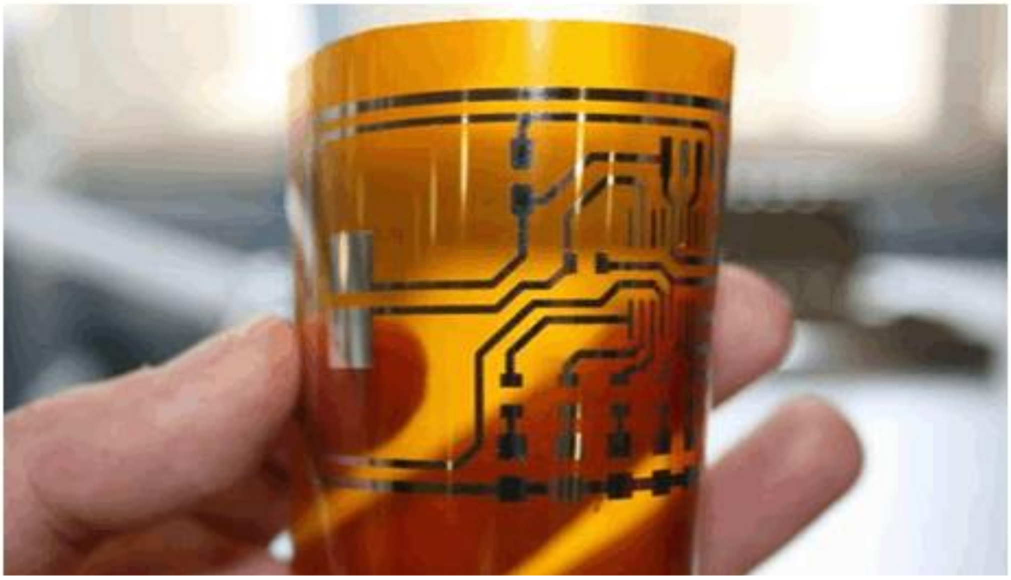
The carrying capacity of strips is very low and heavy-duty strip lights are not sold for home use but only for commercial use on ships and factories for example.
The IP rating value is made up of two numbers which indicate the degree of protection provided against the intrusion of solid objects like body parts, hands and fingers, dust, accidental contact and water.
If someone wants to install strip lights at humid or wet places, outdoors or even under water, then items need to be partially or completely waterproof. An IP rating of 68 means that the item is completely waterproof.
Moreover, the voltage of LED strips must be checked before application. Strips running at mains are often used but most of the LED strips require a transformer since they run at low voltage usually 12 or 24 V.
The variety of moods and effects that can be created with LED strips is very large and depends on the accessories used in combination with dimmers and microcontrollers.
Although the largest varieties of RGB effects are created with panels, there is a lot to do with strips too by applying complex controllers as a DMX allowing setting the rhythm of colour change to music. (http://www.tofoled.com/En/shownews.asp?id=192)

2.2.1 PCB process

In the last few years innovative concepts in terms of electronic technology have emerged like «plastic electronics", "printed electronics" and "organic electronics". These techniques help to develop new manufacturing methods which will bring a revolution in the electronic and micro-electronic industry.

They consist by exploring and adapting traditional technologies which exist in graphic arts as silk-screen printing, lithography, inkjet printing for the manufacturing of electronic devices.

The concept of printing electronic components creates a need for new chemical developments like conductive, resistive, insulating or semi-conductor inks. Commercial inks are designed in such a way to be used in "printed electronics" as well as special substrates for printing purposes and they are already on the market. This is a promising technology in continuous evolution which has had satisfactory results on the market till now.



A flexible circuit by printed inject (http://articles.ides.com/design/2010/plastic-electronics.asp)

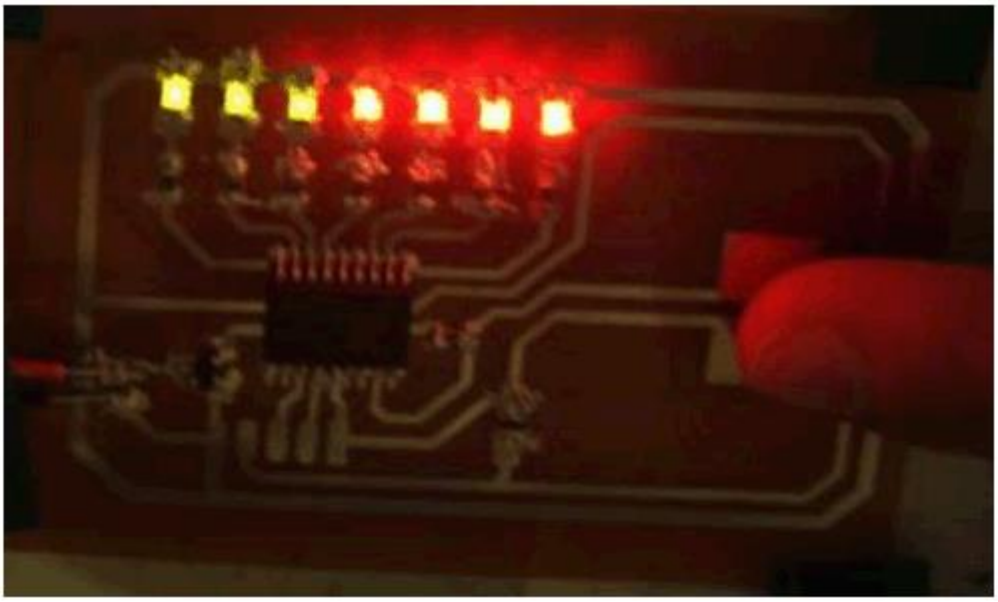
The main applications of flexible electronics are pressure sensors, LED and OLED devices, flexible memories – circuits- batteries – photovoltaic panels, electroluminescent lamps, electrophoretic devices, RFID tags and elastic sensors. Flexible electronics have the potential to provide new products which are having higher flexibility and the possibility to substitute the current wire track used in conventional electronics.

(http://articles.ides.com/design/2010/plastic-electronics.asp)

Cetemmsa is a technology centre with over 19 years' experience in carrying out applied research on Smart Materials and Smart Devices.

The results of this research are the basis of joint projects with companies for innovation and experimental development of smart products that bring new uses and experiences to a wide range of economic sectors.

Cetemmsa has been able to print pressure sensors with inkjet technology and the functionality of an on/off switch. The printing of the required circuits for the correct working of the sensor is being done with the inclusion of several non-hybrid LEDs. This demonstrated that printed systems work correctly and that "printed electronics" technology is feasible.



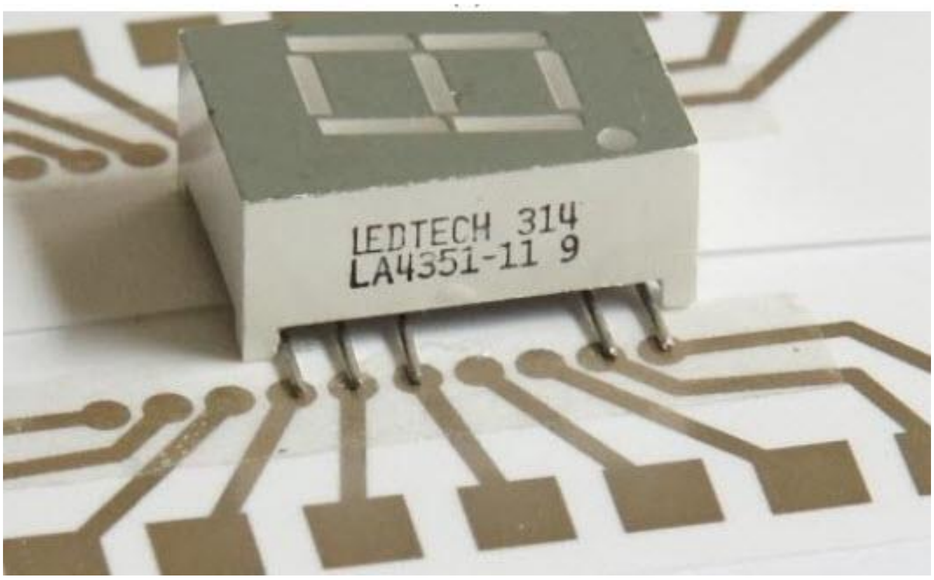
Tactile printed switching by inject technology (http://articles.ides.com/design/2010/plastic-electronics.asp)

The technology of electronic printing made one step further. A novel method to rapidly and cheaply 3D-print electrical circuits has been developed by researchers from Georgia Tech, Microsoft Research and the University of Tokyo. With $300 equipment costs, someone can produce working electrical circuits in 60 seconds, by printing them using common inkjet printers and materials.

The technique is called instant inkjet circuits and allows for printing arbitrary-shaped conductors onto flexible or rigid materials.

Silver nanoparticle ink is injected into an empty cartridge and used in conjunction with an off-the-shelf inkjet printer to enable “instant inkjet circuit” prototyping (Georgia Institute of Technology)

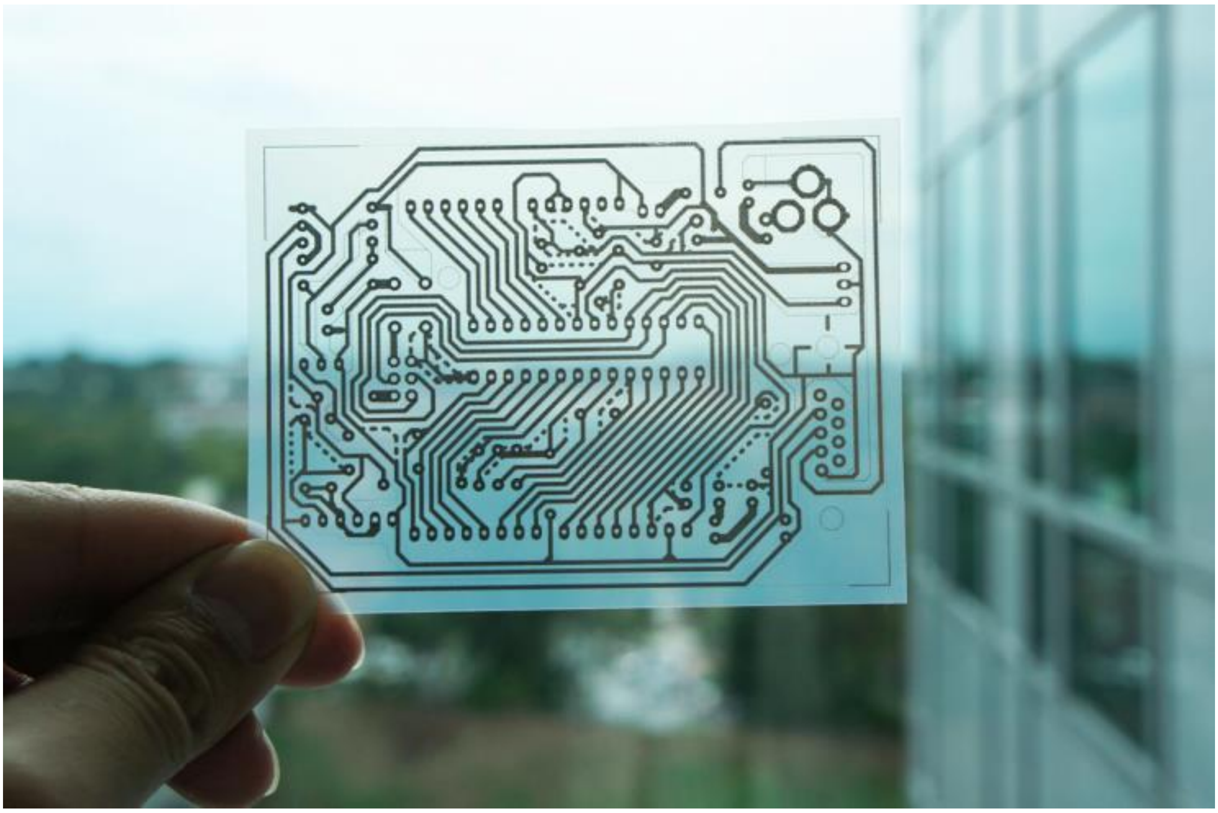
Latest innovations in chemically bonding metal particles gave the opportunity to researchers to use silver nanoparticle ink to print the circuits. With this system they avoid thermal bonding which is time-consuming and damaging technique due to emitted heat.
(http://dl.acm.org/citation.cfm?doid=2493432.2493486)
Printing the circuits on resin-coated or glossy photo papers and PET film is the best solution. Researchers also made a list of materials to avoid, such as canvas cloths and magnet sheets.
The procedure of printing a circuit is consistent of three steps. Firstly you have to design the circuit using desktop drawing software like AUTOCAD or even a photocopy of a drawing. Secondly, you print on inkjet printer using silver ink and finally you attach electronic components to the circuit using conductive double-sided tape or silver epoxy adhesive.



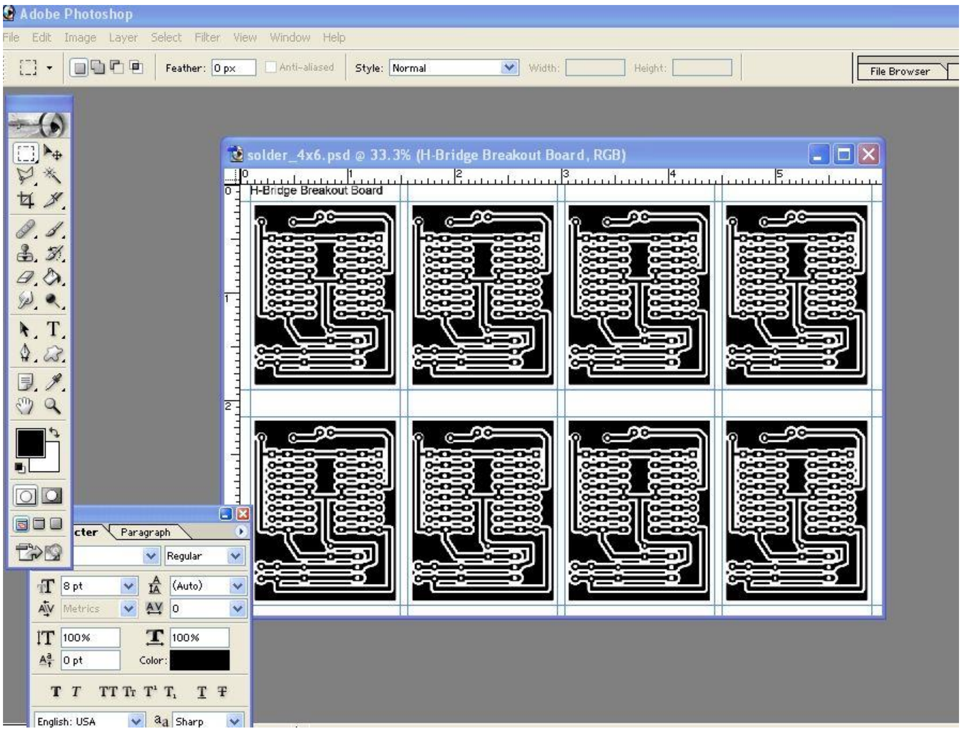
Connecting components using a conductive double-sided adhesive tape (Georgia Institute of Technology)

Homemade circuits allow to quickly prototype simple calculators, battery chargers, LED strips, thermostat controls, capacitive-coupled input devices and many other electronic devices.

With the same technique LED strips are produced during manufacturing. A possible innovation would be to combine transparent film for the base of the LED strip in order to allow more light pass through the strip.



A single-sided wiring pattern for an Arduino microcontroller was printed on a transparent sheet of coated PET film (Georgia Institute of Technology)

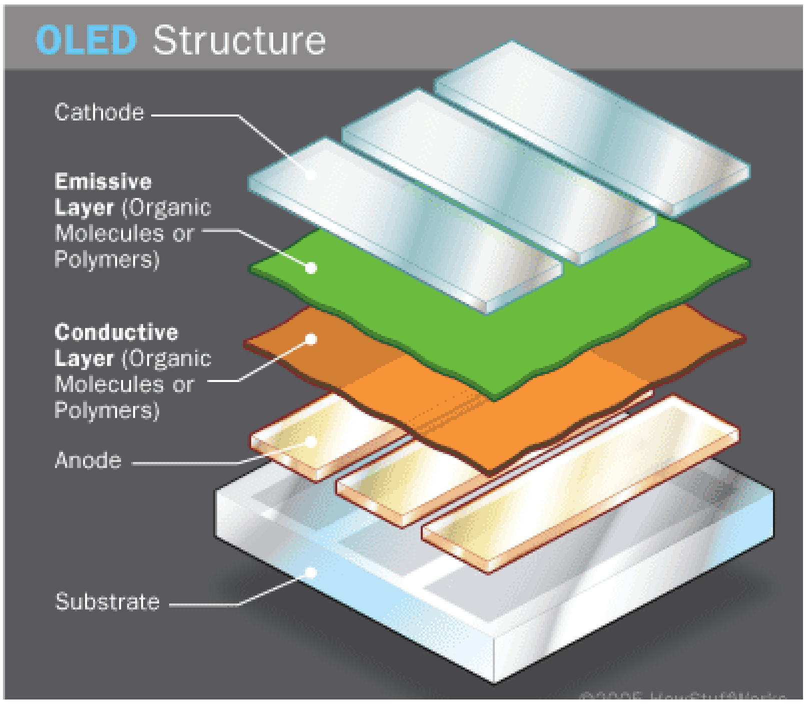


Designing circuits in Photoshop (http://www.instructables.com/)

2.3 Organic Light Emitting Diode (OLED)

OLEDs (Organic Light-Emitting Diodes) represent the next step in the evolution of new light sources which generate light by organic semiconductors. OLEDs work by passing electricity through one or more very thin layers of organic semiconductors based on carbon. These layers are sandwiched between two electrodes one of which is positively charged and the other one negatively. The ‘sandwich’ is mounted on a glass sheet or other transparent material called a ‘substrate’.

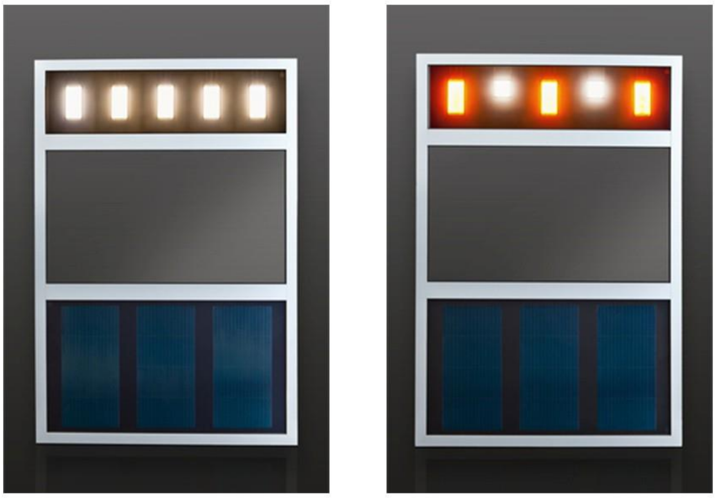
By applying current to the electrodes positively and negatively charged holes and electrons are emitted. These recombine in the middle layer and create a brief, high-energy state called ‘excitation’. When this layer returns to its original state, the energy flows evenly through the organic film and causes the emission of light. OLEDs can emit different coloured light by using different materials in the organic films, something which is still under research.



Exploded view of the OLED structure where the several layers are visual (http://electronics.howstuffworks.com)

Up until recent years it was impossible to predict the exact colour produced by a white OLED and manufacturers had to rely on testing and trials. Researchers at Eindhoven University of Technology, Philips Research, Dresden University of Technology and other institutes have now developed a method that allows the colour of light produced by a specific OLED design to be calculated with high precision. They did this by modelling the complex processes in OLEDs on a molecular scale. This approach allows the prediction where light is produced and lost in the ultrathin layers which enables the development of OLEDs that can produce the same amount of light with less electrical power consumption. The researchers expect that the efficiency can be increased by a factor of three. In the future manufacturers can also use the method to determine how thick the different layers need to be and how much pigment has to be added to the layers in order to produce OLEDs with specific colours. (http://www.tue.nl/en/university/news-and-press/news/color-of-oleds-can-now-at-last-be-predicted-thanks-to-new-modeling-technique/).

In the world of facades it took three years of research to achieve something promising. The manufacturing of individually designed OLEDs with solar cells and their combination can be realized in the near future. The project ManuCloud which was funded by the European Union, now successfully completed its work. As result the project partners Heliatek, Fraunhofer COMEDD, Tridonic Dresden and GSS Gebäude-Solarsysteme GmbH presented a demonstrator of a façade module, which combines the OLED and OPV technology. In terms of efficiency that would be the ideal scenario to have OLED facade elements which can produce all or part of the energy they consume. (http://www.led-professional.com/technology/light-generation/eu-funded-manucloud-project-combines-oled-and-organic-photovoltaic-in-a-facade-module)



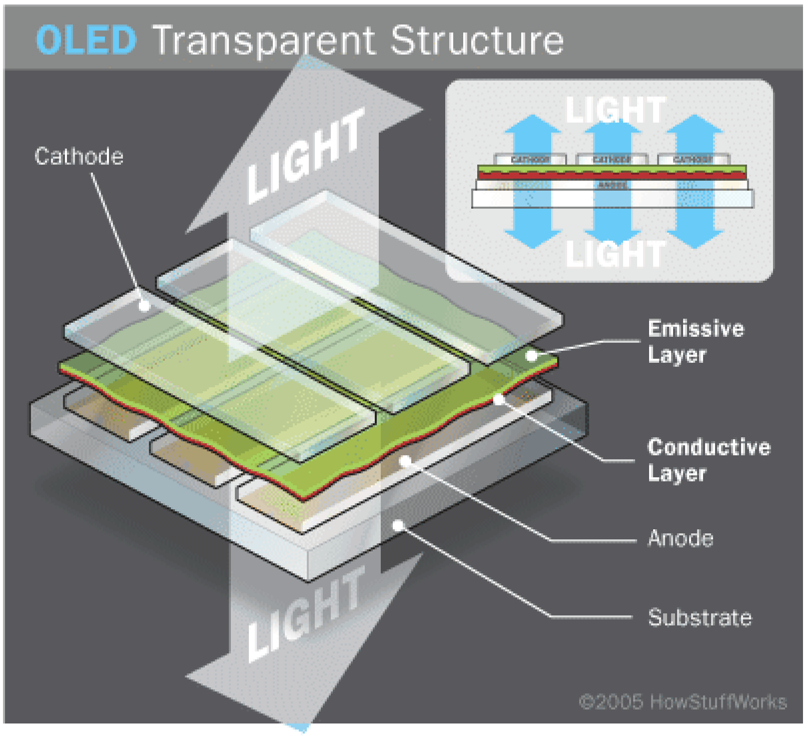
The concept modules from the project ManuCloud with integrated PV cells and OLEDs (http://www.oled-info.com)

Another interesting but concept project comes from the Israeli designer Meidad Marzan. He invented the "Urban Tiles" - urban tiles composed of a photovoltaic surface and a side surface of an OLED screen on the other side. Assembled into lines in a grid structure, these photovoltaic and OLED tiles create a kind of giant and bright store. The solar panels create electricity during the day and they store it, which then power the OLEDs with low consumption. A mini electric motor allows each OLED-PV tile to rotate on its axis in order to orient the solar cells facing the sun or to let natural light penetrate the building. At night, OLED tiles can be oriented either inward to illuminate the building or to form a giant TV in a house or outward to serve widescreen entertainment. (http://www.murs-photovoltaiques.com/urban-tiles-mur-photovoltaique-oled-facade-lumineuse-ecologique)

The "Urban Tiles" with two surfaces rotating through an axis (http://www.designboom.com)

Impression of the interior when the OLED is charged and emits light (http://www.designboom.com)

It is worth mentioning another category of OLEDs, the transparent ones. TOLEDs have only transparent components (substrate, cathode and anode) and when turned off are up to 85% as transparent as their substrate. When a TOLED display is turned on, light is emitted and passes in the up and down directions. That means it can create a display or light emitting surface that is viewable from both sides. TOLEDs can greatly improve contrast, making it much easier to view displays in bright sunlight.



Exploded view of the transparent OLED structure (http://electronics.howstuffworks.com)

Philips and BASF two years ago created a new technology for the upcoming luxury electric vehicles with an OLED that acts as a window when switched off. The technology allows drivers to have a visual contact with the environment outside of the car while driving or a brightly light interior when the switch is flipped. The researchers that time were investigating to add solar cells to create a self-powered, interior lighting sunroof something we see that is materialized by the project ManuCloud. (http://inhabitat.com/philips-develops-a-transparent-energy-gathering-oled-car-sunroof/clear-oled-car-roof-4/)

Technology designed by Philips where the OLED becomes transparent
(http://www.research.philips.com/technologies/projects/oled/index.html)

In general we see that OLEDs are still in conceptual and experimental stage which impresses but is not proven in long term period.

2.4 Comparison of LEDs and OLEDs

A basic structural difference is that OLEDs are created using organic semiconductors containing carbon, while LEDs are built in crystals from an inorganic material like germanium or silicon. The ways in which molecules can be combined and interact in organic materials are much more extensive than in inorganic materials, which significantly widen OLEDs development potential.

There are also visible differences between these two types of lighting. LEDs are glittering points of light like brilliant miniature bulbs and they are very condensed light source which create very high brightness in a compact shape. Additionally, they are perfect to be aligned with optical systems and build sharp, well controlled beams.

On the other hand, OLEDs are extremely flat panels that evenly emit light over the complete surface, diffuse light sources by nature. The illumination they produce is smoother, non-glaring and more glowing and diffuse. The thin flat nature of OLEDs enables manufacturers the use and integration of light in ways that are impossible with any other light source.

OLEDs are not going to replace LEDs because they have their own very specific and useful types of applications. Similar to LED technology blue emitters in OLEDs still have room for improvement, while green is also highly efficient.

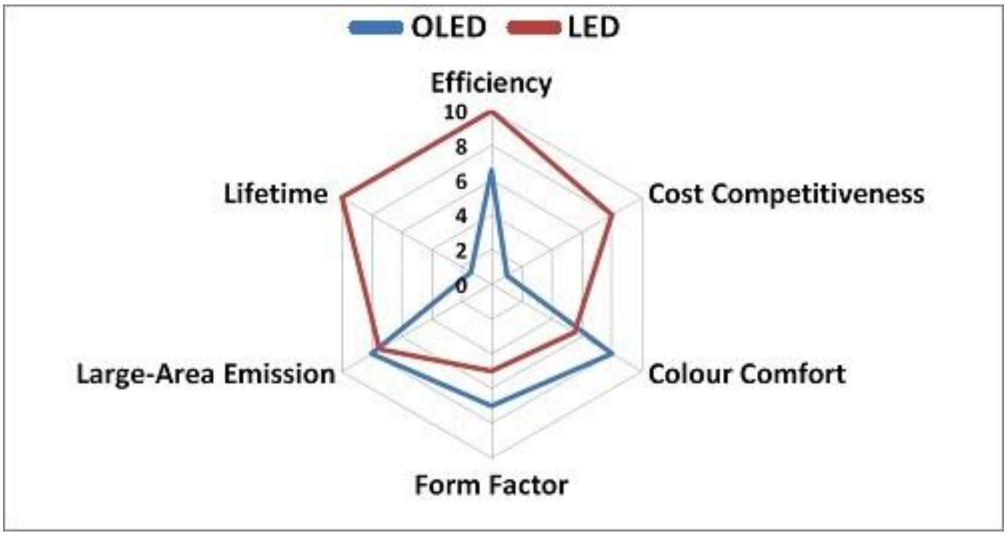
An interesting research comes from IDTechEx. Since 1999 IDTechEx has provided independent market research and business intelligence on emerging technologies to companies across the value chain, supporting them in making essential strategic business decisions. The conclusion of their report is that in its "most likely" forecasts scenario OLED lighting will become a $1.3 billion market in 2023 - equating to 1.3% of the market size of LED lighting at that time. (http://www.idtechex.com/research/articles/oled-vs-led-lighting-is-there-room-for-oled-lighting-00005477.asp)

OLED lighting is likely to struggle to define and communicate its unique selling points and may remain an over-priced and under-performing option compared to LED lighting, unless high innovation occurs. OLED lighting companies will be forced to capitalise on superior design features to catch up in the shopping and architectural sectors. Profits for panel makers will be shrinked due to intense competition and value will migrate downstream to luminaire designers, who will be the demand creators.

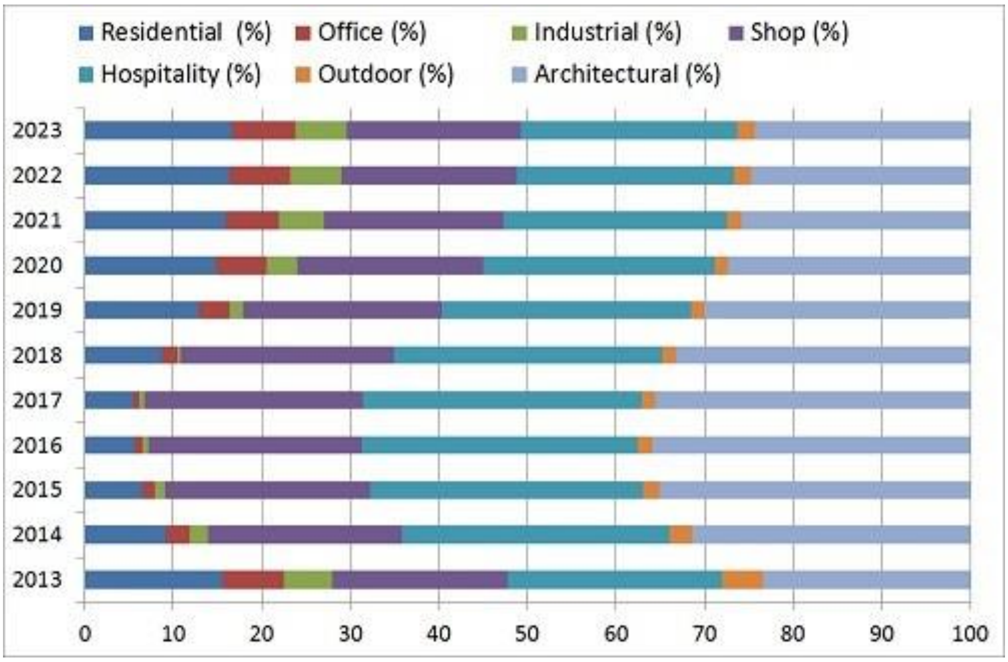
OLED displays are growing rapidly but their lighting counterparts are still actively trying to define their unique selling points compared to LED lighting. Today, they lag behind in terms of performance. This is because LEDs regularly offer 90-100 lm/W at package level with the LED chip encapsulated, while OLED modules are still in the region of 20-50lm/W. The lifetime of LEDs far exceed that of OLEDs with LED lamps regularly offer in excess of 50.000

hours, while OLED lighting offers 5.000 to 15.000 hours of operational life even when encapsulated.

Additionally, LEDs are low cost, with $5/klm (kilolumens) at package level. One high-power LED equals 1 kilolumen. In contrast OLEDs cost $300-$500/klm at panel level. The main cost drivers are the encapsulation layer (barrier, adhesive and desiccant) and integrated substrates (transparent conductive layer, substrate and out-coupling layer). So by a simple comparison OLEDs are almost hundred times more expensive than LEDs.



Spider diagram comparing several variables between OLEDs and LEDs. For example, the efficiency of LEDs 10 scores higher than OLEDs with 6,5 (http://www.idtechex.com)



The relative monetary contribution of each lighting market segment to the total OLED market 2013-2023 (http://www.idtechex.com)

Furthermore, on the Fixture Design conference in London (29 May of 2012) top manufacturers discussed the future of LEDs and OLEDs. The conclusions were also more positive fort LEDs compared to OLEDs. The second ones impress the clients, according to Marc-Olivier Wendling from Osram, but they are not convinced to invest in them. The main barriers for OLEDs are the competing technologies, cost and performance. OLEDs need to get more efficient, longer lasting, cheaper and brighter.
(http://www.luxmagazine.co.uk/#!/issue/33)
There is a lot of research going on in the field of OLED which mainly focuses to improve device performance and especially driving voltage and lifetime. Lifetime is one of the major obstacles for commercial applications for OLEDs. The main reasons for this are that OLEDs have a thinner layer structure than LEDs. Furthermore, as organic materials they are sensitive to oxygen and moisture. Finally, they are not as robust as semiconductors due to larger vibration energy.
Another phenomenon in OLEDs which keeps them behind compared to LEDs is the quick degradation which occurs. It is called intrinsic degradation and it happens due to organic materials' quality, which during time degrades and loses it chemical structure. The degradation will be much higher for a media facade made of OLEDs due to exposure to the sun light and the UV radiation. This is something that happens in LEDs after much more time (Amir Naeimi, *OLED Display with SG-TFT*, Master Thesis, TU Delft, 2011).
In addition, another consulting company ''Hendry Consulting'' offers some results by comparing LEDs and OLEDs. Based in London, it has a global network of consultants in many areas of display, high-technology and semiconductor technologies. In September 2011 they published a report addressing that LED and OLED lighting markets are at different stages of maturity while LEDs are getting to scale. OLED lighting had just getting started and not yet included in most forecasts.
(http://www.hendyconsulting.com/downloads/OLED%20and%20LED%20lighting%20scenarios%20Sep%202011%20HCL.pdf)
Finally, PR Newswire announced a recently published report with the title ''OLED vs LED lighting 2013-2023'' in which is explained that LED lighting has come a long way and offers a better performance than OLEDs and at lower cost. OLED lighting will therefore only gain market success if it clearly defines its unique selling points and carves out initial market niches. (http://www.prnewswire.com/news-releases/oled-vs-led-lighting-2013-2023-240082121.html)

2.5 Top LED manufacturers

Photonics Industry and Technology Development Association (PIDA) made a list of the 10 top global LED lighting manufactures of 2013. Philips, Osram and Panasonic are the top three while no manufacturers from Taiwan are in the list.
According to PIDA the 10 top global LED lighting manufacturers in order are Philips, Osram, Panasonic, Toshiba, Cree, ENDO, Zumtobel, Koizumi, Iris Ohyama and Sharp.
(http://www.ledinside.com/news/2013/11/pida_unveils_top_10_led_lighting_manufacturers_list)
The same companies are producing LED lights for applications in media facades.

LEDinside has attempted to measure Chinese LED lighting market value by formulating a model based on the original demand for general luminous flux and the replacement demand for LED-based lighting (http://www.ledinside.com/)

2.6 Top OLED manufacturers

The same companies which are at the top of LED lighting production are also OLED top manufacturers. They can be divided in several developers. OLEd developers, transparent OLED developers, flexible OLED developers, OLED module developers and OLED luminaire developers. (http://www.oled-info.com/companies/oled-lighting).

3. MEDIA FACADES COST AND MAINTENANCE

In order to design the appropriate media facade for building, specific guidelines need to be considered, like the technology, the media content and many others. One of the most important and essential is the money that the client is willing to pay. A media facade with higher resolution means more pixels and thus more cost compared to a similar system with lower resolution. How much does a media facade cost? That is a hard question to answer. The best option in my research was to contact directly the leading companies in the media facade industry and ask them about the prices of their products because there is nowhere information available. In the beginning I contacted the Media Architecture Institute.
MAI is a non-profit organisation designed to complement the work of established universities and research institutions with a flexible but very focused research activity linking industry, education and academia together. Their work can be found where architecture and urbanism meets digital media. Generally innovation within Media Architecture takes place on different levels: new hardware (like façade systems), new applications (like mobile games) and new architectural forms. The biggest innovation lies in the combination of already existing technologies (like LED displays and social media) and in the creation of interfaces between them. They have expressed their ideas and understanding of Media Architecture and Media Facades in several books and publications in an academic and popular context. (http://www.mediaarchitecture.org/)
This attempt was not so helpful because the Institute does not have direct communication with the enterprises. So they advice me to contact the press offices of the different enterprises and suggested me some more companies.
So I made a list of the companies with the state of the art products and contacted them.

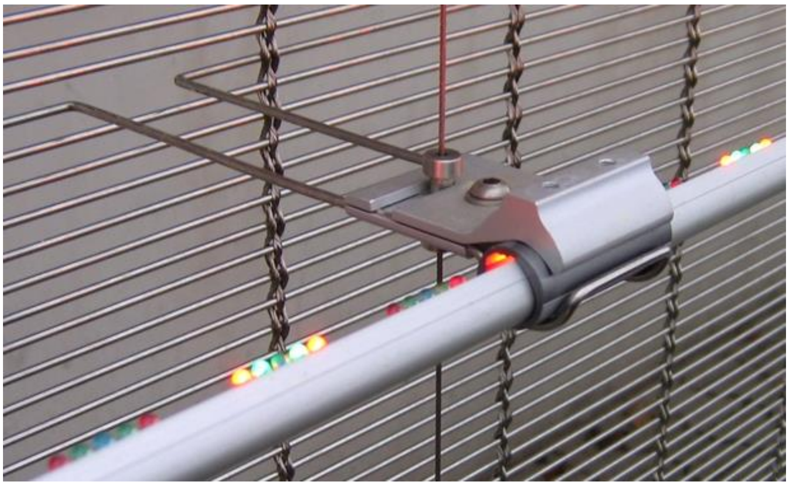
<u>3.1 GKD metal fabrics</u> is the leading full service provider of woven metal fabric for architectural solutions worldwide and is also the innovator of transparent media façade technology. GKD's media façade offering includes two systems: Mediamesh® and Illumesh®, both engineered and manufactured to precise German standards. Being the pioneer of this complex and state-of-the-art architectural solution, GKD has defined the parameters of the category implementing critical factors as installation, methodology, safety procedures and system variations. The answer that I had from this company about the two products mentioned was clear and very informative because they have materialised many projects.

Night view of the media facade with high resolution (http://www.gkdmetalfabrics.com)

Day view of the media facade with high resolution as well (http://www.gkdmetalfabrics.com)

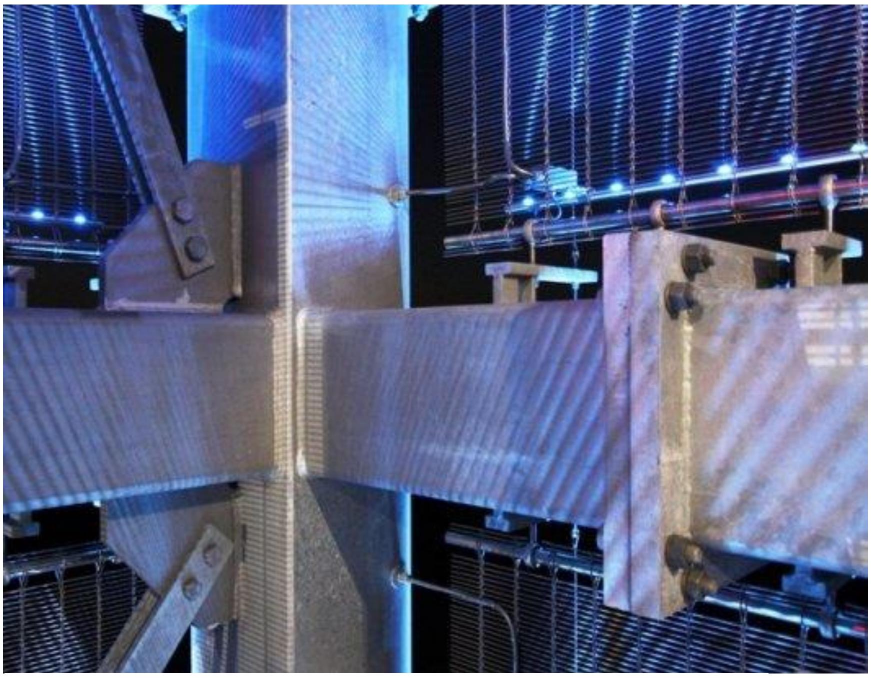
Mediamesh® prices depend mainly on the quantity and the resolution of the desired project. They start at approximately 3.000€/m² for a large mediamesh façade which is over 1.000 m² in moderate resolution and end at approximately 12.000€/m² for a small mediamesh façade which is less than 50 m² in high resolution. A typical price for a mediamesh façade measuring 400-500 m² will be 5.000 – 6.000€/m².
Illumesh® is much cheaper and ranges between 800 and 1.500 €/m². We also have to mention that this type of mesh is designed only for night use whereas Mediamesh® is for both day and night time.
For example the mediamesh surface at the Port Authority Bus Terminal in New York is 557 m². More than 1.325 million LED diodes are interwoven throughout the stainless steel fabric to allow the imagery to come alive from seemingly nowhere. The cost of this high resolution facade can be estimated at 7.000€/m² so in total almost 4 million€ for the whole media façade.

Closer view of the Mediamesh technology (http://www.gkdmetalfabrics.com)



Closer view of the Illumesh technology (http://www.gkdmetalfabrics.com)

Indemann features a transparent façade made of Illumesh® stainless steel metal fabric with interwoven LED profiles (http://www.gkdmetalfabrics.com)

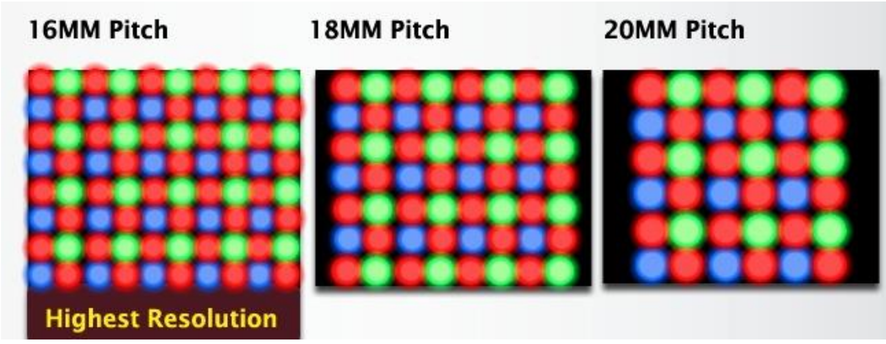


Interior detail with the connection of the steel structure and the mounting of Illumesh® to the beams and columns (http://www.gkdmetalfabrics.com)

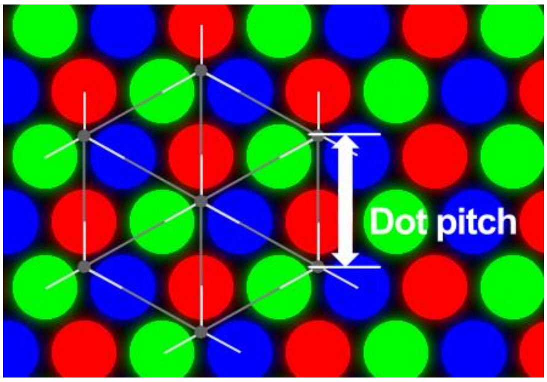
Illumesh® was not as favourable as it seems, given that GKD has materialised only three projects instead of ten with Mediamesh® which is also far more expensive. In Germany designed as a symbol of the structural-political evolution of a former mining district, the 36m Indemann Observation Tower in Inden, serves as a visual representation of progressive planning for the future. Indemann features a transparent façade made of GKD Illumesh® stainless steel metal fabric of 1500m² with interwoven LED profiles. The cost of this facade is estimated to 1.200€/m² so in total 1.8 million€. We see the difference in the two types of technology, where on the one project they dress 557m² with 4 million€ while in the other almost the triple surface with half the price.

As far as the maintenance is concerned it is infrequent and typically minimal. The façade requires a simple mechanical washing to eliminate natural contaminants and maintain display brightness. Factors such as heat, operating intensity, corrosives and operating durations will affect the life of the façade but LED life is typically estimated in the 10 year or 60,000 hour range. Manufacturers are available to inspect and service a façade as required. Mediamesh® and Illumesh® are constructed of T316 series stainless steel metal fabric with the fundamental qualities of woven metal and the addition of unprecedented artistic and communicative capabilities. As a non-structural material, Mediamesh® and Illumesh® can clad any surface or structure, integrated into new construction or retrofitted.

3.2 LEUROCOM®, with more than 30 years experience in this line of business, is a worldwide successful LED specialist. Their factory offers a broad scope of products and installations that are exclusively manufactured in Germany. They customise selected material, design and software to every customer specification and that is the reason why they cannot give standard prices for the several products for media facades. The cost depends on the final configuration, how strong is the brightness of pixel, the LED pitch and the resolution. Pixel pitch is the distance from the centre of an LED cluster (or pixel) to the centre of the next LED cluster/pixel measured in millimetres. Pixel pitch typically ranges from 4mm up to 20mm for indoor LED displays and for outdoor displays from 10mm to 34mm or higher. The lower the pixel pitch, the closer a viewer can stand to your display and still have a great resolution.



Different types of LED pitch. The denser the pitch grid the higher the resolution is (http://www.westcoastsigns.com/)



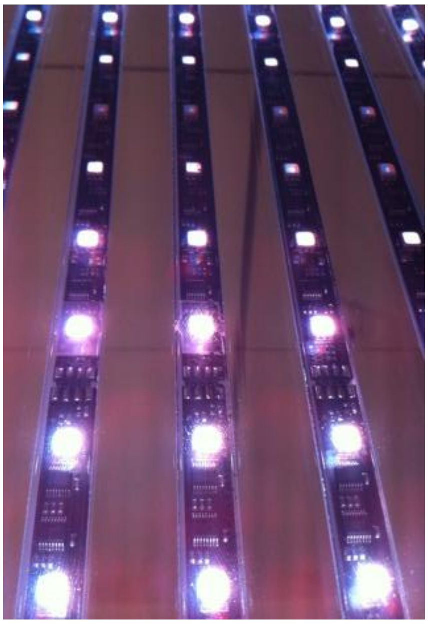
Pitch can be defined as the distance between two centers of the isosceles triangles shaped by 3 LEDs (http://en.wikipedia.org/wiki/Dot_pitch)

In LEUROCOM® they use special technology to produce Mediaglass®**,** the latest innovation in LED and glass integration for large facade displays. LED stripes are incorporated into laminated glass, which is manufactured out of pre-stressed glass components. The maximum production size dimensions are 2 x 3,20 meters.

The integrated high-efficiency RGB multichip LEDs can be controlled by video signal with 16-bit colour depth. By adjusting the pixel pitch and stripe distance, the pixel matrix can be individually adjusted to the project and the installation. Prices of this product range from 7.000€ /m² with 25 mm pitch and over 42 mm pitch 4.500€ /m² to 1.000€ /m² for night configuration and low brightness.

In December 2010, the first Mediaglass® facade with a size of about 11, 5 m x 2 m and with 31.500 pixels, was manufactured and installed at the IMAGINARIUM store in Calle Serrano, Madrid, Spain. The cost of this facade measuring 23m² with 25mm pitch is estimated at

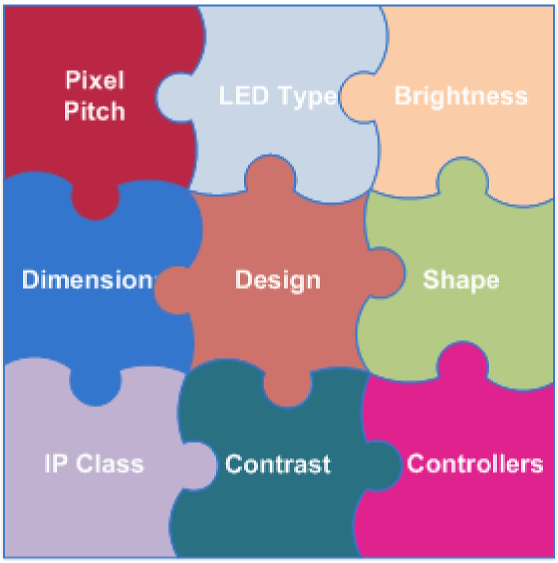
160.000€ which is less than a small Mediamesh® facade with high resolution and more expensive than an Illumesh® facade.



Integrated LED stripes in laminated glass (http://www.leuro.com/en)

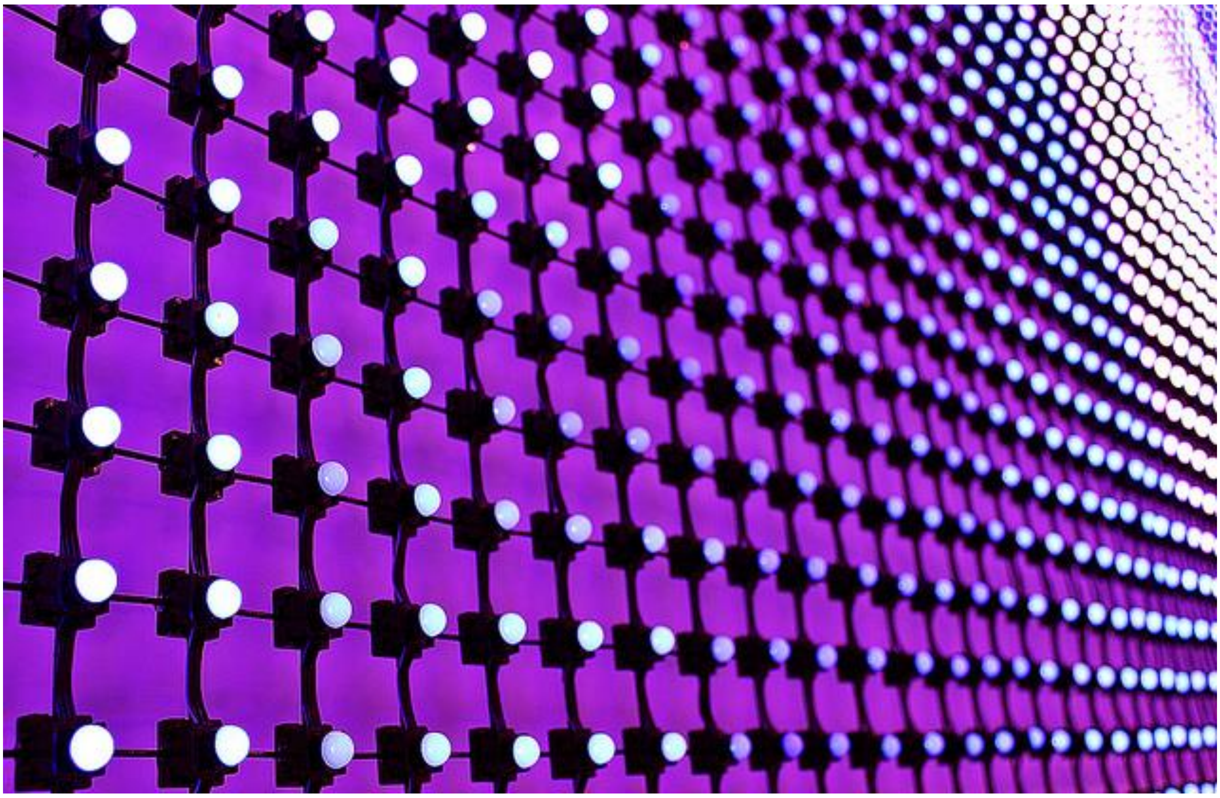
Media facade at Imaginarium in Spain with Mediaglass® technology (http://www.leuro.com/en)

This company uses a platform which offers parameters you can toy with to match budget and technical requirements. The installation and attachment to the façade is planned very individually and depends on the service access, concept, wall conditions, special façade integration etc.



Puzzle board designed by Leurocom where customer can take into account several aspects for the design, like budget, technical requirement, etc. (http://www.leuro.com/en)

3.3 iColor Flex MX gen2 by Philips® are flexible strands of high-intensity and full-colour LED nodes designed by Philips for effects and expansive installations without the constraints of fixture size, shape, or space.



iColor Kinetics grid created by the nodes (http://www.colorkinetics.com/)

Each strand consists of 50 individually addressable LED nodes, featuring dynamic integration of power, communication and control. The flexible form factor accommodates two and three dimensional configurations, while high light output affords superior long distance viewing for architectural accent and perimeter lighting, large scale signage and building covering video displays for media facades.

The package of the iColor Kinetics as it arrives to clients

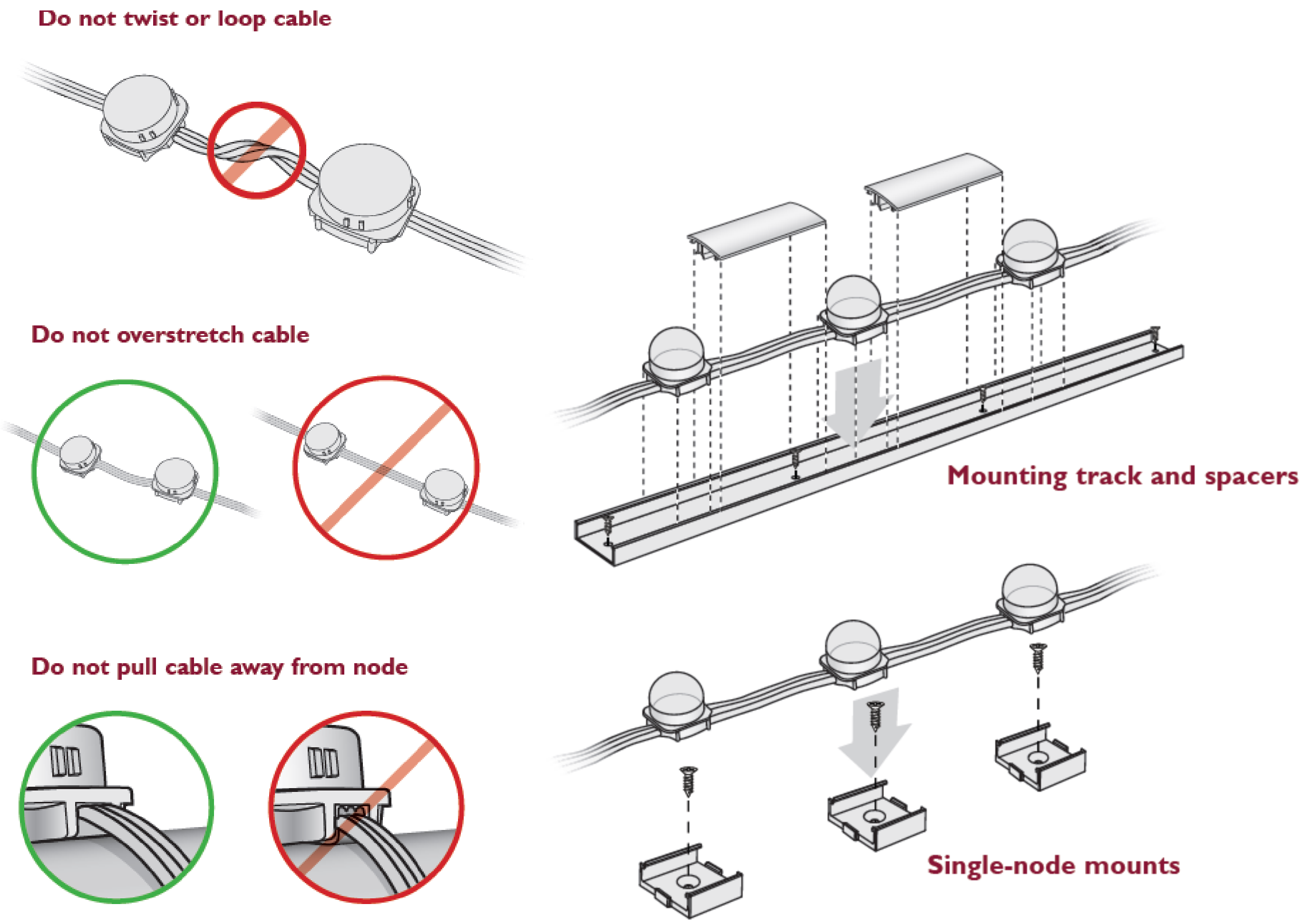
Each node produces full colour of up to 2.3 candelas and is formed by a standard clear dome or translucent dome lens. These strands can be mounted directly to a surface like traditional string lights. Detachable leader cables in multiple lengths allow you to install strings at the appropriate distance from power to data supplies.

Furthermore, there are optional mounting tracks which ensure straight linear runs, while snap-on spacers hide cabling and mounting hardware between nodes. Single node mounts can be positioned individually to provide anchor points for installations with uneven node spacing or complex geometries.

Due to their potential complexity, iColor Flex MX installations require upfront planning for configuring, positioning and mounting the fixture strands. Planning includes understanding how to position strands in relation to power-data supplies and the number of strands each power-data supply can support. Planning for video displays involves additional considerations, such as how to space iColor Flex MX nodes to achieve the desired pixel pitch, minimum and maximum viewing distances, sampling and display resolution.

All installations involve three main steps: 1) create a lighting design plan and layout grid, 2) mount fixture strands, 3) Address, configure and test fixtures.

The installation procedure can be achieved with diagrams by following the instructions. (http://www.colorkinetics.com/ls/rgb/flexmx/)



Diagrams on the Philip's manual explaining the assembly of the nodes and the fixing(Philips namual iColor FLEX)

Item	Specification	Details
	Lumen Maintenance*	50,000+ hours L50 @ 50° C (full output)
	LED Channels	Red / Green / Blue
Electrical	Input Voltage	7.5 VDC via PDS-60ca or sPDS-480ca
	Power Consumption	.5 W max. per node at full output, steady state
	Power Factor	.98 @ 120 VAC
Control	Interface	sPDS-480ca 7.5V (Ethernet) PDS-60ca 7.5V (Pre-programmed or DMX / Ethernet)
	Control System	Philips full range of controllers, including Video System Manager Pro, Light System Manager, and iPlayer 3, or any third-party controllers
Physical	Node Dimensions *(Height x Width x Depth)*	.63 x .63 x .75 in (16 x 16 x 19 mm)
	Weight	13.4 oz (381 g) 50-node strand, 4 in on-center node spacing
	Housing	White or black polycarbonate
	Lens	Clear or translucent plastic
	Fixture Connections	Integrated watertight 3-pin connector
	Temperature Ranges	-4° – 122° F (-20° – 50° C) Operating ≥ 32° F (≥ 0° C) Handling -4° – 122° F (-20° – 50° C) Startup -22° – 185° F (-30° – 85° C) Storage
	Humidity	0 – 95%, non-condensing
	Maximum Fixtures Per Power / Data Supply	sPDS-480ca 7.5V: 16 strands PDS-60ca 7.5V: 2 strands
Certification and Safety	Certification	UL / cUL, FCC Class A, CE
	Environment	Dry / Damp / Wet Location, IP66

Brightness Per Node

Lensing	On-Axis Candela	Viewing Angle
Clear flat lens	1.44	104°
Clear dome lens	1.23	110°
Translucent flat lens	0.81	109°
Translucent dome lens	0.52	149°

Luminance of 1 m^2 Grid

All figures in nits (cd / m^2)	On-Center Node Spacing		
Lensing	2 in	4 in	12 in
Clear flat lens	520	144	23
Clear dome lens	444	123	20
Translucent flat lens	292	81	13
Translucent dome lens	188	52	8

Specifications of the system by Philips(Philips namual iColor FLEX)

Stockholm Lighting Company have completed a large installation of Color Kinetics Flex controlled by a Pharos LPC X. Rockheim is a rock music museum in Trondheim, Norway. 1860m^2 of façade is covered with 13.767 Color Kinetics SLC Nodes. A Sarian GPS provides remote access and an on-site PC allows local access to the LPC X’s web interface for diagnostics and additional triggering.

‘Arcs’ (Rockheim) is a generative animation for the media facade of the cube structure that sits on top of the Rockheim Museum for Rock and Pop in Trondheim, Norway.
The animation is made using algorithms and consists of radially oriented lines tracing out a curved 3D surface. The piece is currently uses rendered video rather than using real-time software, although in principle it would be possible to create a real-time version.
‘Arcs’ was designed specifically with the limitations of the pixel grid in mind, prioritizing dynamic movements and bright, high-contrast colours, which wrap around the cube’s facade in varying densities.
(http://mariuswatz.com/2012/02/07/arcs-rockheim/)

The privilege of conducting my graduation project in a big facade company like Rollecate is that you have instant contact with suppliers and clients which are cooperating and negotiating offerings for running projects.

More specifically, Rollecate had two offers from two different companies for their office media facade. Consequently I was asked to compare them and see advantages and disadvantages for both offers. First company was Brakel Atmos and second one Philips. Leurocom Mediaglass and iColor Kinetics were the two different technologies to be applied respectively. After analysing and collecting the offers in boards I was led to some conclusions.

A) PHILIPS

Pitch	35mm	50mm	70mm	100mm
Vertical pixels	210	140	100	70
Horizontal pixels	253	177	127	89
Total pixels	53.130	24.780	12.700	6.230
NITs	2.230	1.040	533	261
Netto price	€ 439.254	€ 212.688	€ 120.069	€ 66.226
Netto price per pixel	€ 8,27	€ 8,58	€ 9,45	€ 10,63

B) BRAKEL ATMOS

Pixel pitch: 42 x 45 mm

Pitch per m^2: 529 pixels

Brightness: 5.000 Nits (cd/m^2)

a) Total number of pixels 17.200 pixels.

b) Total number of pixels 9.600 pixels.

Price: €150.000-200.000

COMPARISON

- Brakel Atmo's offer has better resolution on the media facade due to the fact that the pixel pitch is smaller (42x45mm) than Philips with (50x50mm) almost in the same price. Don't look at the number or pixels. It is not always related with the resolution.
- Brakel Atmo's offer has more competitive price because as I understood the mounting works are included in the final cost except the 230V supplier, while Philips states clearly that the missing issues like mounting, assembling etc. are not included in the price.

- Brakel Atmos seems that is has much more light intensity at his LEDs per m^2 surface! Philips offers 1.040 Nits while Brakel Atmos 5.000Nits.Big difference. Nit is candela per m^2 (cd/ m^2). So the Mediaglass will be better visible during day.
- As far as the installation is concerned Philips seems easiest. You add something extra without intervention in the existing facade.
- Maintenance is better for Philip's solution given that it is an exterior system and can be reached easier.
- Philips has a good description about installation and specifications for power suppliers for the media facade while in Brakel Atmos they just mention it general in the price inclusive package.

4. REFERENCE PROJECTS

4.1 King's Road Tower, Jeddah.

Citiled® is a company with headquarters in Paris and whose founders have combined experience over 30 years in the LED industry.

This company specialises in the design, engineering, supply and installation of LED lighting and video systems, also known as ´´MediaLighting´´ and ´´MediaFacade´´. One of the last years they announced the official launching of the latest patented technological innovation during Cityscape Saudi Arabia, the Digital Media Facade 2.0. DMF 2.0 allows absolute architectural integration of video systems into the facade of a building. By integrating LED circuits within the double or triple glazing of the windows and integrating all cables and the connections within the mullion, the whole installation can be installed and controlled from a central room.

This solution was conceived and created as a plug and play solution for real estate developers, investors, engineers and architects. With performances like high colour accuracy, dimmable brightness and a large variety of possible content formats, the DMF2.0 can broadcast TV signals and colour branding.

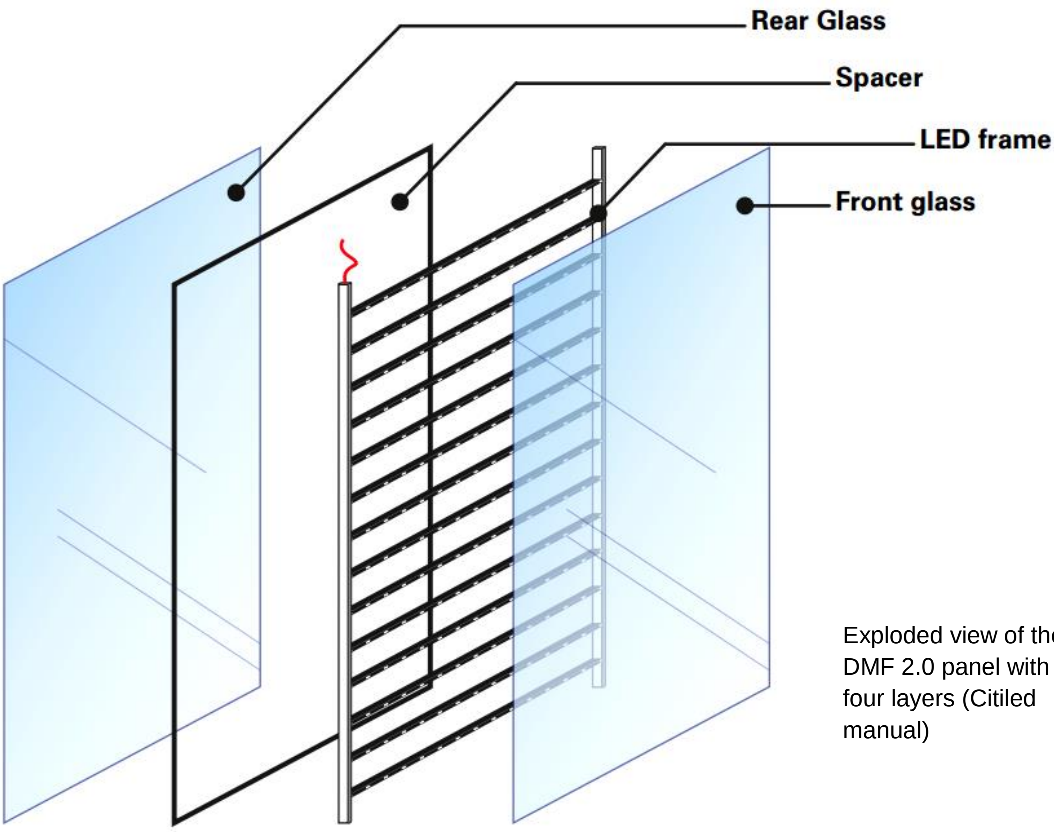
One of the latest and bigger projects that Citiled® materialised is King's Road Tower in Jeddah. Jeddah's Corniche won't ever be the same after final completion of the King's Road Tower and its breath-taking, cutting-edge and largest in the Middle East, with almost 10.000m² custom-made LED media facade.

King's Road Tower in Jeddah where technology meets architecture. Incorporated LED glass panels as a curtain wall facade. There are though several questions unanswered like what happens if a LED stripe is damaged, or how do you change it? (http://www.citiled.com/)

Image during the construction phase where the glass panels are mounted on the facade like a curtain wall system (http://www.citiled.com/)

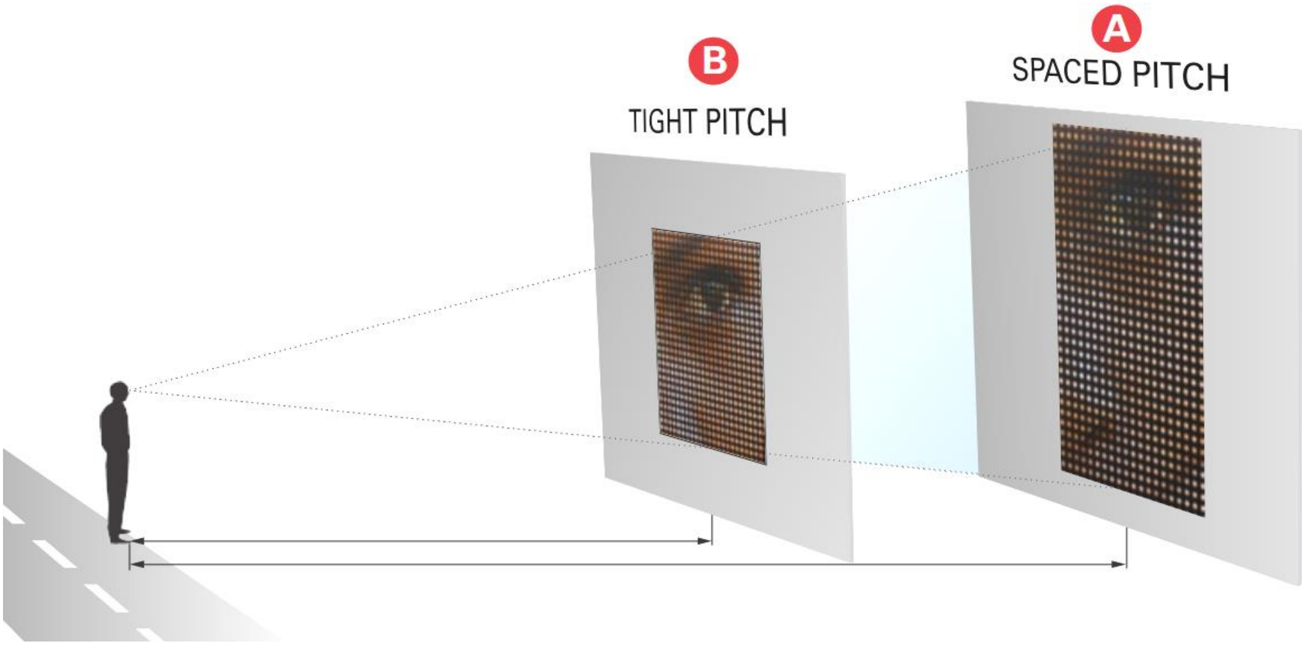
Night impression of the skyscraper where the building turns into a large display (http://www.citiled.com/)

While responding to the usual standards for external glazing (solar control, thermal and acoustic insulation, etc.), DMF 2.0 is a solution for large-dimension double-glazing facade incorporating grid of LEDs enabling display of several types of digital content without obstructing totally the view from the inside of the building. It enables to act as a large-scale creation support for facades. The LED bars are integrated in double or triple glazing making it an easy and adaptable solution allowing the animation technology integration into glass façade. The front glass can be a high performance coated glass. In this case, partial coating can be processed to reach the optimum brightness of the LED system. Standard spacer used is 16mm.



Exploded view of the DMF 2.0 panel with the four layers (Citiled manual)

The solution being integrated into the glazing units does not impact inside and outside cleaning of the windows. The elements with lowest span life like power supply and video distributor are fixed outside of the glazing for easy access.
The resolution and brightness can be optimised according to the application of the installation. A minimum amount of vertical pixels per line is required in order to guarantee a good visibility, depending on the complexity of the content.
Because LED bars are directly incorporated into the glazing, DMF 2.0 is one solution with the best outward vision of media facade systems. This visibility is related to the pixel pitch density. LED bars are 8 to 14 mm thick depending on the configuration. The distance between the facade and the spectators impacts the implementation of DMF 2.0 to insure the integration of the installation in its urban environment. The minimum viewing distance is the closest a spectator can approach to the screen before pixels appear as dots. This distance affects the density of the pixel pitch; the shorter it is the denser the pitch has to be.

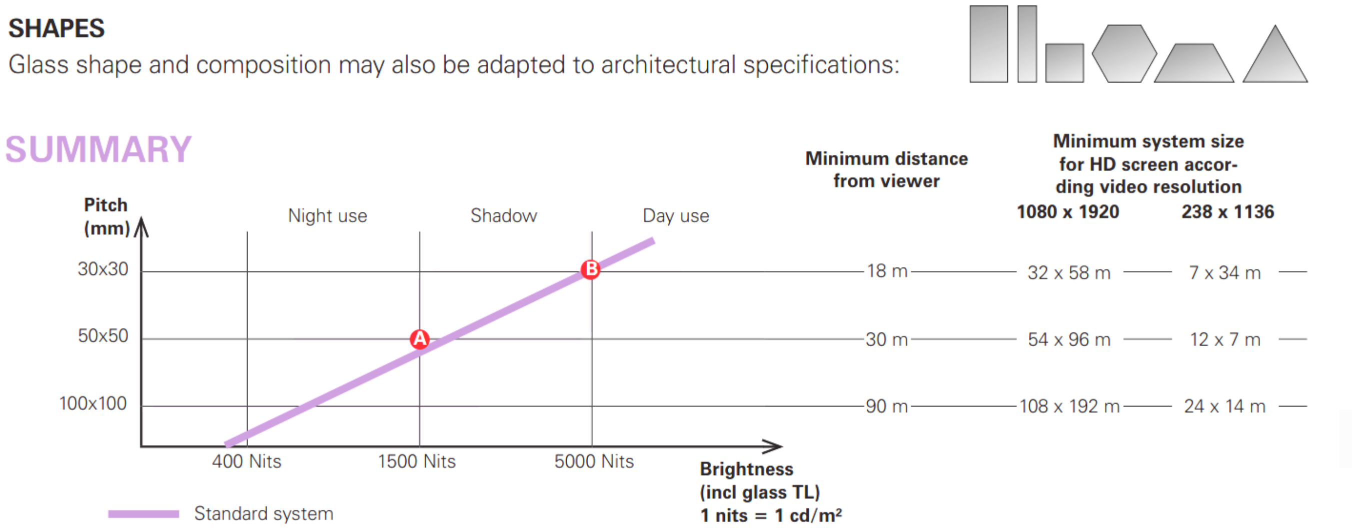


Sketch illustrating the relation between distance and resolution. The closest the observer the denser the pitch and the better the resolution (Citiled manual)

Closer view of the LED matrix into the glass (Citiled manual)

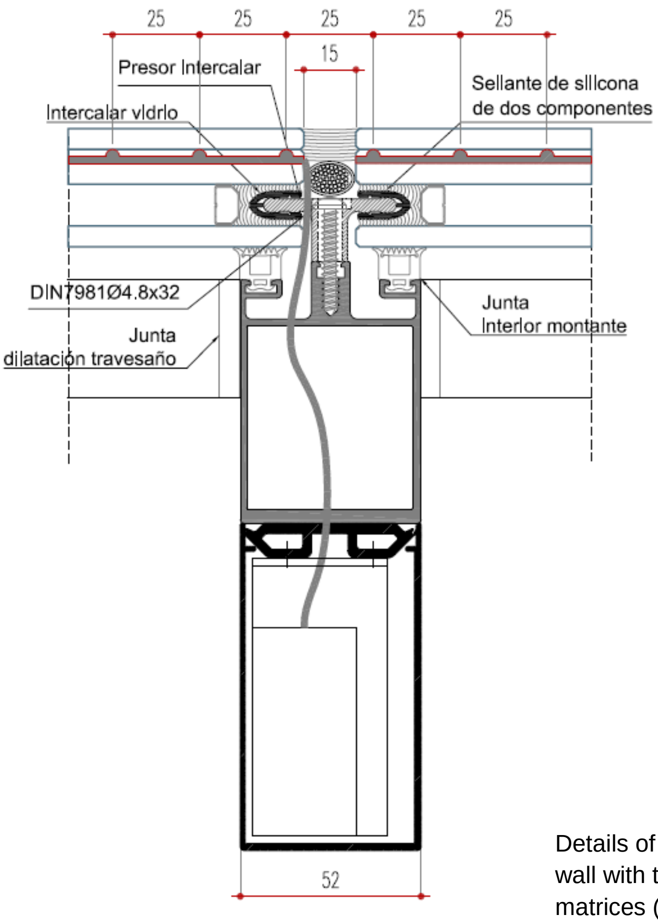
The view from the interior is unblocked. You can distinct only the effect of the horizontal stripes (Citiled manual)

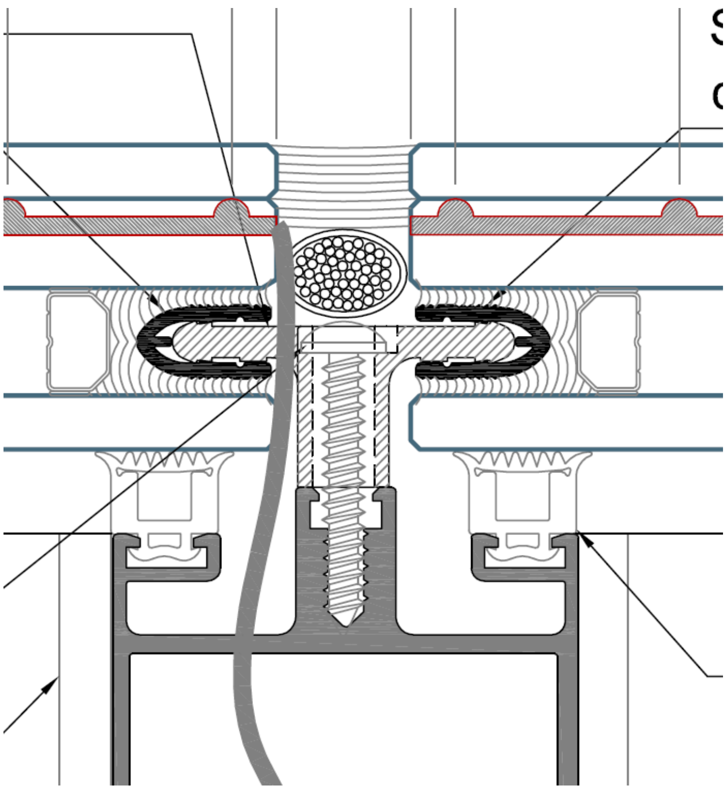
The following diagram illustrates the relationship between the pixel pitch and the brightness of the facade panel as well as the distance. A unit of nit is one candela per m². Candela is the luminous intensity or power emitted by a light source in a particular direction. The more nits the more brightness on the facade and that means that it can be visible even during day. In addition, we can see several options for shapes of the glass according to architects will.



This type of technology offers the flexibility in customised glass shapes. In addition, the diagram above presents that the brightness increases as the LED pitch becomes smaller (Citiled manual)

LEUROCOM® is another company in the media facade industry which uses the same system of LED matrices in laminated glass and provides some technical details of a curtain wall.

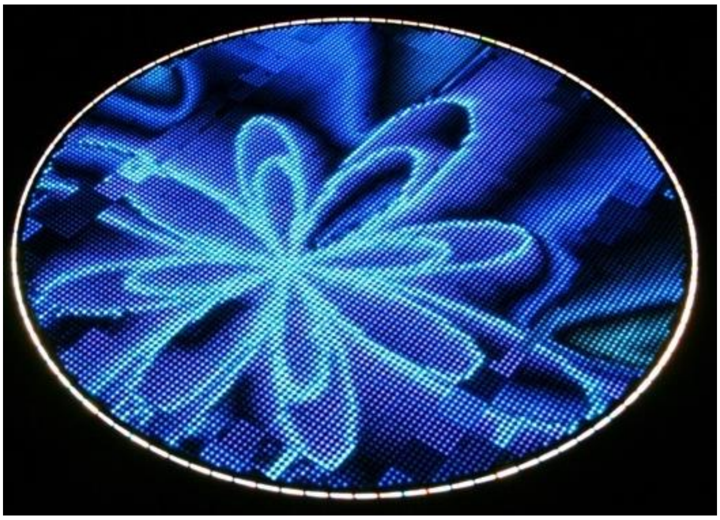




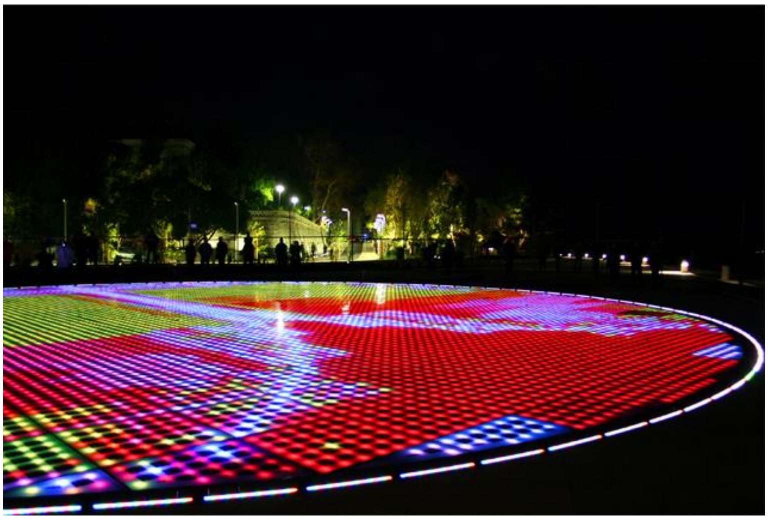
Details of the Mediaglass where we see that it is a common curtain wall with the addition of electrical connections to supply the LED matrices (www.leurocom.com/en)

4.2 Sun Salutation

Another interesting and green project comes from Croatia. At the coastal town of Zadar Nikola Basic created the ″Sun Salutation″. This project is based on a large circle of photovoltaic cells, interspersed with LED lights that come to life after sunset. The installation uses the rhythm of the waves to create the colourful series of light pulses. The cells absorb the solar energy during the day, converting it into electricity. When dusk comes, the lights switch on, displaying the colourful and bright patterns. Their intensity and shape depend on the amount of energy stored during the day. The installation mirrors the movement of the sun and the planets, which are represented by solar lights of proportional size and distance from "the sun". The electricity produced by the photovoltaic cells is also used to light the whole waterfront.



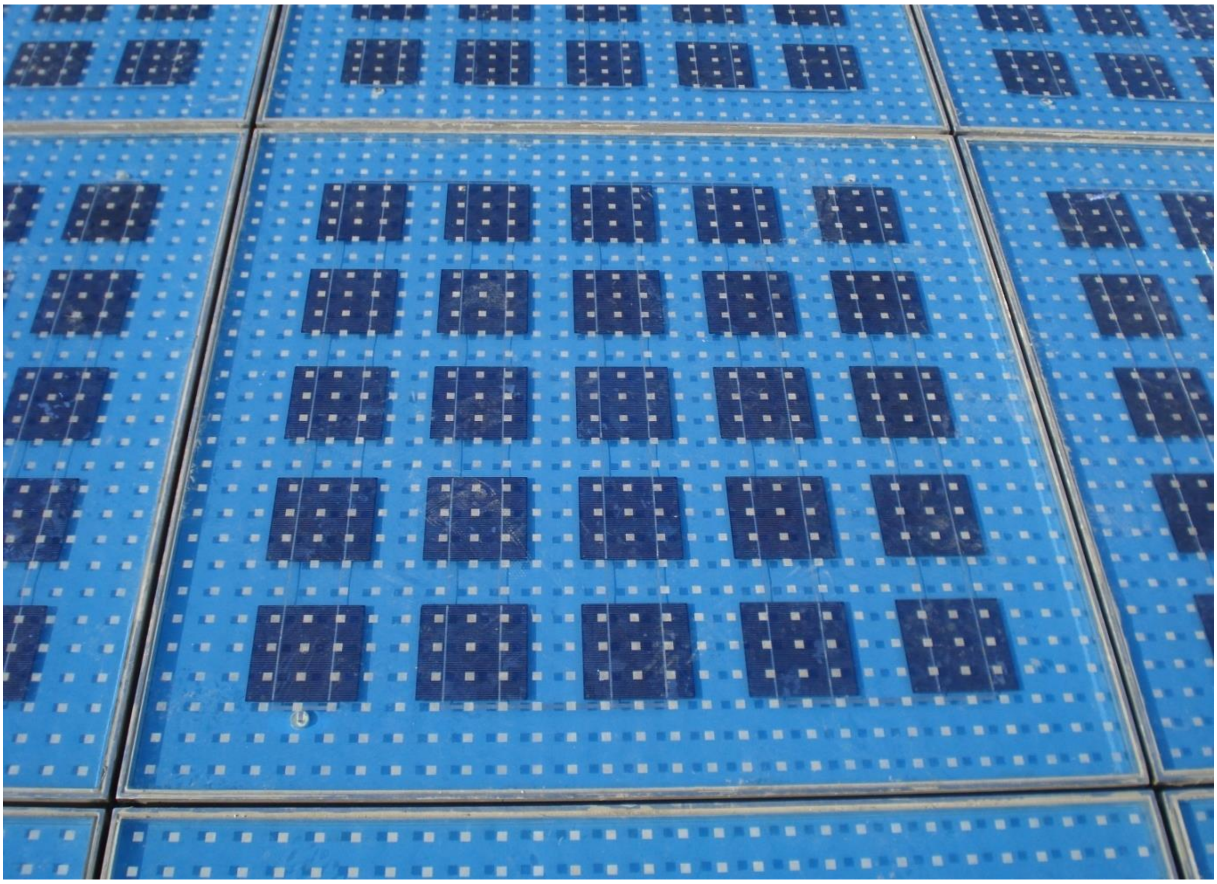
Night impression of the installation ''Greeting to the sun'' (http://www.tzzadar.hr/)



Here you can distinct the black rectangles created by the PV cells (http://www.tzzadar.hr/)

During construction the prefabricated panels with the PV cells and the LED lights. Also wires are needed (http://hr.wikipedia.org/wiki/Pozdrav_Suncu)

The entire system was expected to produce around 46.500 kWh. Energy has only symbolic meaning, because the energy invested in the production of modules and the entire installation cannot pay over the life of the PV cells.
(http://hr.wikipedia.org/wiki/Pozdrav_Suncu)

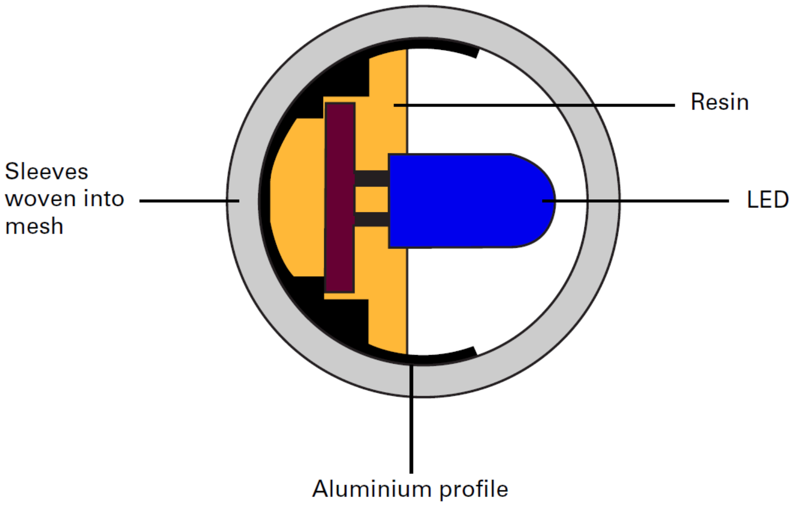


Closer view of the project. Because it is loaded by the people in some parts the glass started to get damaged (http://hr.wikipedia.org/wiki/Pozdrav_Suncu)

This type of technology in media architecture is not common and can be characterised as innovative. The project Green Pix in China materialised by Arup is famous for its zero energy media wall. On the other hand it is not a solution for offices which need transparency and view to outside. In addition such system cannot display good quality graphics because of the PV blue/black grid. Of course the energy specialists know that vertical photovoltaic modules do not provide the most efficient sun orientation but it is a good leap in LED technology for facades.

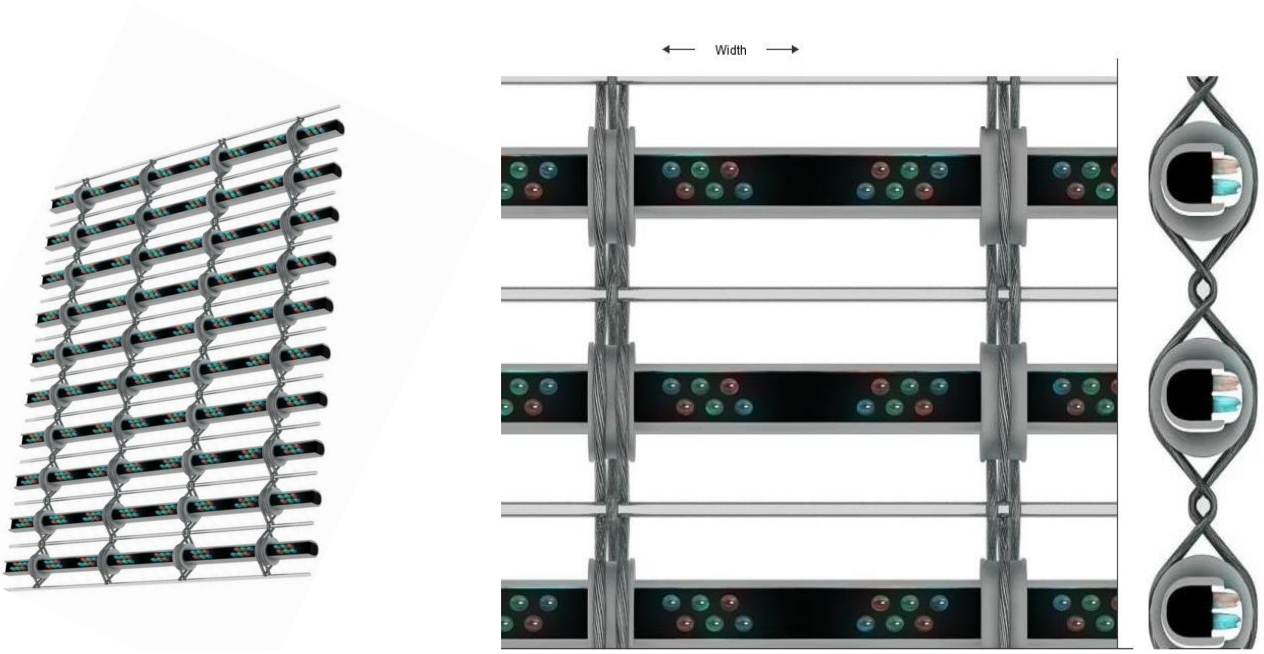
4.3 Port Authority Bus Terminal in New York

Furthermore, one of the state of the art reference projects is the previously mentioned, Port Authority Bus Terminal in New York. Here we will analyse it technically with some specifications of Mediamesh®. This media facade type is a patented system of LED tubing integrated into robust stainless steel metal fabric. It can offer both vertical and horizontal resolution. The vertical resolutions is adjustable in 10 mm increments from 40 mm spacing and upward while the horizontal resolution is standard at 50 mm pixel spacing or customized to fit the requirements. Tubes are consisted of LEDs, an aluminium profile to support LEDs, a resin to cover the aluminium and the sleeves which are woven into mesh.



Section of the tube with the integrated LED lights. The construction seems simple and functional (GKD metalfabrics manual)

By some images we can observe that fist there is a substructure system to support the metal grid of the media facade. This system is installed in a distance from the building's facade.



3d drawings provided by GKD which illustrate the Mediamesh technology, front view and section (GKD metalfabrics manual)

Live image of the media facade in the corner with direct sunlight

Different types of grid and LEDs are integrated according to client's needs. GKD offers a table explaining the specifications for the three different systems that uses

Specification	V4xH5.0	V5xH5.0	V6xH5.0
Vertical LED Pitch	40mm	50mm	60mm
Horizontal LED Pitch	50mm	50mm	50mm
NIT m²	7766-9527	6213-7621	5177-6351
Open Area	56.2%	58.1%	59.4%
Viewing Distance	35m/115ft	35m/115ft	42m/138ft
Weight (lbs per ft²)	1.9	1.77	1.7
Rods Between LED Tubes	1	2	3

*table data February 2013

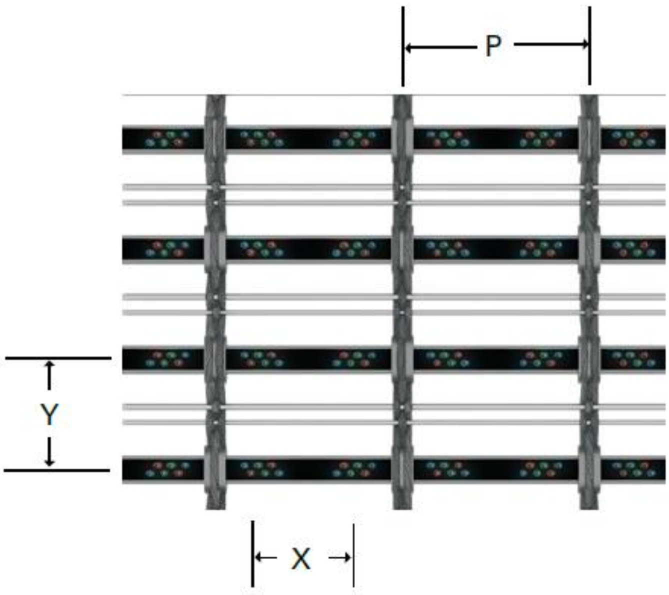


Diagram and drawing explaining the connection of cable pitch, horizontal and vertical pixel spacing. There are three types of Mediamesh (GKD metalfabrics manual)

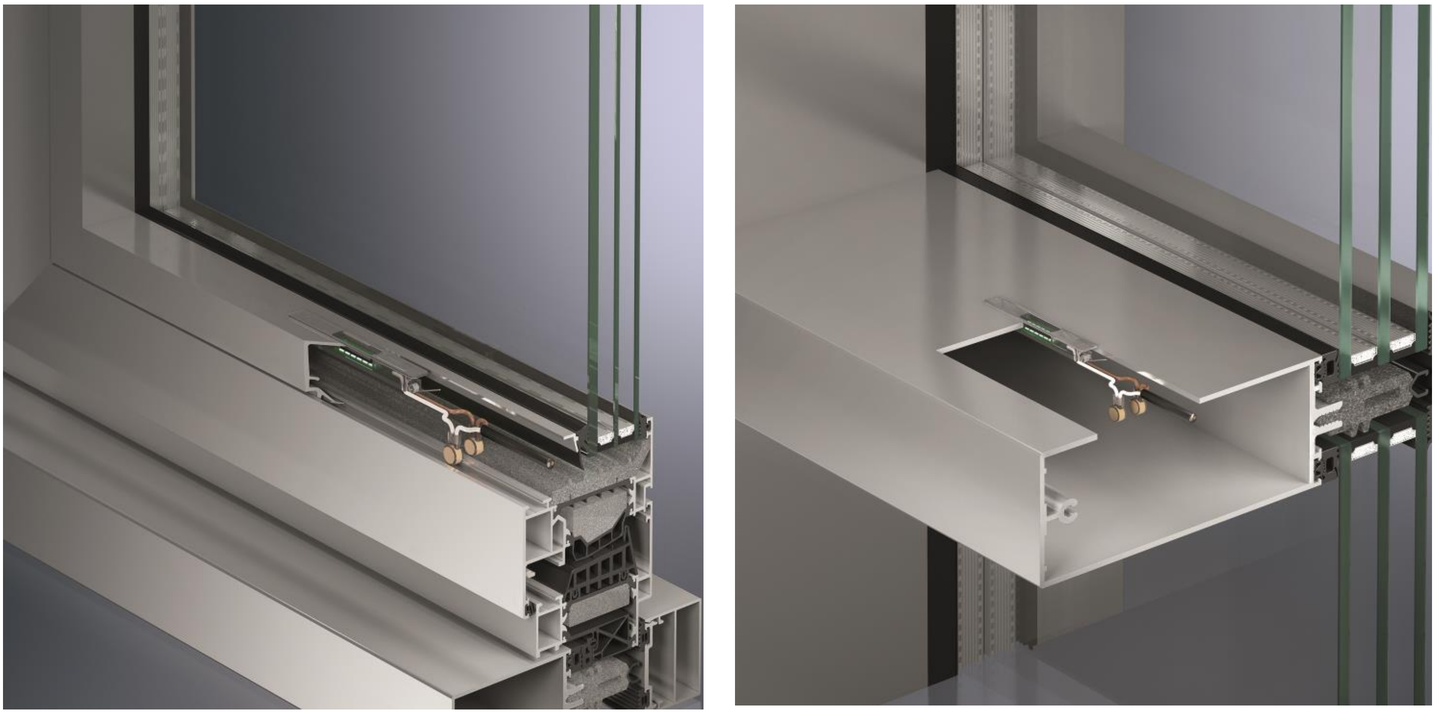
P= cable pitch
X= horizontal pixel spacing
Y= vertical pixel spacing

4.4 Schuco® Lightskin

In conjunction with the Zumtobel Group, a market leader in façade illumination, Schüco has succeeded in designing a highly efficient illumination solution, which is suitable exclusively for Schüco window profiles thanks to its unique size and photometry. The integrated illumination solution has concealed cabling and fully integrated light units.

Night impression of a building illuminated by the Lightskin (Shuco Lightskin manual)

The Schüco LED illumination solution is used in the glazing bead or the BS vent profile. The asymmetrical, ellipsoid radiation properties distribute the light evenly onto the window units. From the LED module to the cabling, converter and wire connections, Schüco delivers all the components from a single source.



Different aluminium profiles with LED integration(Shuco Lightskin manual)

Schüco LightSkin is exclusively for Schüco window and façade profiles. It can be installed in the cover cap or transom profiles. The asymmetric-ellipsoid beams distribute light equally over the façade profiles with no glare. (https://www.schueco.com/web/lightskin_en/lightskin) In terms of cost efficiency for both exterior and interior lighting the savings are huge when using this system. The company has two examples of comparing a HIT-Fluter with the Schüco LED for lighting a facade.

1) Example: Exterior lighting

* Lighting a reference building with 5.000 units. Energy consumption in kWh per year.
[1]**HIT flootlighting** 150/161 W including powering the operating device, lights six window/façade units.
[2]**Schüco LED,** typically 1.2/1.44 W, including 20% power loss, driver lights one window/façade unit.

2) Example: Interior lighting

[1]**Indoor lighting** 54 W, including operating device, lights six window / façade units.
[2]**Schüco LED** typically 2.4 / 2.88 W, including powering the operating device, lights one window / façade unit.

The purpose of including this reference project by Shüco in this research is that it worth's mentioning the effort that leading companies make in the facade industry for a better environment with less energy consumption. Although it is not appropriate to create a media facade, it gives a nice impression on the outer skin of the building itself. It makes the building alive at night.

4.5 louvreLED

Another reference project comes from a company in England. Starting from an initial enquiry by a leading architectural practice handling a major project in the Middle East, louvreLED is the result of collaboration between a group of businesses. Working across electronic, mechanical and software engineering disciplines, the partnership brought brise soleil solar shading and LED video screen technology together in one product to create media facades that can be designed to meet specific requirements.

Brise soleil solar shading provides an eco-friendly façade that saves energy enhances building design and in some projects made from sustainable materials. By integrating into this LED video technology the results turn the elegant elliptical blades into a media façade that presents a stylish architectural feature.

Aluminium louvers with integrated LED lights
(http://www.louvreled.com/)

Louvre systems can be fabricated from aluminium, timber, glass and many other materials and can be manufactured with different profiles, sizes and finishes.
Pixel pitches vary with the initial louvreLED systems based on a design that uses 125 mm horizontal pixel pitch LED strip located along the front edge of the louvre in a routed channel. The louvres also have a vertical spacing of 125 mm, meaning that lower resolution areas can be formed by not populating every louvre with LEDs. Lower resolution areas of the LED louvre media facade use 375 mm spacing on the vertical plane by inserting LEDs into every third louvre. This provides 21 pixels per m^2. Higher resolution areas use LEDs inserted into every louvre to provide 125 mm vertical and horizontal pitch giving 64 pixels per m^2. (http://www.louvreled.com/)

Closer view of the system with LEDs integrated on the front edge (http://www.louvreled.com/)

Specifications of the 125 mm pixel pitch system are:

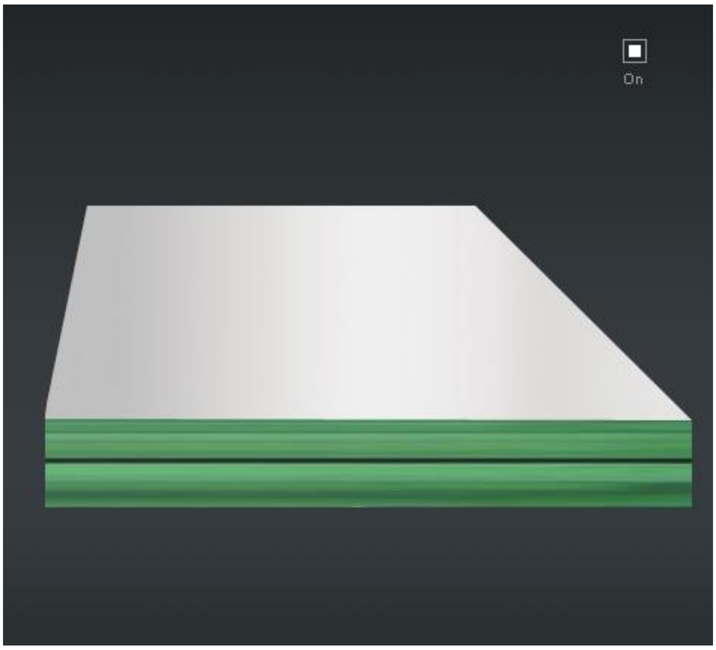
Pixel pitch	125 mm
Number of pixels	12
Pixel brightness	15 Cd
Pixel density*	64 pixels/ m^2
Surface brightness*	960 Nit
LED configuration	3R2G2B
Viewing angle (Hor/ Ver)	1400/500
Transparency*	87%
Dimensions (LxWxD) mm	1500 x 12 x 20
Orientation	Horizontal
Weight	1.0 kg
Processing	48 bits
Environmental rating	IP44
Operating temp range	-20 to +50 °C
Operating voltage	9Vdc
Power consumption (Max/Typ)	8.5w / 3.45w

Although it is a smart and environmental solution no known projects are being materialised with this system. Similar system has being developed by VML technologies where LED lights are integrated in aluminium and wooden louvers.

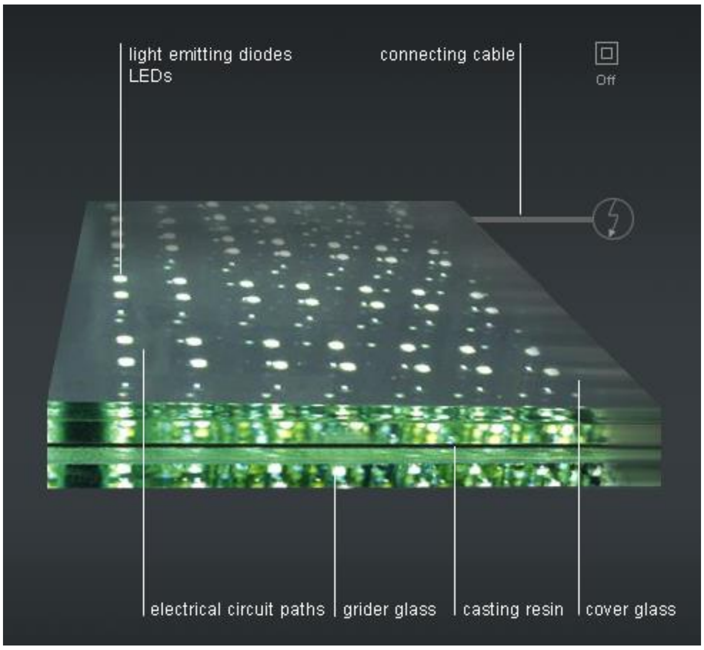
VML technologies with aluminium and timber louvers including LED lights on the front edge (Rollecate)

4.6 Powerglass

Last reference project with interesting technology comes from a German company called Glas-Platz. This company invented 15 years ago, powerglass, a technology which integrates LED chips into laminated glass on completely transparent circuit path structures. Therefore it is possible to provide electrical power supply without visible wires. Power supply and signal transmission happens via the transparent and conductive lamination of the powerglass® panel.



Powerglass without electricity (http://www.glas-platz.de/)



Powerglass after applying electricity (http://www.glas-platz.de/)

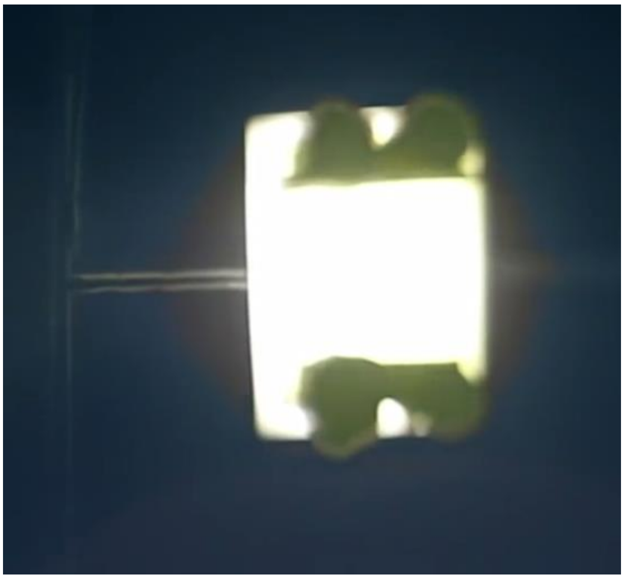
technical data May 2007

LED Colours	white*/red/blue/green
Glass Formats	max. outer dimension of conducting glass: 1200 x 2800 mm
Thickness Carrierglass	4* or 6 mm, also available as toughened glass
Composite Material	resin laminate, 2 mm
Resin	clear*/black or white opaque
Thickness Resin	2 mm
Thickness Coverglass	4, 6, 8 or 10 mm, also available as safety glass or laminated glass
Glass-combinations	mirror e.g.
Edges Works	edge grounded and polished*, tolerance range depending on technical parameters
Contacting	contacting strips along the long glass edges inside sealing, connection cable strain-relieved affixed
Power Supply	external power supply unit or in-wall power supply unit output voltage depending on design 12/24/48 VDC
Control	display and graphics available upon request
Outside Utilization	possible
Moisture-Proof Utilization	possible

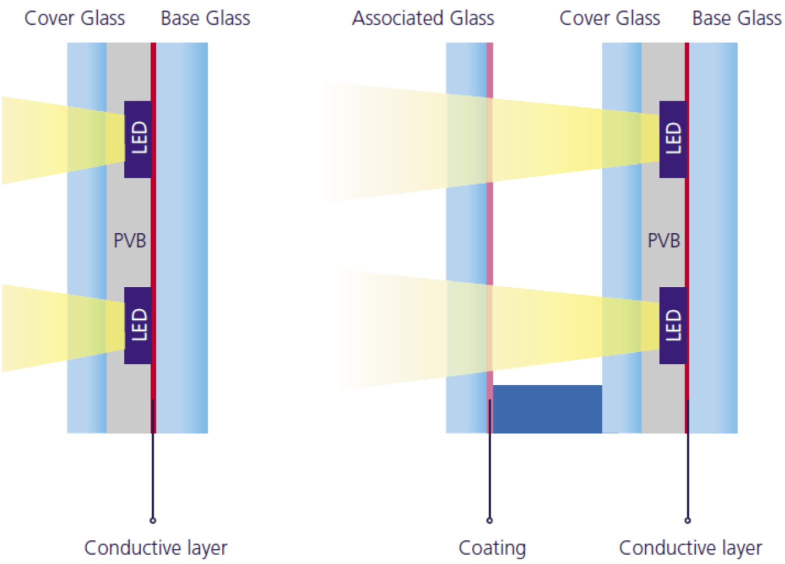
Technical specifications of powerglass (http://www.glas-platz.de/)

* standard

This technology has being adopted afterwards by other glass manufacturing companies like AGC and Schott to produce similar LED glass panels and made the industrialization possible. On the two longest sides of the double laminated glass there are two bus bars at 10 mm from edges, metal grey 2 x 6 mm for monocolour or 2 x 18 mm for RGB. Furthermore, there are two connecting cables with each 1 plug out of the middle of each vertical side of the glass.



Closer view of the mounted LED chip and the transparent wires (http://www.glas-platz.de/)



Facade glass with LEDs from AGC Glasssiled (http://www.yourglass.com/)

The limitation of this technology for not being able to project good graphic media facade is based in many reasons.

First reason is that this type of LED chips cannot be addressable and thus only standard images and signs can be projected. There is no way to control each LED individually, so only basic animated images can be displayed.

Another reason is the limitation in pixel pitch, so consequently on image resolution. This type of mounting the LEDs in invisible circuits cannot allow less than 50 mm distance form LED to LED for an RGB and monocolour LEDs. Thus, pixel pitch lower than 50mm cannot be achieved.

Except for the distance limitation from LED to LED there is also a limitation from LEDs to the glass edges since space is required for the side wiring and power supply. Again a space of 50 mm is necessary. Consequently if you want to join two pieces of glass in a facade you will have a gap of 100 mm from all edges of the glass panel.

Finally, this type of LEDs used for powerglass do not have a blocking back surface in order not allow light in both directions. Thus it cannot be used in working spaces like offices as people will get distracted from the light emission to the interior.

On the other hand the impressive thing about this type of media facade is the transparency which is offered through the almost invisible wires and the only visible LED chips. It is very favourable for interior light decorations and partition walls. However it is a system which is tested and develops gradually throughout the latest years, especially by AGC which achieved to integrate RGB LEDs for the airport in Brussels National Airport.

Brussels Airport facade at the evening with the project by AGC (http://www.glassonweb.com /)

Brussels Airport facade in the afternoon with the project by AGC (http://www.glassonweb.com /)

5. POLYCARBONATE STRUCTURAL SHEETS

5.1 PCSS description

Multiwall or cellular polycarbonate has been a major building material for architects in Europe. Given that PCSSs offer a variety of design solutions for canopies, skylights, translucent walls and signage, barrel vaults, it is essential to be familiar with its characteristics, benefits and appropriate use. Equally important is a proper framing and fastening design that meets both the technical requirements of PCSS and the aesthetic goals. Most of the manufacturers have the knowledge of providing frames for their products, so their role in solving technical problems is very important.

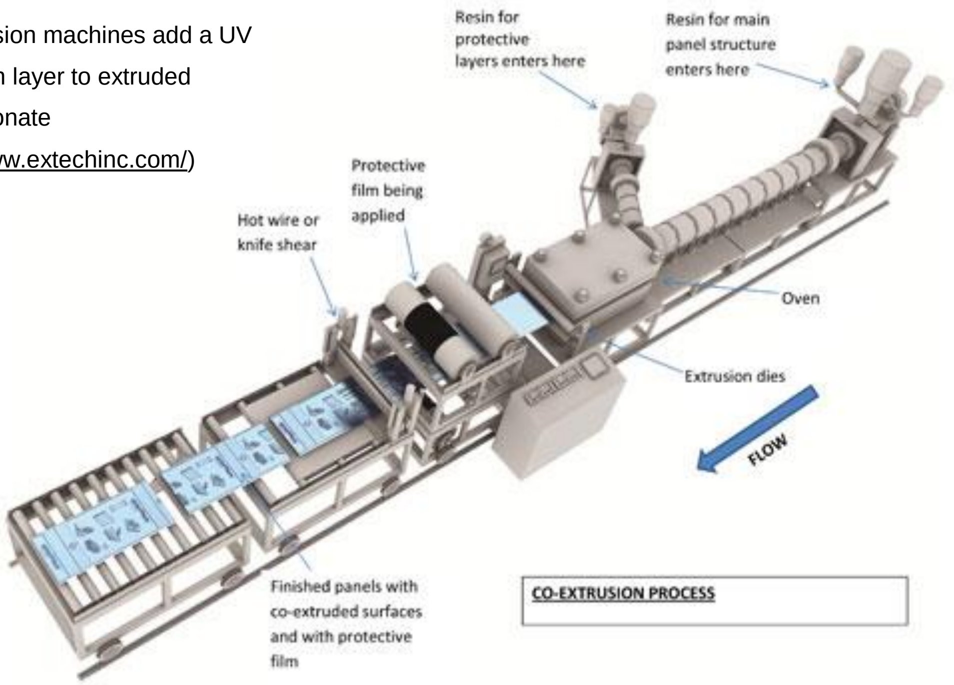
Polycarbonates are polymers containing carbonate groups and they are widely used plastic made from a particular group of thermoplastic polymers. Monolithic polycarbonate has no internal cavities. On the other hand, PCSSs are available with multiple honeycomb-like chambers known as “flutes”. Such polycarbonates are versatile due to their high impact resistance, optical properties, temperature and fire resistance.

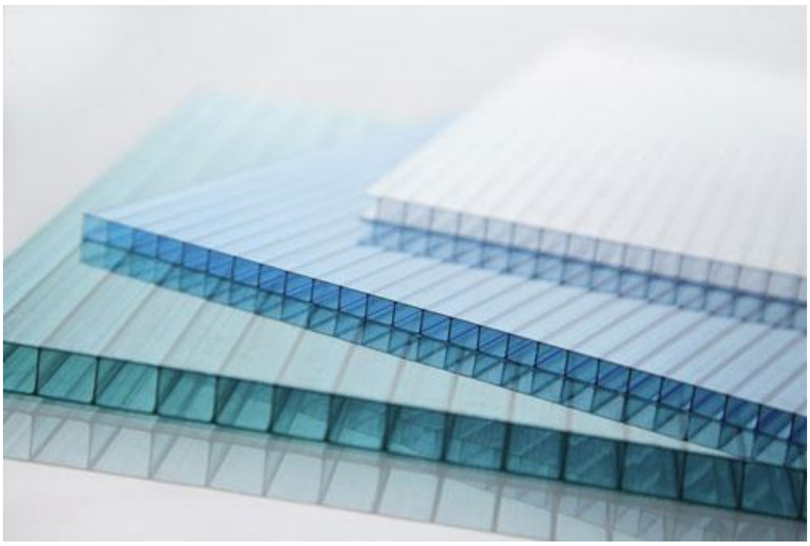
Made from polycarbonate resin and is inherently stronger than both glass and acrylic. Polycarbonate is 200 times stronger than glass, and 30 times stronger than acrylic (http://www.lifeofanarchitect.com/some-of-my-favorite-things/)

PCSSs are manufactured by using extrusion technology. Plastic resin in the form of clear or tinted pellets is melted and pumped through a die. After travelling through the die, the sheets enter a heated oven to relieve tension. They then being transported over a series of rollers to be cooled and cut to the final dimensions. This technology allows the continuous production of any length of product in a wide variety of profiles that is limited only by its ability to be

transported. For sheets coming from overseas, the maximum length is 12 m because it fits to a 12 m container. For local production in Europe lengths can reach 30 m. The key to manufacturing polycarbonate profiles are sophisticated dies that set the width, height, thickness and structure according to the particular specifications of design professionals. Co-extrusion technology involves adding a thin layer of a different resin mixture to one or both sides of extruded polycarbonate to create different end products. The added material can serve as an ultraviolet light protection layer since UV rays can degrade unprotected polycarbonate. The co-extruded resin can also serve as a means to colour a sheet or to add improved solar heat-rejecting performance.
(http://continuingeducation.construction.com/article_print.php?L=307&C=913)

Co-extrusion machines add a UV protection layer to extruded polycarbonate (http://www.extechinc.com/)



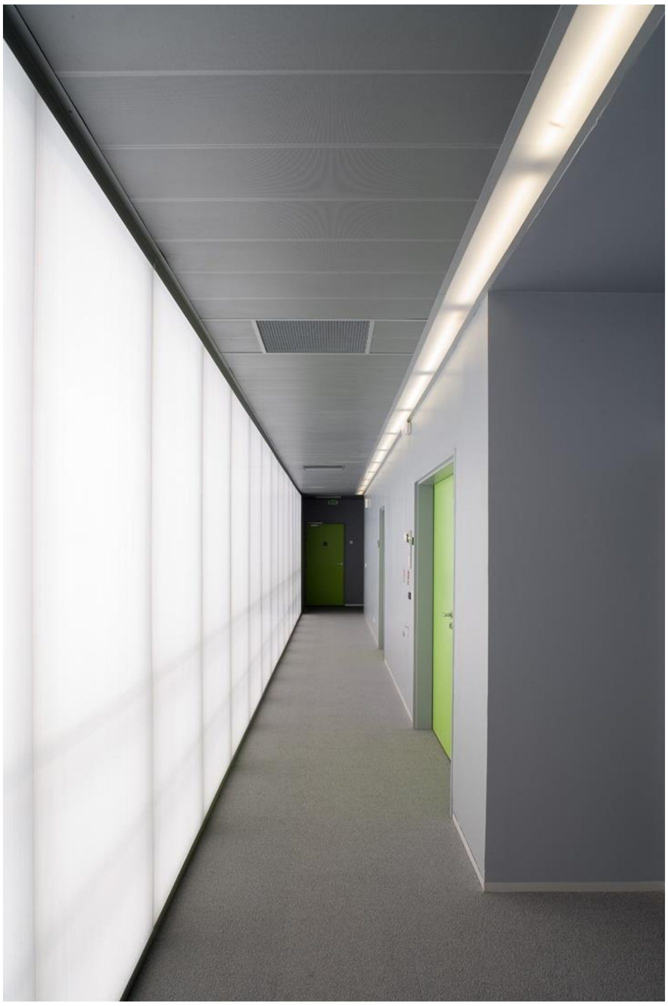


Polycarbonate sheets with two walls (http://machinemakers.typepad.com/machine-makers/2013/06/polycarbonate-sheets.html)

5.2 Properties and performance

Polycarbonates have versatile properties and thus the second largest use of them is in construction materials while the first is for electronics components. Consequently, they are placed between commodity plastics and engineering plastics. A testament of their strength is the fact that airplane windows are made of them. PCSS products offer high impact resistance and protection against storm damage and vandalism. In some applications they have been demonstrated to be impressively unbreakable. Polycarbonate is 30 times more impact resistant than a same thickness of unmodified acrylic and 250 times more than annealed glass.
A PCSS surface is softer than glass and its structure is more crushable. Some manufacturers incorporate special framing designs to restrict the pressure of the gasketing against the polycarbonate known as “controlled gasket pressure.”
In terms of clarity and light transmission, clear PCSS allows more light to enter than fibreglass reinforced panels and less than glass. Soft light and day lighting can be achieved through opal or frosted polycarbonates. Studies have found that access to daylight promotes well being and quality of life. Daylight is also linked to improved learning, increased retail sales and office worker productivity.

Police shield made of polycarbonate (http://www.iplasticsupply.com/)



Light transmission to the interior at HQ13 Parisian subway line (http://www.archdaily.com/9218/hq-13-parisian-subway-line-atelier-phileas/)

Furthermore, polycarbonate sheets offer significant benefits in thermal insulation due to the chambers created by the inner walls between inner and outer panel faces. Due to the variety of available profiles and resins the sheet can deliver high levels of light transmission and at the same time maintain high R-values for thermal resistance.
25 mm of cellular polycarbonate, compared with 25 mm of insulated glass, has an R value of 0,52 compared with 0,37 for the glass and their U values are 1,92 and 2,70 respectively. Increased thermal performance can be achieved by combining polycarbonates with translucent aerogel. This substance is derived from a gel in which the liquid component of the gel has been replaced with a gas. However, we should mention that aerogel filling in cellular polycarbonate is a relatively new item and long term field performance has not bee established yet.

PRODUCT	U-value	R-value	LT%
10mm	3.03	0.33	81
16mm	2.27	0.44	74
16mm	2.08	0.48	67
25mm	1.92	0.52	72
25mm	1.47	0.68	58
35mm	1.19	0.84	51
40mm	1.07	0.93	51
45mm	1.02	0.98	50
50mm	0.96	1.04	50

Table content giving the values of different thickness polycarbonates for heat loss, thermal resistance and light transmission

Special consideration should be taken during assembly because polycarbonate expands and contracts thermally more than most materials. Compared to glass and steel seven times more and three times more than aluminium. It is very sensitive with the temperature changes that even from day to night expands and contracts. Thermally induced expansion and contraction of PCSS can be to 3,175 mm per m for 100 degree temperature change. Thus manufacturers design retention clips and framing that allows the movement of the sheets. Engineered framing and clip designs can also reduce sounds caused by the expansion or contraction of the polycarbonate panels.
In addition, polycarbonate sheets are very lightweight. A 25 mm thickness piece of polycarbonate weighs approximately 3 kg/m^2 while same thickness insulated glass weighs 30 kg/ m^2 . This difference is very important to construction that buildings incorporating PCSS skylights or canopies can be built with lighter and cheaper framing systems. Light weight also offers cost savings in transportation, handling and installation.
Another physical property of PCSS is the elasticity that they have. They can be curved by cold bending on site across their length over supports which are spaced to determine the curvature. When the sheet is removed from its form it will return to its flat profile. Cold bent

polycarbonate is a solution for canopies and barrel vault skylights. In my project we will use them also for wall elements for the media facade. It should be noted that curving also adds significant spanning strength to the panels.

2610-4	minimum radius 3.00m
2625-5	minimum radius 8.00m
2253-2	minimum radius 2.00m
2250-10-4	minimum radius 3.00m

Multifunction panels by RODECA can be cold curved over an appropriate substructure. The minimum radius depends on the panel thickness (http://www.rodeca.de/?L=1)

In terms of acoustics, these sheets reflect sound more than other materials that have softer and more textured surfaces. Manufacturer's product data sheets note the decibel level (dB) or level of transmission of sound for different thicknesses.

Multiwall polycarbonate sheet	
4mm-8mm	18dB
10mm-16mm	20dB-21dB
20mm-35mm	22dB
40mm	23dB

Table content giving the values of different thickness polycarbonates for sound transmission through them. A conversational speech for instance is 70 dB and a busy road 80dB

Moreover, we should mention the properties of polycarbonates in fire condition. Polycarbonate is specially developed for excellent flame retardant properties and is classified as Self-Extinguishing. PCSS offer better results than FRP or acrylic in smoke density, flame spread and self-combustion. Self-ignition temperature of polycarbonates is above 450° C. According to the International Broadcasting Convention plastic materials in constructions must have a self ignition temperature of 343° C or higher. Softening temperature point is at 160° C and decomposition at 380° C.
(http://continuingeducation.construction.com/article_print.php?L=307&C=913)
Last but not least, polycarbonates have the advantage of taking various colours and coatings during manufacturing even in the same sheet. Rodeca has developed this system by creating the products Bicolor, Decocolor, Duocolor and Multicolor.

Bicolor

This product version is available for the 40 mm panel with four layers. The inner layer of a panel is differently coloured than the three outer layers. Consequently, special colouring colour appears three-dimensional and lighting effects vary depending on day light and perspective.

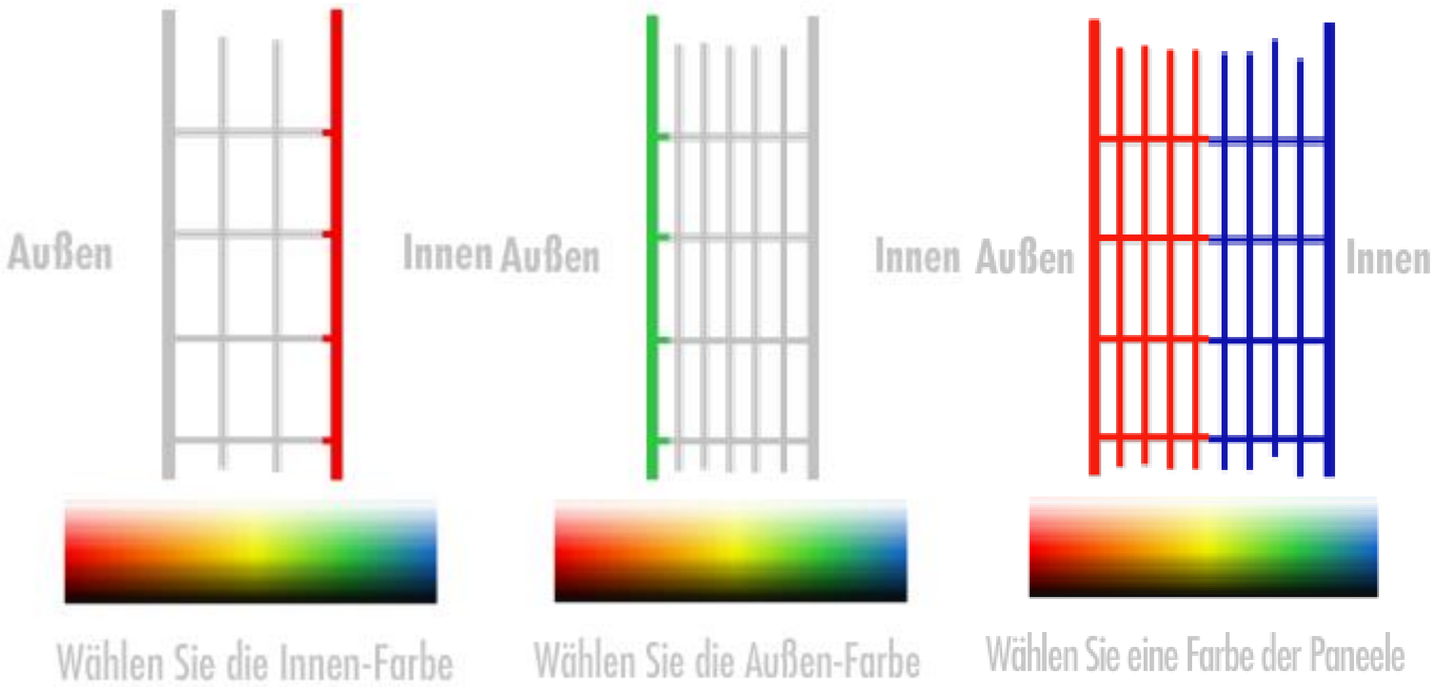
Their colour range includes eight colours following the model of a rainbow in combination with three outer layers in colour crystal.

Decocolor

This product means that one outer layer is differently coloured than inside layers of the polycarbonate sheet. Decocolor version is very popular for façade applications when customers wish a building with opaque look from outside view but inside a building glare free light. Additional integration of LED lights makes a façade look more special and gives an aesthetic view to the building.

Duocolor

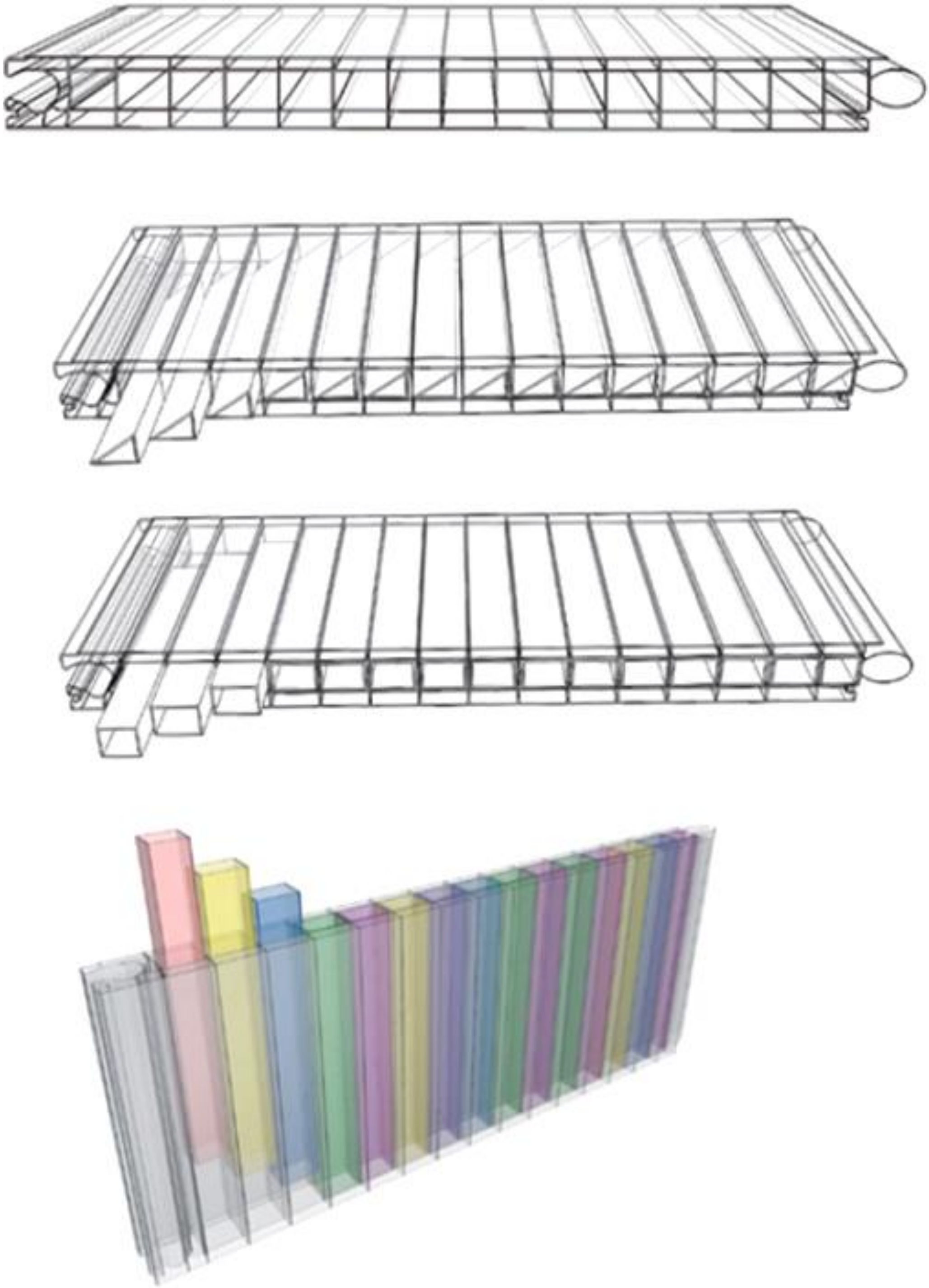
This version is another possibility to produce a two coloured panel or multi wall sheet. It is available in thicknesses from 25 mm to 50 mm. The colour separation takes place during manufacturing processing exactly in the middle of the panel.



Diagrams existing in the site of Rodeca expressing the products of Bicolor, Decolor and Duocolor from left to right (http://www.rodeca.de/?L=1)

Multicolor

The Multicolor panel of 40 mm thickness provides numerous opportunities for wall and facade designing. Polycarbonate tubes in varying shapes and various colours can be shifted into the panels' middle chamber. This allows the creation of different patterns and colour shades on the facade.

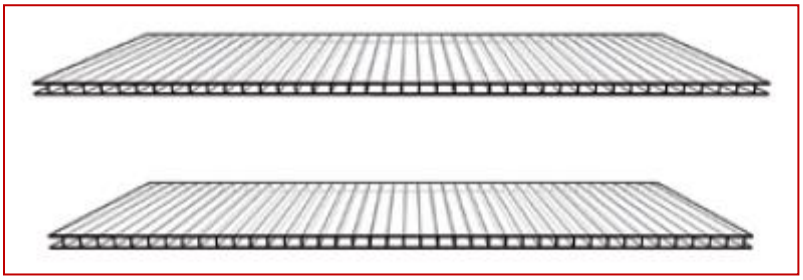


The concept of multicolour facade walls by Rodeca. Coloured tubes can be in rectangular, triangular or concaved profiles (http://www.rodeca.de/?L=1)

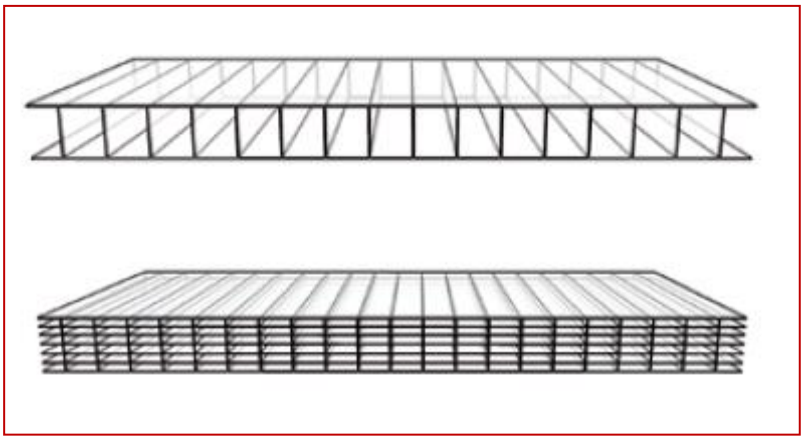
5.3 Polycarbonate sheet profiles and framing

Most polycarbonate sheets in the construction industry are flat except the corrugated ones for roofing applications. The length and width can be adjusted for maximum width to 2 m and length to 30 meters.

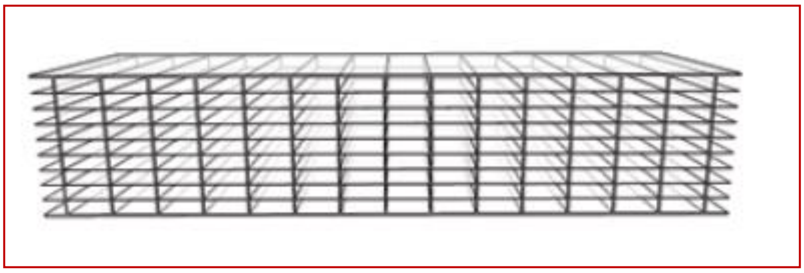
They are fabricated in many configurations such as three-wall, five-wall, x-structure etc. These multiwall sheets can be used as a standard glazing material. Simple applications include greenhouses and signage with usually 6 mm and 8 mm thickness or office dividers and dropped ceilings with usually 16 mm. Curtain walls and skylights with heavy wind loads require panels bigger than 16mm which can reach 60 mm thickness. These thicker panels also offer higher insulating value.



4 mm polycarbonate sheet by Rodeca with U value 4,00 W/m^{2}K, weight 1kg/m^2 and widths up to 2100 mm (http://www.rodeca.de/?L=1)



20 mm polycarbonate sheet by Rodeca with two or seven walls. For the multiwall the U value 2,7 W/m^{2}K, weight 2,9 kg/m^2 and widths up to 2100 mm (http://www.rodeca.de/?L=1)

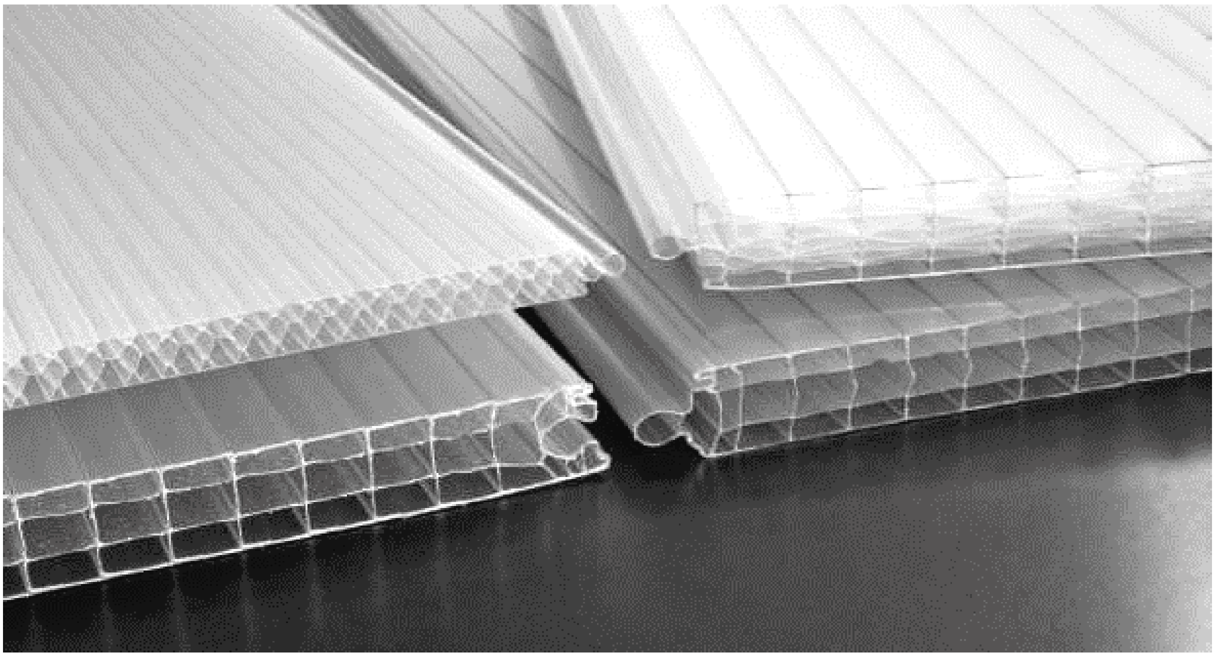


50 mm polycarbonate sheet by Rodeca with ten walls. U value 0,9 W/m^{2}K, weight 4,6 kg/m^2 and widths up to 1200 mm (http://www.rodeca.de/?L=1)

RODECA® is the market-leader for translucent building elements in Europe and specialises in polycarbonate sheet manufacturing. It was founded in 1971 and was the innovator and first producer of translucent building elements with integrated coupling mechanisms for glazing applications on industrial and athletic facilities.
Their panels with formed coupling system are ideal for a glazing alternative in almost all applications. They are made of high strength co-extruded polycarbonate with UV long term protection and 10 years guarantee from yellowing. The unique systems allow for seamless façades and a daylight expression that is unparalleled in the building product industry.

Variety of wall types and structures in the panel (http://www.sepitalia.com/)

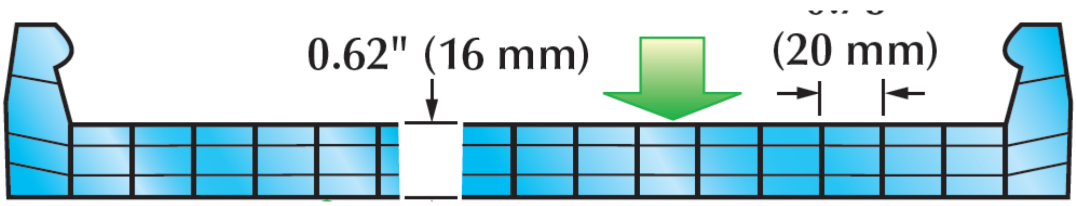
A tongue and groove profile is the most commonly used for vertical walls. Joints which exist inside the panel create a visually uninterrupted wall. Tongue and groove panels are typically available in 40 mm or 50 mm thicknesses. Some panel types allow the insertion of steel bars in the chambers to increase the spanning capability.



Tongue and groove PCSS clicking to each other in order to form the facade (http://www.sepitalia.com/)

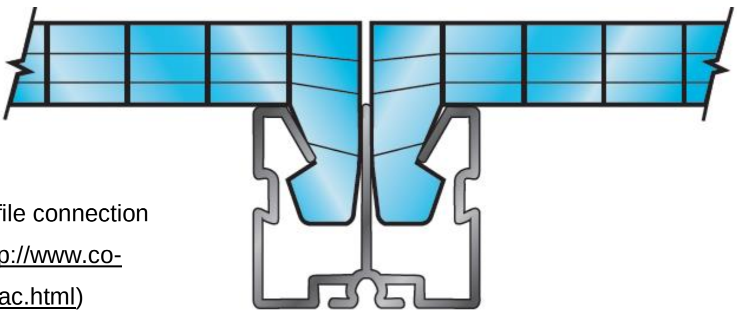
Panel installation by Rodeca (http://www.rodeca.de/?L=1)

Another type of panel profile is that of having the 'griplock connection system'. This profile is used in thinner polycarbonate walls and the advantage is that it can be used both vertical and horizontal by keeping the two sheets with aluminium or polycarbonate connector.

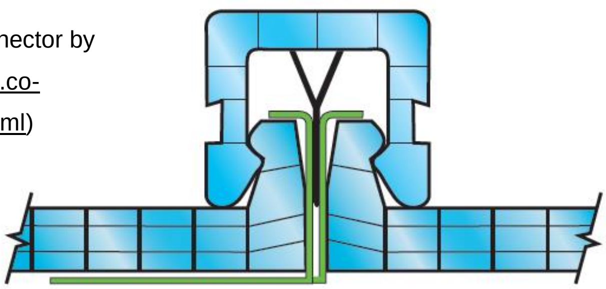


Polycarbonate sheet with the two edges extruded for locking by CO-EX (http://www.co-excorp.com/mac.html)

Aluminum profile connection by CO-EX (http://www.co-excorp.com/mac.html)



Polycarbonate connector by CO-EX (http://www.co-excorp.com/mac.html)

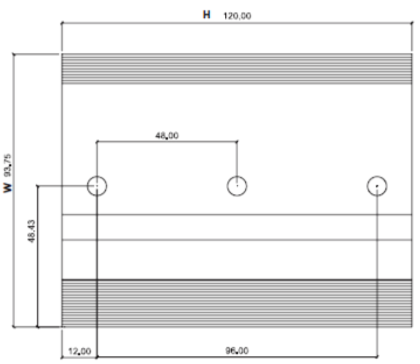
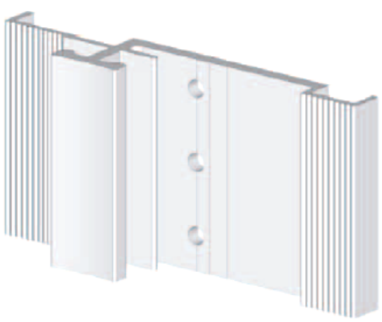
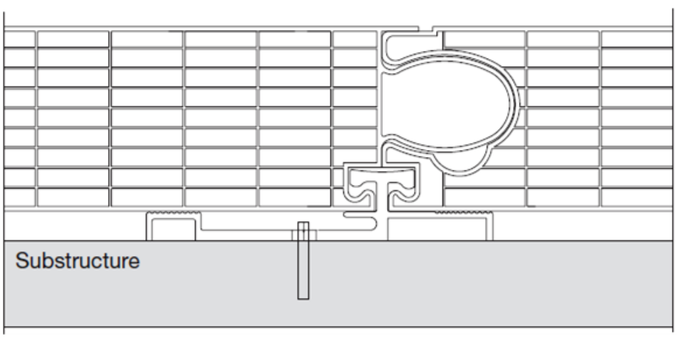


All manufactures of the PCSS offer their aluminium profiles for assembling the facade and thus there is a big variety of them pleasing different requirements.

Article no.		Soffit assembly			Curtain wall assembly			assembly as an inclined surface (min. 15 degrees)		
		Top Profile	Side Profile	Base Profile	Top Profile	Side Profile	Base Profile	Top Profile	Side Profile	Base Profile
Frame profile Series 4060 – non-thermally broken										
406051										X
Frame profile Series 4460 – thermally broken*										
446040		X	X		X	X		X	X	
446090		X	X		X	X		X	X	
446062		X	X	X	X	X	X			
446041				X			X			
		For light bands with large span width, combinable with windowsills from 50 to 300 mm. when windowsills will be used >110mm, elevation provided from client is necessary.								
4460003					X	X	X			
		For light bands with low span width, combinable with windowsills from 75 to 100 mm.								
446072			X			X			X	

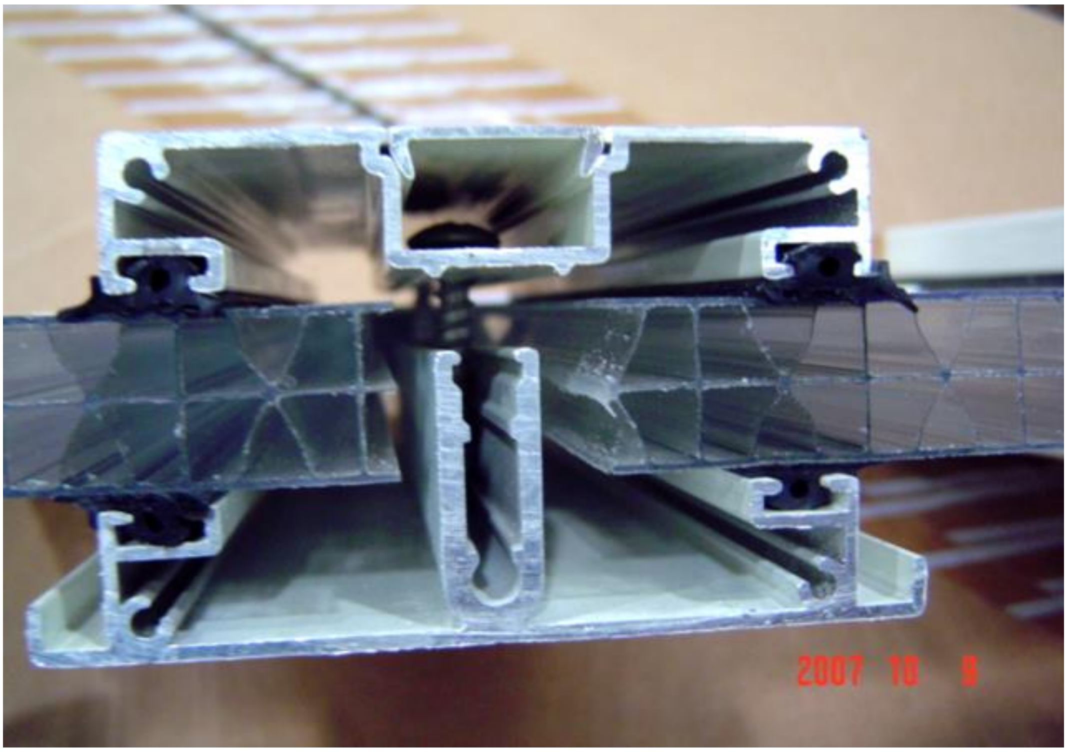
Table with a variety of aluminium profiles thermally broken or not offered by Rodeca (http://www.rodeca.de/?L=1)

If necessary due to the glazing height or to the high load required several intermediary supports must be installed and the fixing must be made with the aluminium clips. These clips allow a solid anchoring but do not prevent the thermal expansion of the polycarbonate panel.

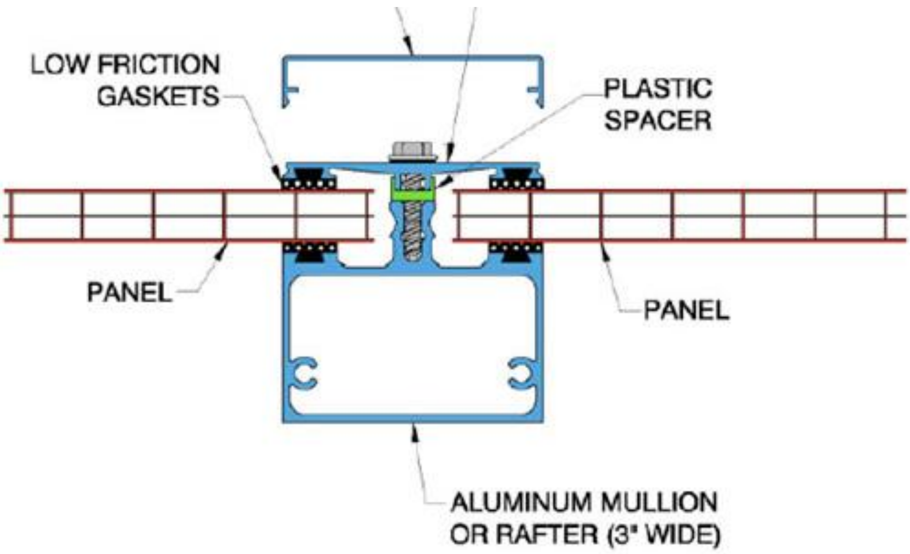




Intermediate clip by Rodeca to keep the panels straight and connected to each other (http://www.rodeca.de/?L=1)

Except from the simple aluminium frame polycarbonate sheets are possible for curtain wall systems in buildings. There are still though issues to improve with thermoplastics before they will totally replace glass in curtain walls because long term creep deformation is a disadvantage. The elastic modulus of extruded polycarbonate can be reduced to 40% after 1.000 hours of constant loading. Another issue is the thermal movement of plastics which should be taken into account. The coefficient of thermal expansion of polycarbonate is 7 times greater than that of glass. Therefore, special consideration needs to be taken during the design and the space allowance between frames.



Polycarbonate sheet with combo walls integrated in an aluminium curtain wall profile (http://www.wf.org.tw/ch60/CH2/2945/N/301594.html#)



Curtain wall with polycarbonate sheet by Extech (http://www.extechinc.com/)

5.4 Advantages and disadvantages of PCSS compared to glass

In this part we will compare the two basic structural materials for facades: polycarbonate walls and glass.

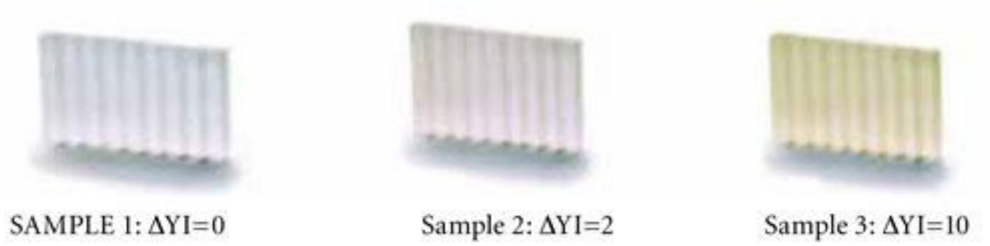
For facades the glass must be laminated for safety reasons. Expensive laminated annealed glass cracks easily, so the alternative is to choose laminated tempered glass which is more costly. If we also want an insulated unit two pieces are needed to create an insulated unit which doubles the cost. Glass has the highest cost per m^2 of all glazing materials. In addition this type of glass is heavier, something which requires massive under structure.. The benefits of choosing a polycarbonate system over a glass system include firstly their light weight and higher strength as we mentioned in the properties of PCSS. They can withstand higher forces and have greater impact resistance compared to glass.
(http://facadesconfidential.blogspot.nl/)

		Thermoplastic				Glass
		Polycarbonate PC	Polyesters PET	Polypropylene PP	Polymethylmethacrylate PMMA	
Mechanical Properties						
Density (ρ)	Mg/m^3	1.14-1.21	1-1.40	0.89-0.92	1.16-1.22	2.44-2.5
E-modulus (E)	GPa	2.21-2.44	0.3-0.41	0.9-1.55	2.24-3.8	68-72
Poison's Ratio (ν)	dimensionless	0.38-0.42	0.34	0.43	0.37-0.43	0.2
Yield Strength (σ_y)	MPa	58.6 - 70.0	1.30 - 72.2	20.7-37.2	45.0 - 86.0	31-35
Ultimate Strength (σ_{ult})	MPa	65.0 - 72.4	9.70 - 53.0	17.2 - 31.0	30.3 - 100	31-35
Elongation at yield	%	6.00 - 50.0	20.0 - 50.0	5.00 - 37.0	-	0
Elongation at break	%	10.0 - 125	50.0 - 900	10.0 - 600	3.50 - 40.0	0

Table comparing thermoplastics with glass (http://facadesconfidential.blogspot.nl/)

Furthermore, glass transmits heat and cold quickly and thus it needs to be made into units with double or triple panes to get any insulation value. Visually glass offers high clarity but that can also lead to hot spots when sunlight is not diffused. This is exactly what polycarbonate takes over to glass with the high quality diffused daylight and the better insulation in one panel unit. No exterior or interior shading devices are needed when choosing the proper polycarbonate sheet. On the other hand, polycarbonate is not as clear as the glass and in office installations you need to leave open parts on the facade to be filled with glass.

A disadvantage of polycarbonate compared to glass is that degradation occurs with time. Sheet degradation is measured using a yellowness index called ΔYI and calculated from spectrophotometric data that describes the change in colour of a test sample from clear or white toward yellow. In addition to change in colour correlates with a proportionate amount of loss of the sheet's ability to transmit light. A ∆YI over 5 will also have a reduced impact resistance. Different warranties for polycarbonate products reflect the effectiveness of UV protection. When evaluating polycarbonate sheet materials for use as glazing, design professionals should compare warranties to see which offers the best protection against yellowing, impact resistance and light transmission degradation. Most current architectural panels qualify for a ∆YI of 2 or less even after the equivalent of 10 years in a south-facing application. (http://continuingeducation.construction.com/article_print.php?L=307&C=913)



Example of degradation in three samples by EXTECH (http://www.extechinc.com/)

A 10 year warranty is the industry standard for polycarbonate sheet products while the working life is considerably longer. Actual performance depends on many aspects like individual applications and local environmental factors. With the addition of special coating UV layers 20 years of lifespan is also possible. Most thermoplastic materials suffer from slow deterioration as a result of UV exposure. Build ups of moss and dirt will also lead to lower levels of light transmission and thus a lowering of performance.

During installation workers should always be careful to fix the panels with the UV protected side on the exterior elevation. This is marked on the protective film and may also be discreetly printed along the side of the sheet.

Another advantage of polycarbonate constructions is that they have faster installation than glass walls due to the click system with the tongue and the groove. No screws are needed to fix the panels and in case of replacement it is easier. Furthermore, polycarbonate curves easily in site with cold bending to fit the design, something that glass is not capable of without special machines and not so easy.

A very important advantage of polycarbonate is that it is100% recyclable material, something which allows the disassembly of the facade, reproduce the material and use it again. Many companies use up to 20% post-consumer recycled materials in manufacturing polycarbonate, depending on the performance and clarity needs of the project.

Post production scrap material can be reprocessed and used in the production of re-granulated sheet material. Polycarbonate disposed of in approved landfill sites will slowly degrade without producing by-products that contribute to soil or water contamination and is inert in terms of its environmental impact. (http://www.rockwellsheet.com)

Finally the characteristic of polycarbonate sheets being manufactured in long lengths reduces the needs for joints and intermediate framing which cause many times leakage and possible misconstructions.

6. REFERENCE PROJECTS (PCSS)

6.1 ´´Laban Dance Center´´(Herzog & de Meuro)

In 1997 famous Laban dancing school received an extra building, Laban Dance Centre in London. It is located in south-east part of the city, on the edge of Deptford Creek, surrounded by decaying blocks of council flats, scrap yards and industrial warehouses. It is one of Europe's leading and largest institutions for contemporary dance artist training.

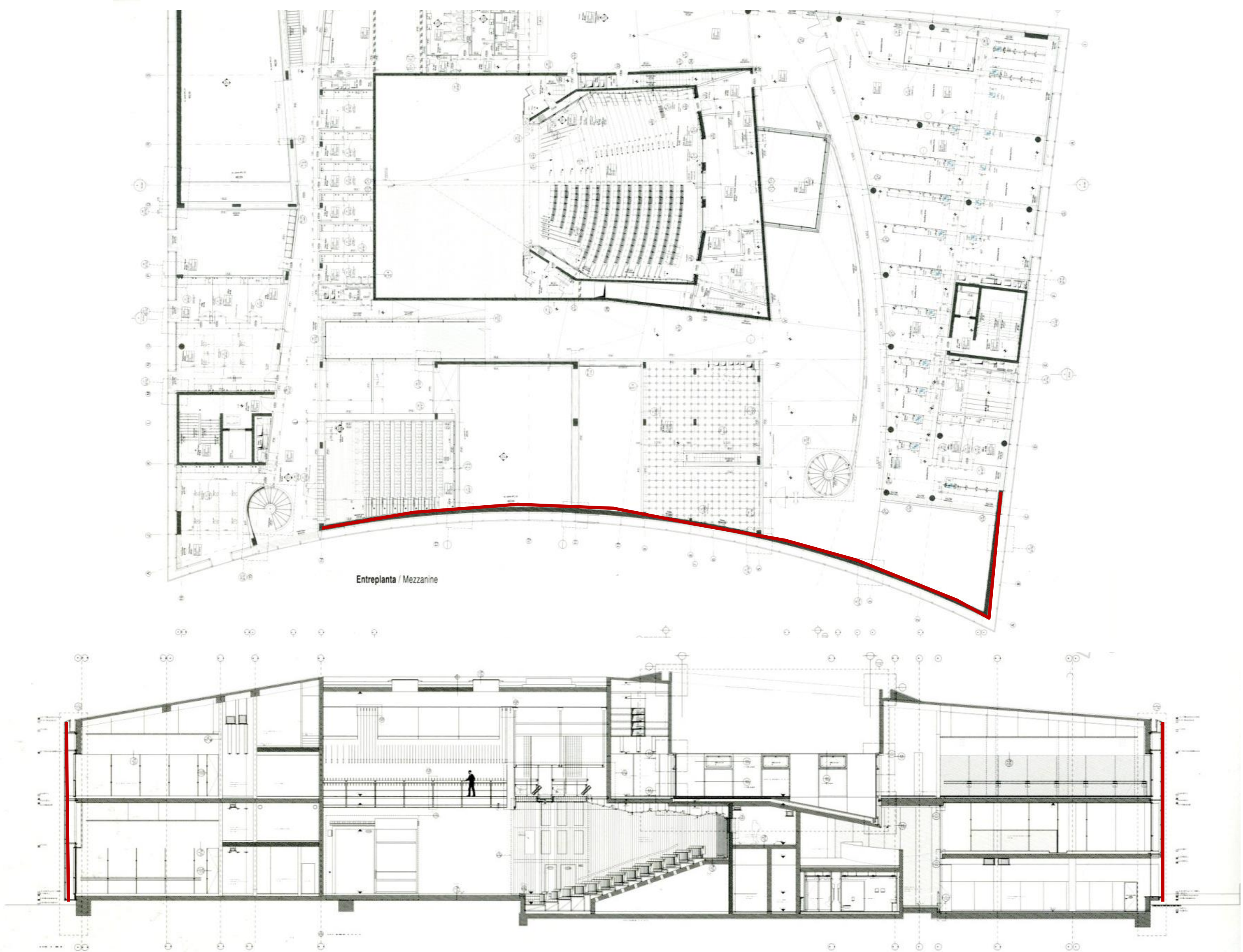
West facade of the centre with coloured PCSS (http://designenaction.gatech.edu/?p=78771)

West facade at night illuminating the interior lights (http://designenaction.gatech.edu/?p=78771)

The complex is located right by the river like the old warehouses around. It does not display the classic rectangular shape but it opens up towards the baroque church St Paul's, 360 m away with an inviting curved gesture. In this way a large public square was created in front of the building which can be used as open air stage in summer.

The curving facade is being cladded in transparent and translucent glass panels, depending on whether the spaces behind them require a view. Magenta, lime and turquoise polycarbonate panels are mounted in front of the glass panels giving to the building a pale interesting glow.

The cladding on the Laban Centre has four layers with U value of 1,45 W/m^{2}K and it is better than a low-e double glass unit. Present multiwall polycarbonate sheets with 60 mm thickness have reduced the U value to 0,85W/m^{2}K which is similar to a triple glass with argon and low-e coatings. These panels used at the Laban Centre have dimpled inner skins that diffuse the light. The structure is enclosed in a double-skin facade with a 60 cm ventilated cavity between the two layers.



Floorplan and longitudinal section of the building illustrating
with red the polycarbonate surfaces (http://designenaction.gatech.edu/?p=78771)

Sections on the west facade showing the cavity and the materials (http://designenaction.gatech.edu/?p=78771)

Fachada Oeste
Sección por Departamento de Prensa, Sala de Tutoría y Estudio

Fachada Oeste
Sección por Áreas de Circulación

Fachada Oeste
Sección por Salón de Actos y Estudio

6.2 ´´Reiss HQ London´´

This project began with a competition organised by David Reiss, owner of the British global fashion chain Reiss. Four UK offices were selected to propose their designs for a new headquarters building. The building was to house a concept with a store over the basement, ground and first floors, design studios, cutting rooms and administrative headquarters on the floors above and a penthouse for David Reiss at the top.

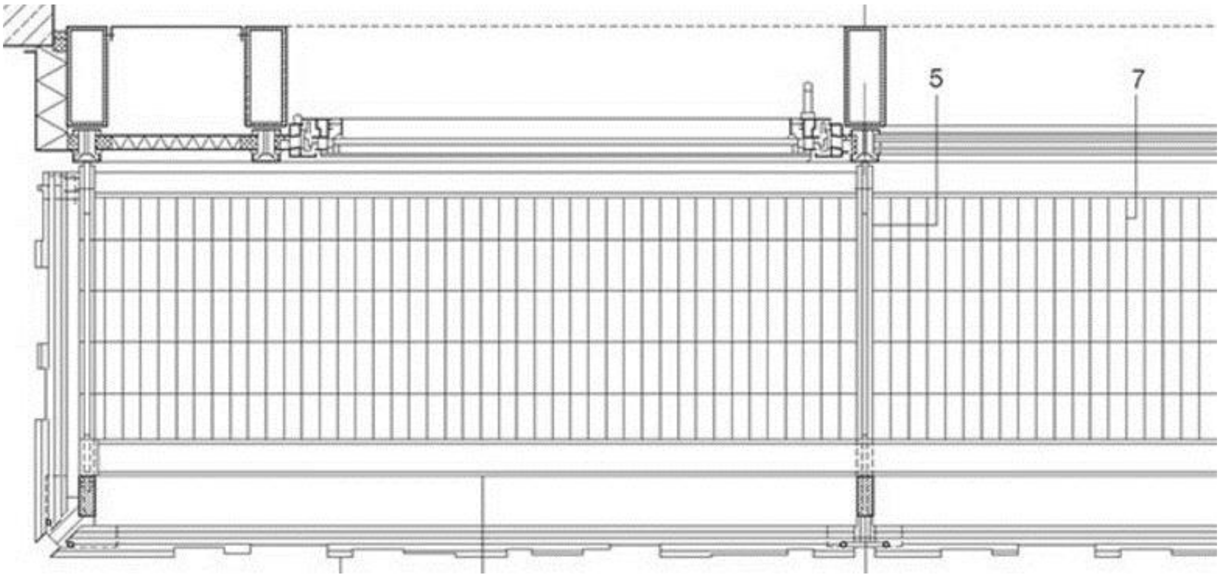
The façade was conceived as a translucent and dynamic filter, presenting a semblance of the varied activities behind it. The initial idea was for a cast glass facade behind which a material layer would provide an elegant screen capable of changing colours and moving. The facade design conceals the entire building behind an opaque wall which offers glimpses of light and movement only from inside. (http://www.whowithwhat.com)

Headquarters of Reiss at night (http://www.whowithwhat.com)

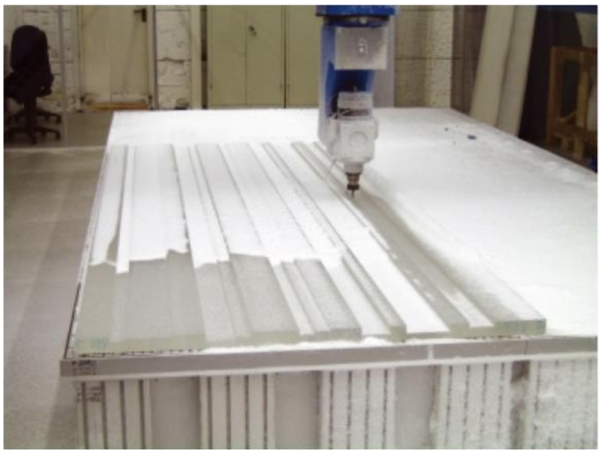
Because of the limitations of glass, the designers searched for alternative materials and settled on a highly engineered acrylic which is milled vertically to mimic fabric draped across the facade.

The milled acrylic has a very high light conductivity which was important since the initial concept was a glowing facade. LED light strips attached to the base of each panel light up each panel.

The acrylic rainscreen is part of a triple skin facade that helps cooling and heating during summer and winter. The acrylic is supported at the foot of each panel and a continuous rod runs up the edge of the panels to transfer the wind loading. Both of these structural elements are connected back to a steel structure hung from the roof slab.

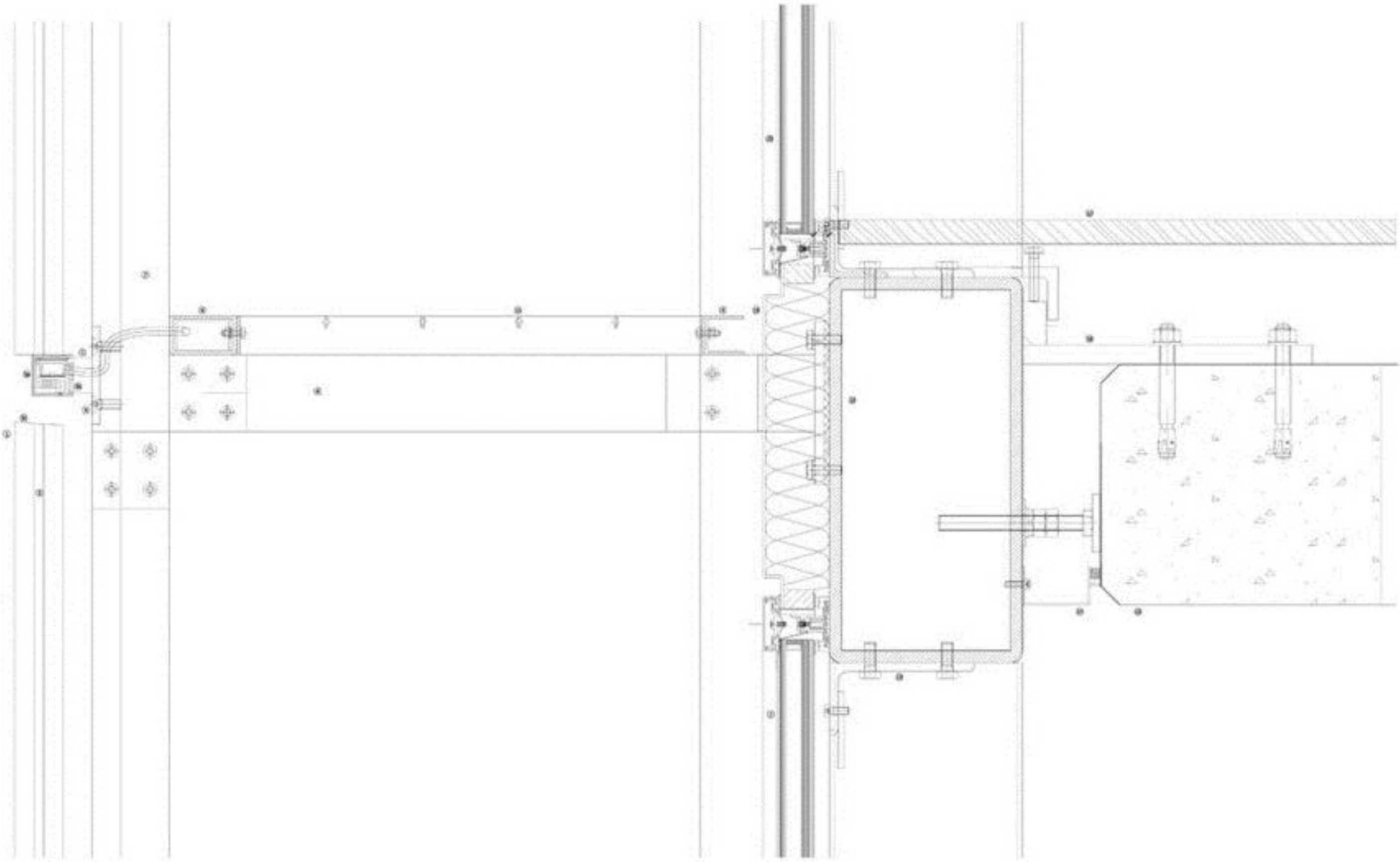


(Up)Detail floorplan of the 60 cm cavity with the exterior polycarbonate material and the glass interior
(Left)Image from the exterior looking up to the building where the LED cables are visible
(http://www.whowithwhat.com)

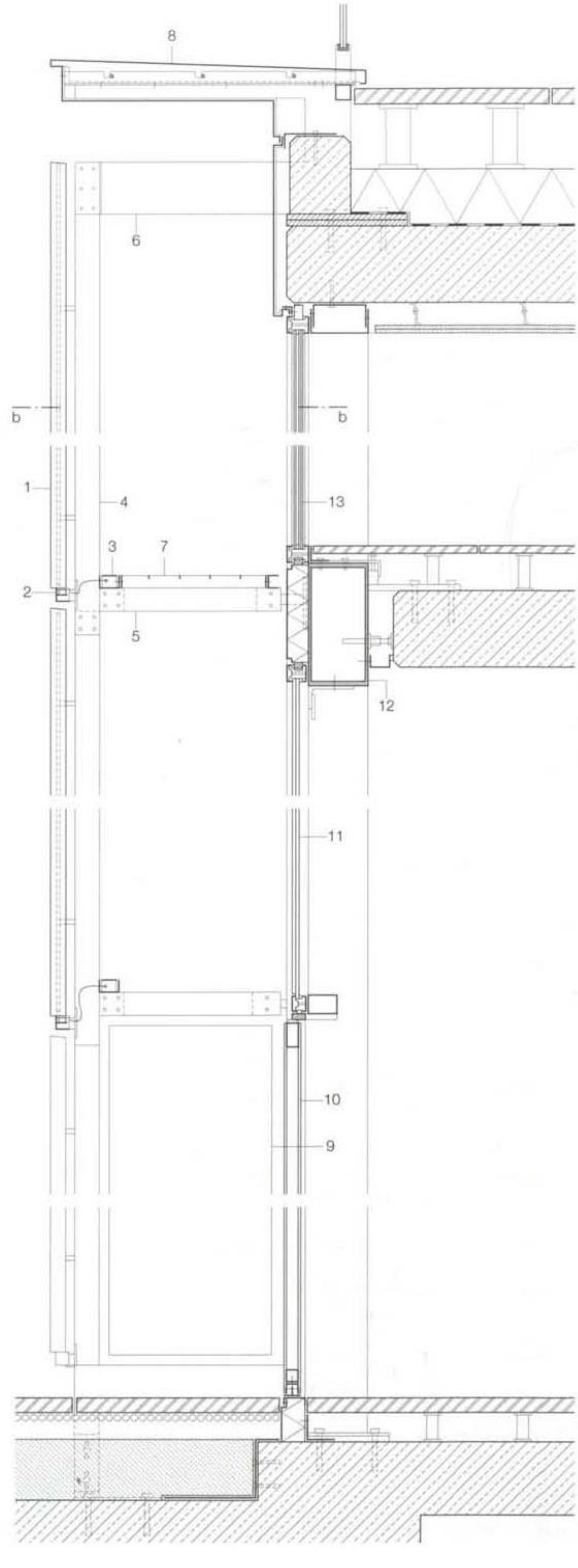


Acrylic milling process and finished facade panel. acrylic sheets can be cut and mechanized using laser cut CNC machines to provide extrusion-like profiles (http://www.whowithwhat.com)

Since completion, Reiss HQ has picked up an RIBA Award, a Civic Trust Award, a British Council for Offices Award and was shortlisted for a World Architecture Festival Award.



Detail of the facade. Led cabling is running through a hollow steel profile (http://www.whowithwhat.com)



Total section of the facade in the Headquarters (http://www.whowithwhat.com)

6.3 ´´IKARUS office and warehouse´´

Ikarus Design Handel GmbH is selling design products for private homes and gardens since 1993. Customers can purchase high-quality items for their homes from two offline shops. In 2005 the new office and warehouse was built in Gelnhausen, Germany.

Warehouse of IKARUS from the back side were the transport of goods is taking place. The smoothness of the facade is profound (http://www.rodeca.de/?L=1)

A cubic structure with a length of 65 m, a width of 24 m and a height of 9,60 meters was built within nine months. The building's basis is a steel skeleton. The construction's geometric grid determines the individual rooms and their equipment. Windows and high racks were adapted to the steel skeleton's modules and also the façade structure is based on that. The steel skeleton with its large spans allows for a flexible division and usage of the hall, based on the shipping processes. The level ceilings for the upper floor have been realized with prefabricated ferro-concrete elements. (http://architecture.mapolismagazin.com)
The steel construction is covered by a shell of green-tined polycarbonate multiwall sheets manufactured by Rodeca. The individual 800 mm wide, 8 m high and 40 mm thickness with 6 chambers façade panels were assembled together with the click fit system. The U value reached by these panels is 1,2 W/m^{2}K.

Image during assembling of the facade. Easy and quick installation with intermediate supports (https://kluedo.ub.uni-kl.de/home)

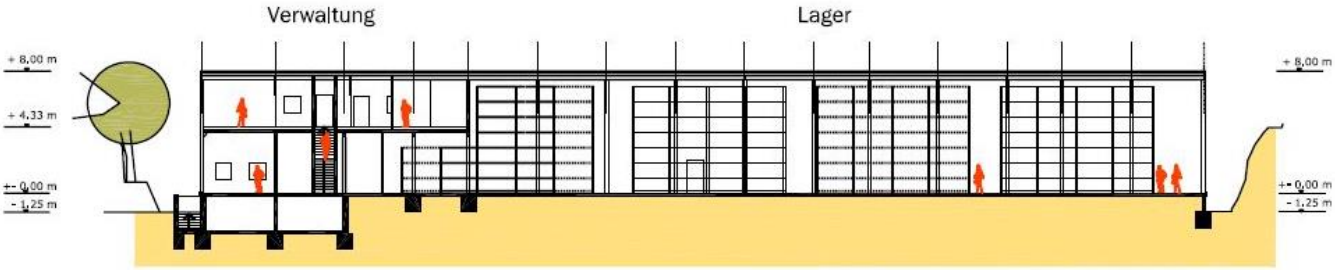
The edge free corners are very impressive. In order to achieve this, individual chambers were cut out of the panels by hand and bent by 90 degrees. This way the panels can run around the corners at a narrow radius. Only at one point at the hall's back the facade shell touches itself.

The green-tinted plastic panels let light through and thus create an interesting light effect day and night. On the upper floor, square-shaped windows made of acrylic glass have been inserted in the office area. No glass can be found inside the whole building. The translucent façade panels let so much light inside that during the day the warehouse hardly needs any artificial lighting. (https://kluedo.ub.uni-kl.de/home)

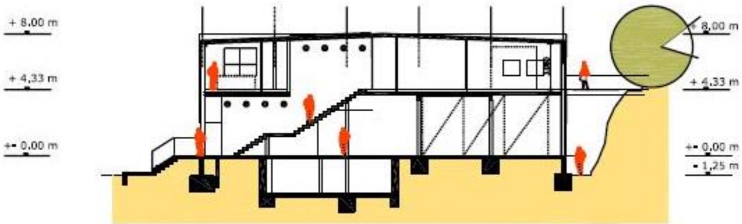
Continuous surface of the corner (https://kluedo.ub.uni-kl.de/home)

Corner detail on the bottom (https://kluedo.ub.uni-kl.de/home)

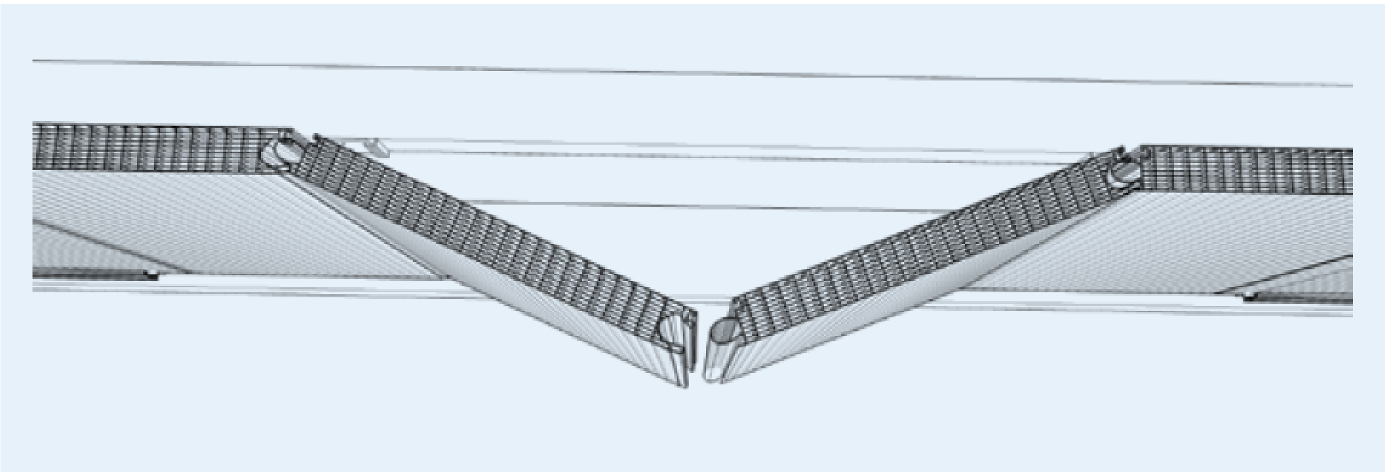
Light entering to the office (https://kluedo.ub.uni-kl.de/home)



Längsschnitt



Sections across the two directions of the building (http://architecture.mapolismagazin.com)



3D representation of the system used to click the panels to each other (http://www.rodeca.de/?L=1)

6.4 ´´Heerenstraat Theater Wagenigen´´

In the heart of the small town Wagenigen in the Netherlands, the Heerenstraat Theater adds a different note. Two polycarbonate boxes are hosting the cafe of the theatre created in 2008 and designed by ROZA Ontwerburo. This project is materialised again by Rodeca and the 158m^2 facade of the two boxes is dressed up by the click system of panels with thickness of 50 mm.

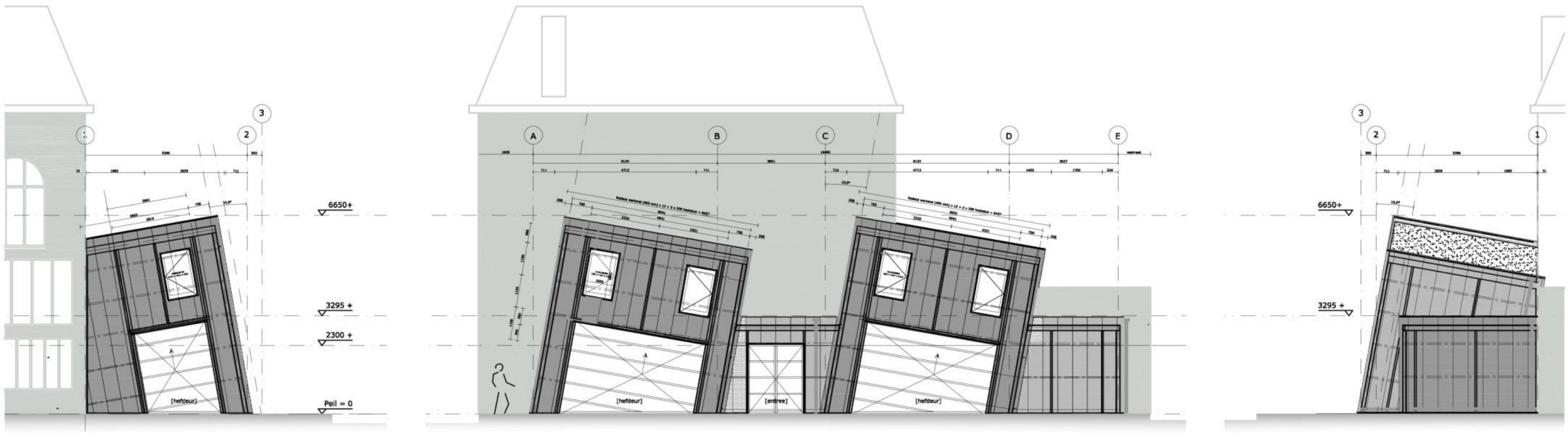
The two volumes are under an angle and special profiles were used to support the facade panels (http://www.ontwerpburo-roza.nl/)

Night view of the theatre with nice play of light (http://www.ontwerpburo-roza.nl/)

The 50 mm thick panel has 10 walls and achieves a U-value of 0,83W/m²K. The system 4050 used here includes non-thermally broken perimeter frame profiles.

View from the inside of the cafe. Aluminium profiles are visible (http://www.ontwerpburo-roza.nl/)

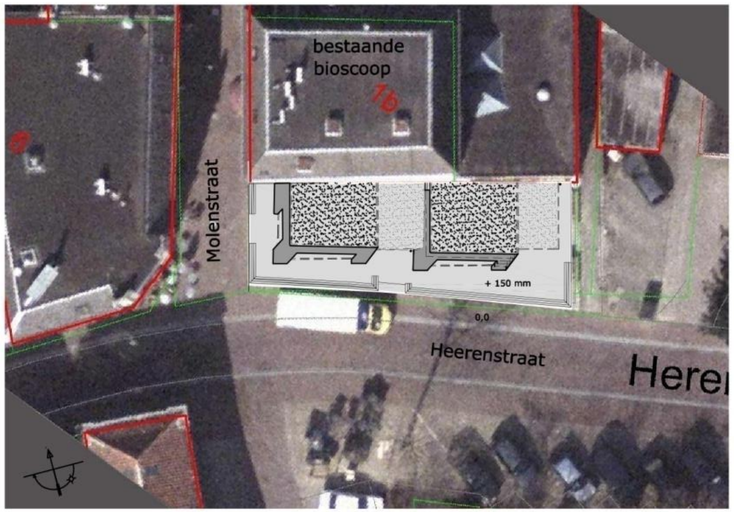
Geveltekeningen 1:200

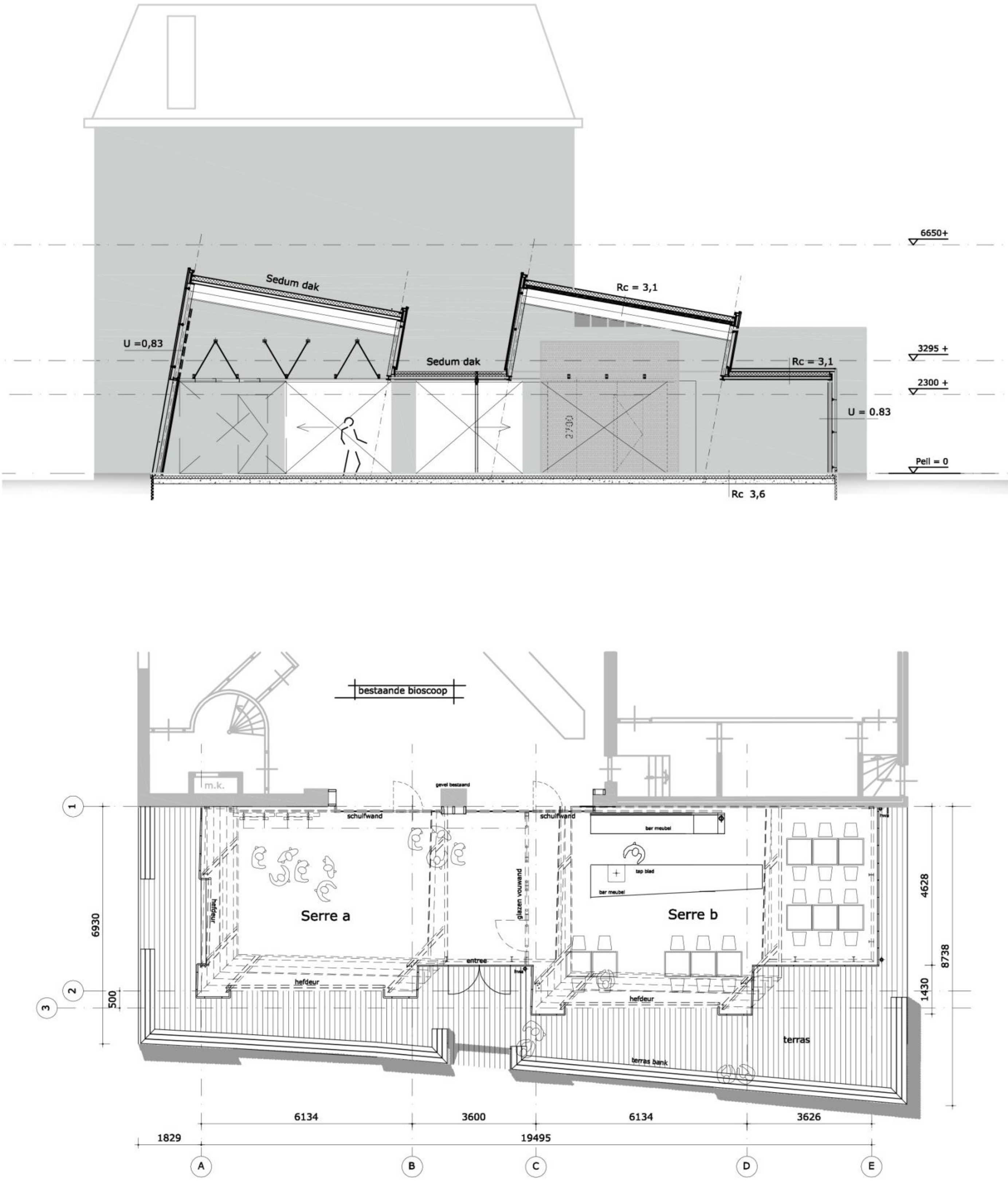


oostgevel zuidgevel westgevel

Heerenstraat

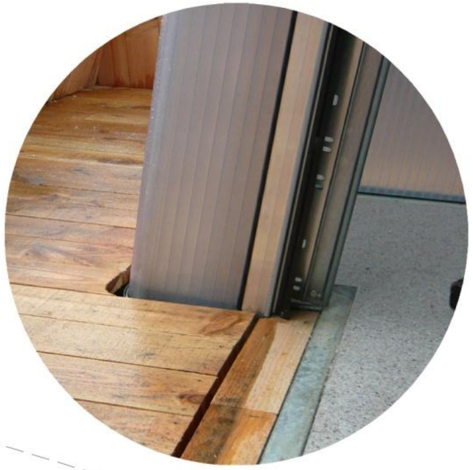
Situatie 1:500

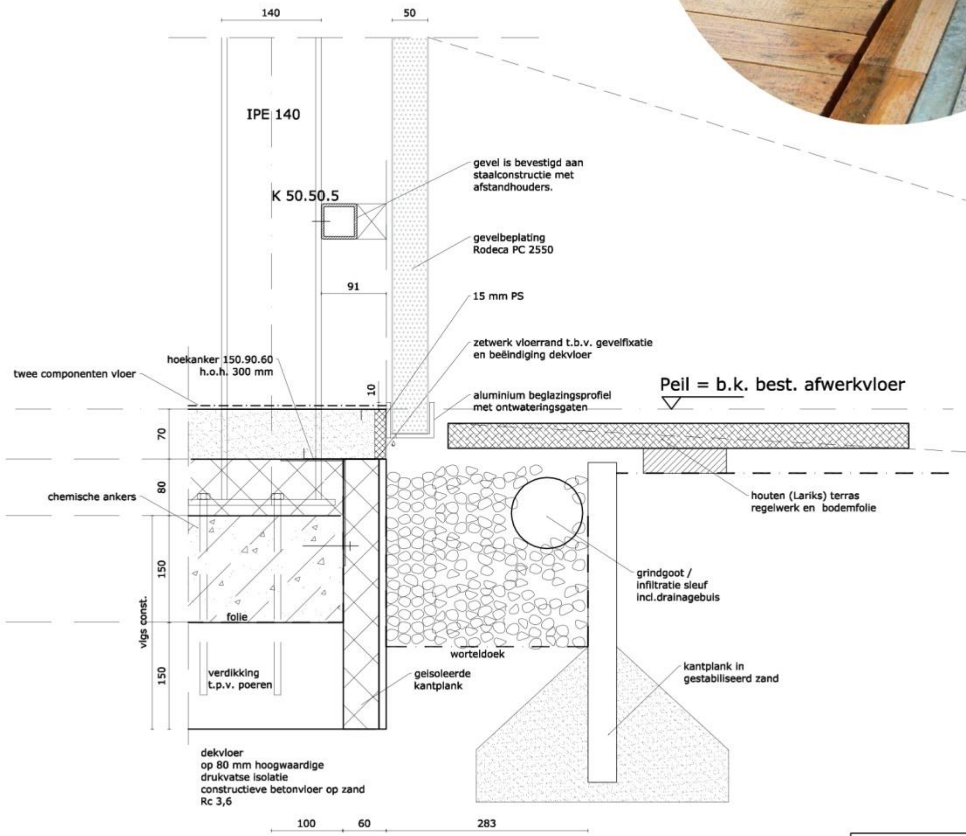




Elevation and plan (http://www.ontwerpburo-roza.nl/)

Gevel ontmoet vloer en terras niveau





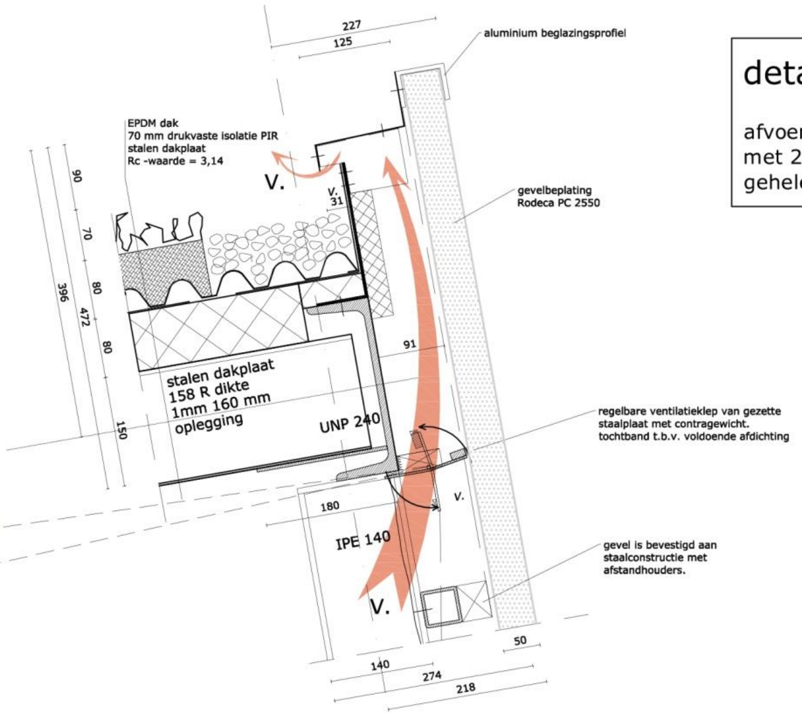
detail 3

schaal 1:10

Heerenstraat Theater

ontwerpburo [Roza] bna

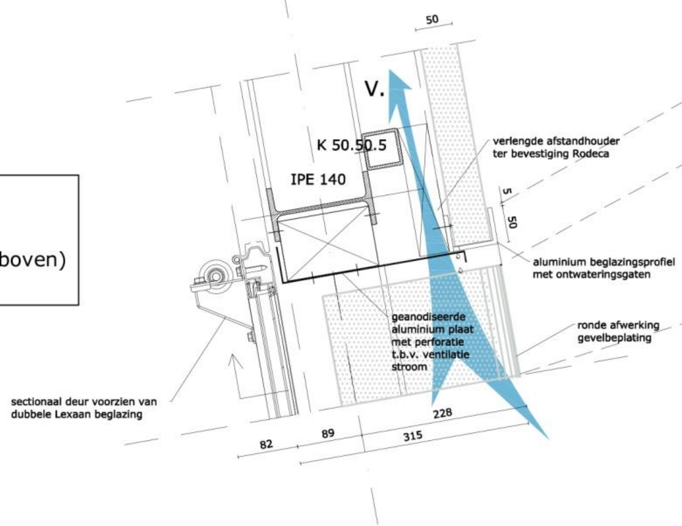
Natuurlijke ventilatie



detail 1

afvoercapaciteit is regelbaar met 22 kleppen langs de gehele dakrand

aluminium profielen volgen de gevel lijn



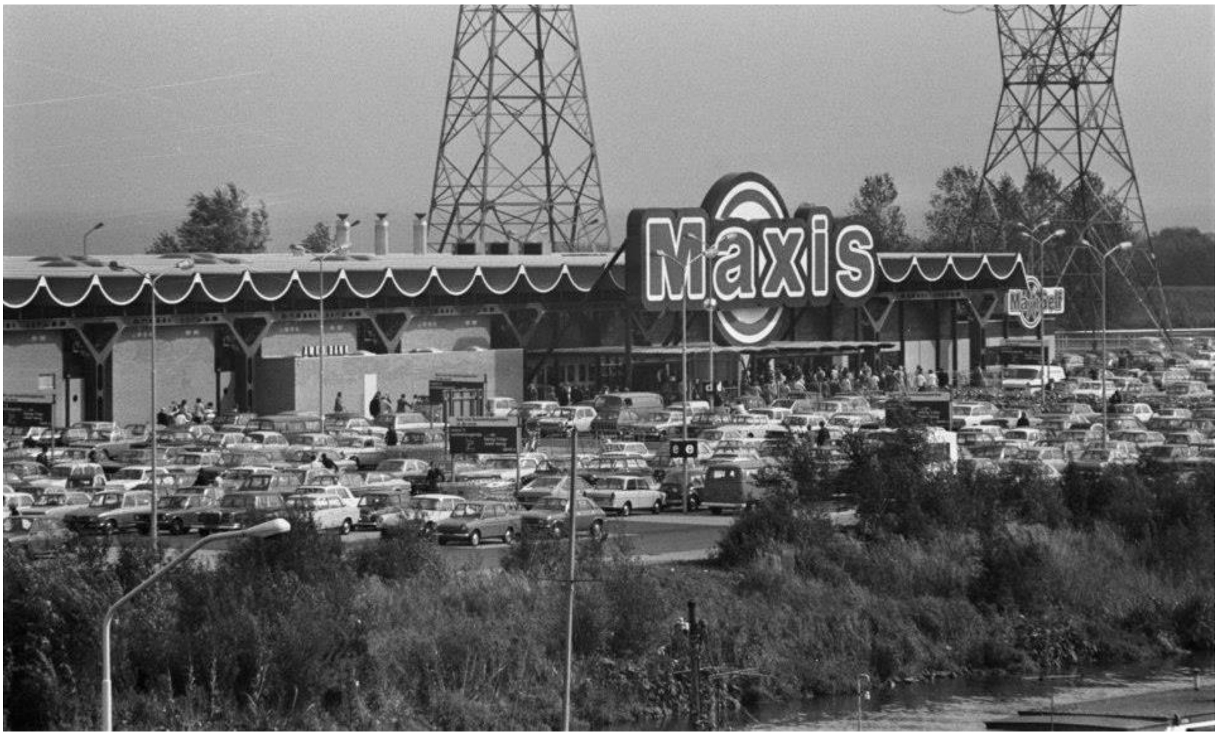
detail 2

toevoer via (roosters boven) de hefdeuren

schaal 1:10

6.5 ´´Muiden-Maxis´´

Maxis in Muiden has been restyled in 2005. The 30 year old complex has been transformed from a big store to a shopping centre with amenities. Royal Haskoning Architects, made this metamorphosis accomplished in a short time through a multidisciplinary approach.



Maxis in 1980 (http://www.gahetna.nl)

The shopping centre almost ten years before and as it looks today with the polycarbonate facade (http://www.rodeca.de/?L=1)

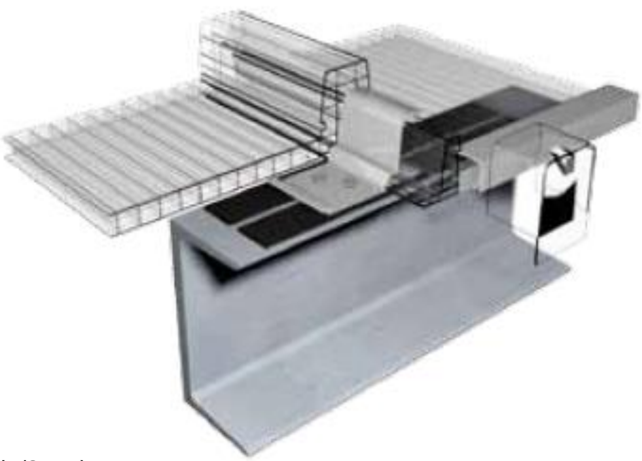
A total of 4.400 m^2 polycarbonate sheets from Rodeca with thickness 40 mm and 10 mm are covering the facade. The aluminium profiles used are the series 4040 which are non-thermally broken.

Rodeca Multi Function Panels are suitable for translucent roofing applications for internal and external spaces, flat and curved surfaces. The absence of glazing bars creates an almost seam free, economical interior finish. They let natural daylight into covered spaces. These systems provide flexible solution for roofing and canopies of various sizes and shapes. Combined with their light weight, high thermal properties, impact resistance and ease of installation they are an economical daylight solution.

Closer view of the construction (http://www.rodeca.de/?L=1)

PC 2610-4

Thickness (mm)	10
Building width (mm)	600 (+1/-1%)
Weight (kg/m²)	2.60



System used by Rodeca (http://www.rodeca.de/?L=1)

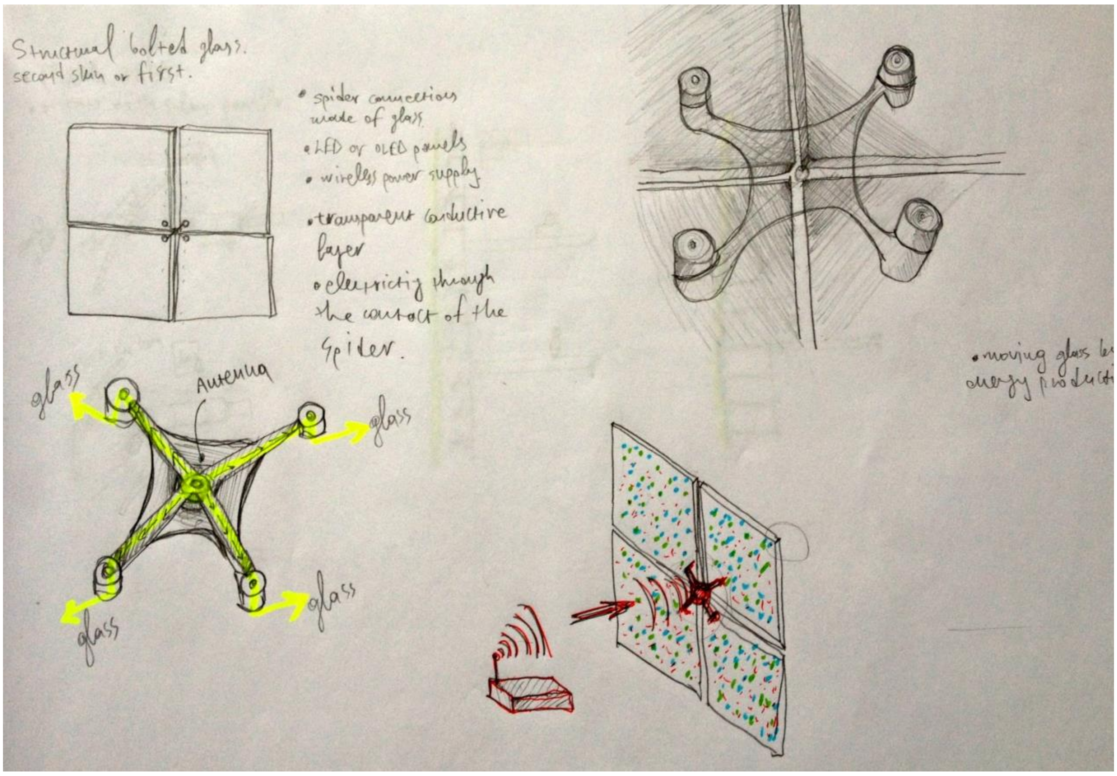
7. DESIGN PROPOSALS

7.1 Spider glazing media facade

7.1.1 Wireless control concept

The first design attempt started with the integration of LED light strips in big panels of glass. The black lines created on the image display by the mullions in the curtain wall facades was an issue which intrigued me to get rid of. Therefore, I searched for clear facade solutions which could minimise the connections between the panels and have a more unified image. Spider glazing seemed to be the perfect solution for this time and I decided to use it in my first design. Laminated double glass units of 1,5 m width and 3,00 m height would be fixed on a spider glazing component.

The main issue though was the cables which would feed the LED lights for illumination and programming. So, it seemed to be no other way but to pass electricity through the spider or with wireless power transmission.

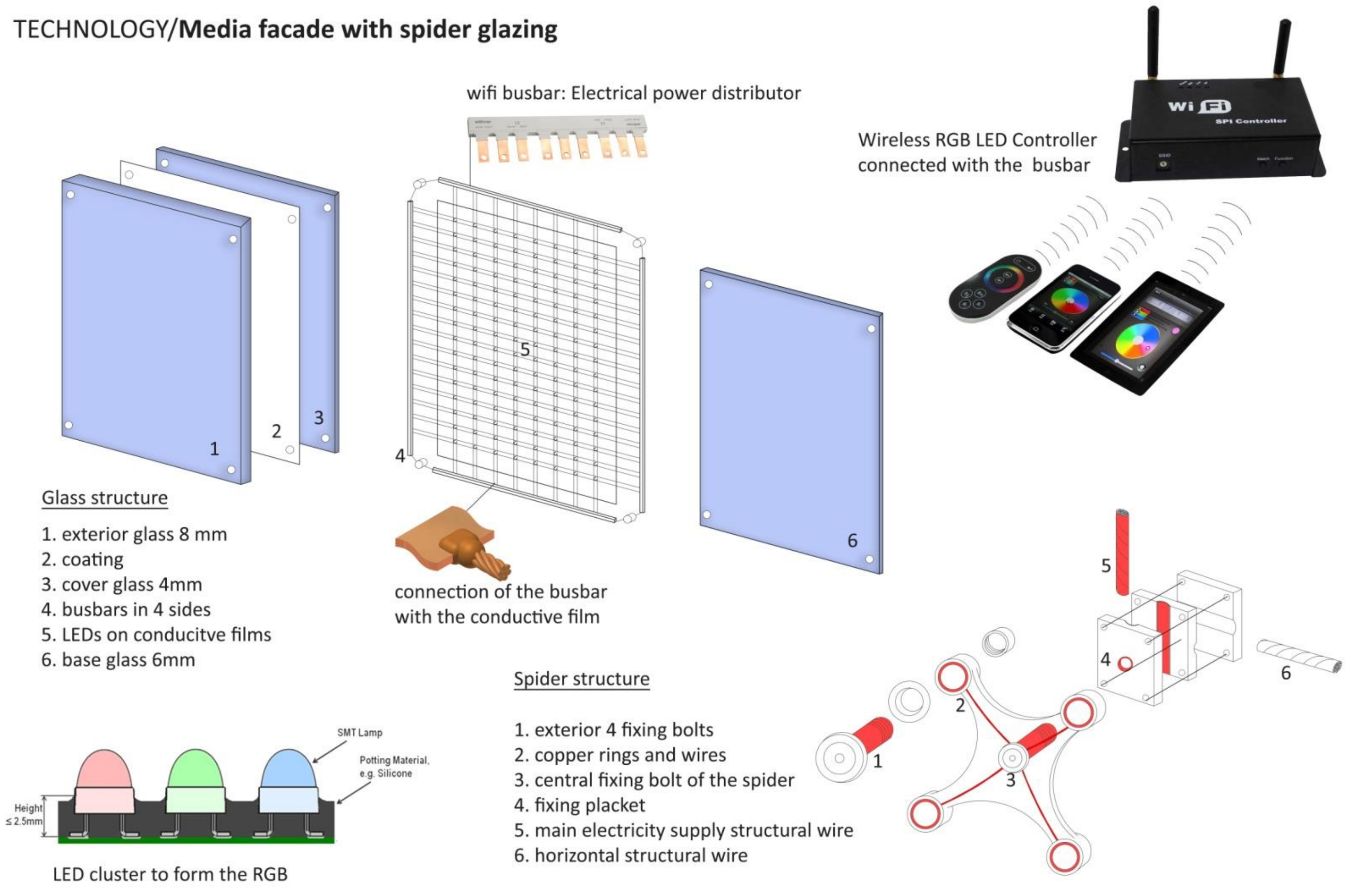


First ideas about using the spider glazing to create a media facade

Consequently, I proceeded with developing the concept using the wireless transmission. On each panel there would be 4 wifi bushbars for electrical power distribution. A wireless RGB LED controller would be connected with the bushbar to adjust the LEDs.

In this part of my thesis, I have to thank Rollecate Groep for their contribution by providing me with details about spider glazing in façades, examples of spider 3D printed components and information for suppliers which could have helped me in my thesis.

It was at this time that I needed the advice of experts from the Faculty of Electrical Engineering in TU Delft, because some parts of my design were still in concept stage and after making a list with professors to visit I made my way to the EWI. After explaining my concept to them they advised me not to pass the electricity through conduction to the glass with the component as this is not acceptable by building regulations. Furthermore, addressable RGB LEDs require many cables which could not fit through the spider. In addition, a proofed technology for the electrical distribution would be safer for my design than using a wifi bushbar which is not proofed yet. Finally, wireless transmission is more efficient with direct contact of the two surfaces, so the distance wireless control might have effects on the response of the LEDs, something which would spoilt the image of the façade.



Developing the first idea with concept diagrams and technology

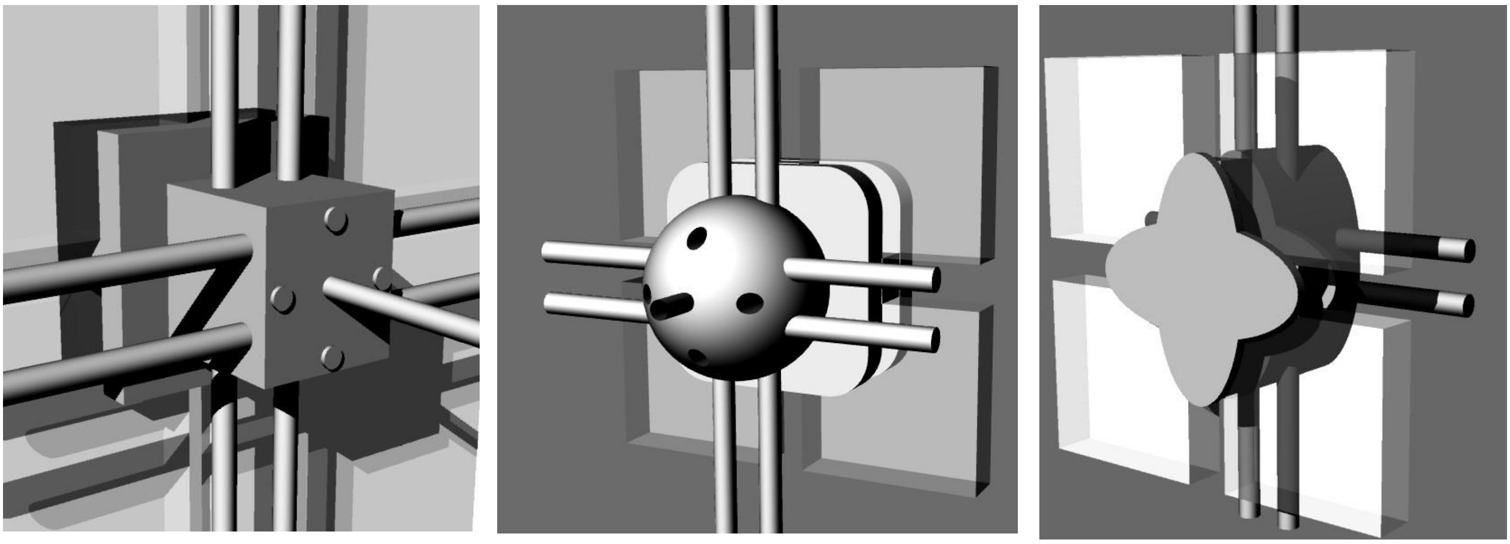
7.1.2 Media facade component

After developing the first idea and concluding that the wireless transmission wouldn't work I proceeded with designing the spider component in order to function as a structural connector and path for the electrical supply to the glass panels by cables. A Planar 2D inox prestressed cable system from the company Glasscon gave me the initial spark to improve my design.

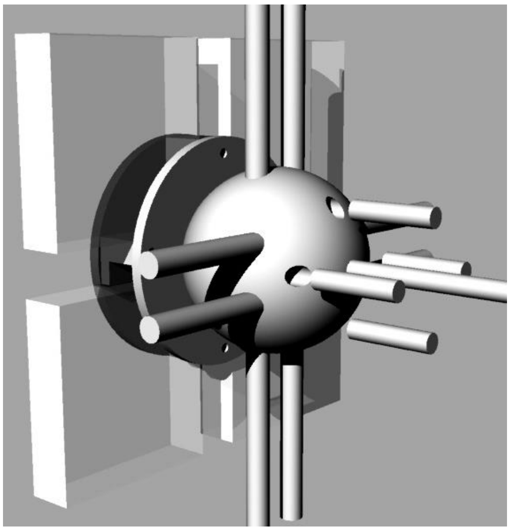
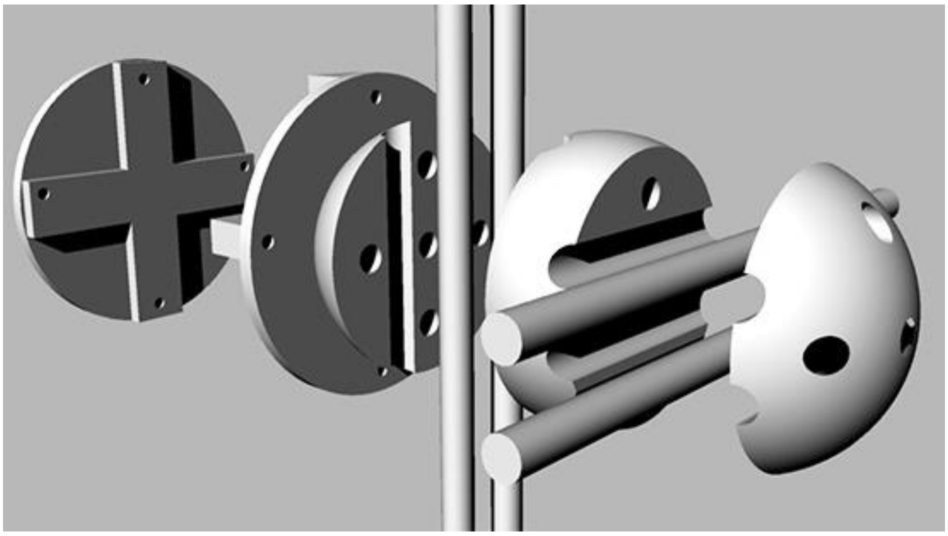
Office building in Athens using 2D inox system (http://www.glasscon.com/)

Closer look at the component (http://www.glasscon.com/)

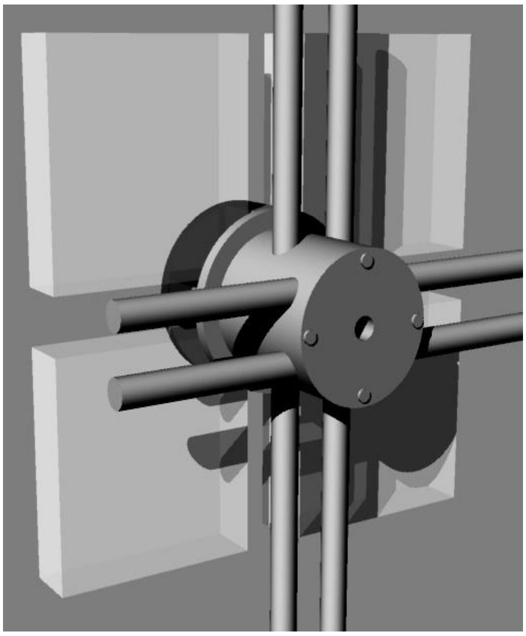
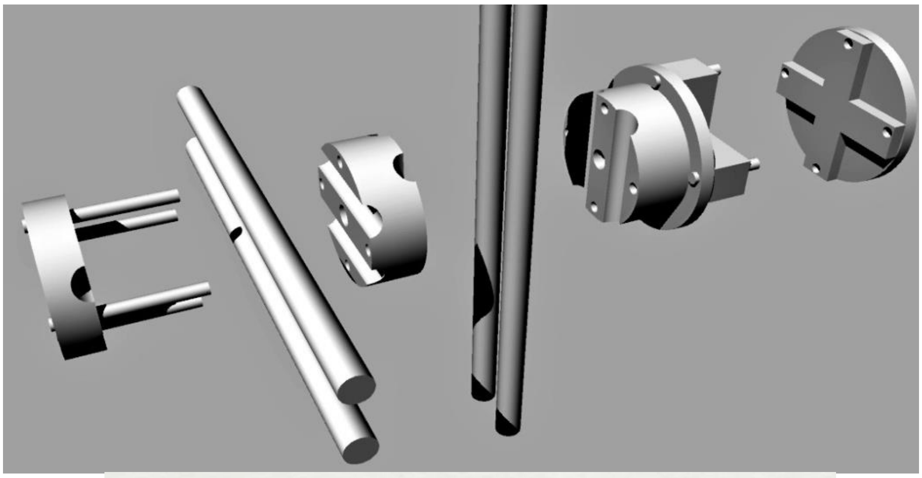
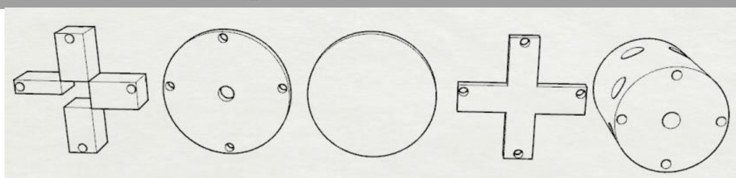
This system needs vertical and horizontal support cables to take the forces of the glass load. The difficult part was the path of the electrical cables which needed to be transferred through the component and go to the power supply and microcontrollers. In order to keep the good aesthetics of the system a central path of diameter 10 mm would be the ideal. This led me to start designing alternative geometries of the component.



Rectangular, spherical and asteroid components during design process. The central horizontal cable path is unavoidable

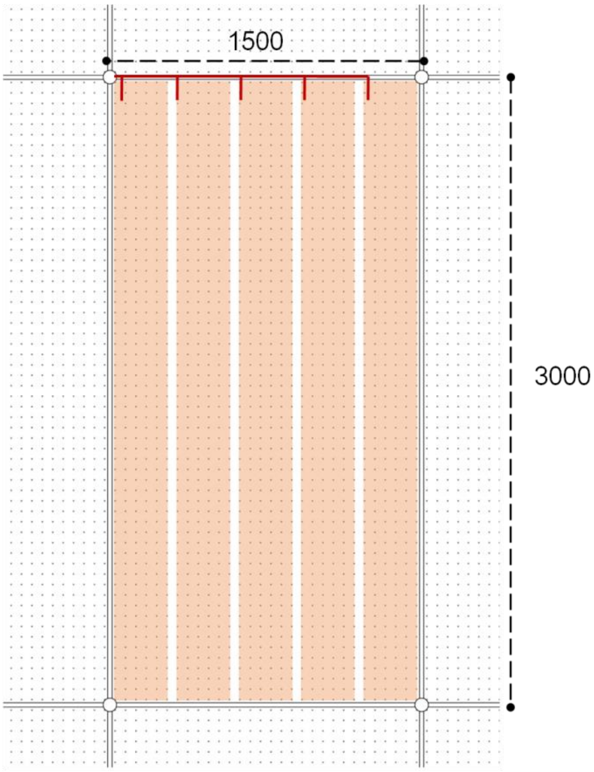



With the spherical shapes more efficient place is not blocked on the facade

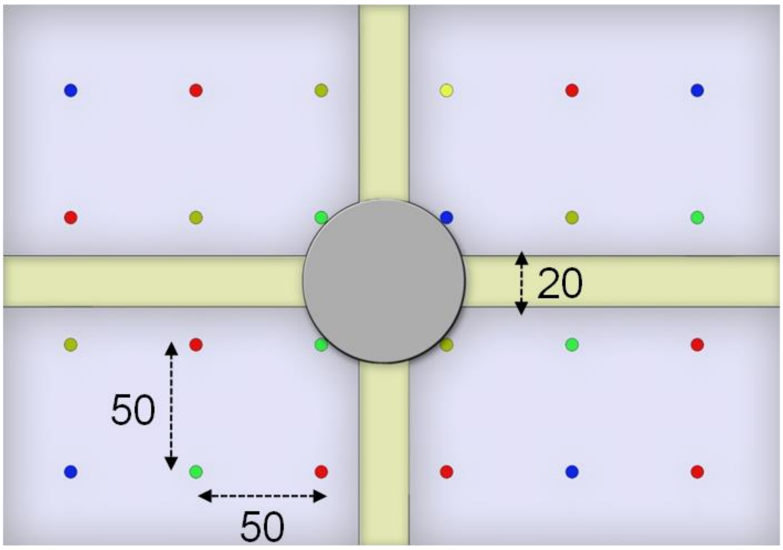




Final component after the design evolution. Assembly order is from left to right in the exploded view

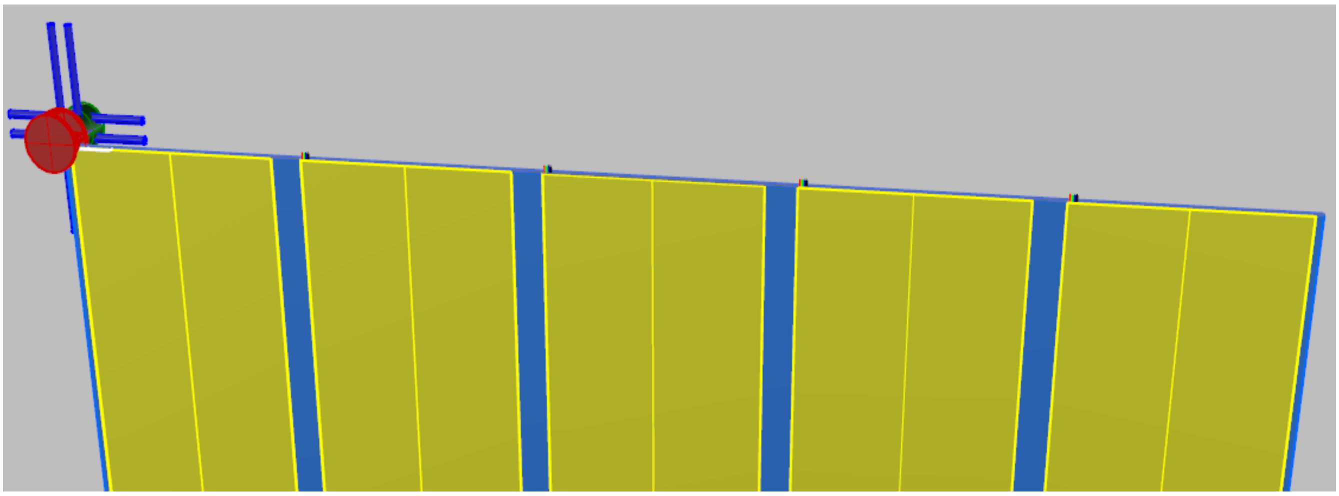
By minimizing the dimensions the circular fixing component reached 30 mm radius and thickness of the plate 5 mm. Each part is connected with screws of 4,5 mm diameter.
As far as the glass panels are concerned they are consisted of double glazing, base 6 mm, gap 9 mm and exterior glass 5 mm. In the gap between there are 5 rows of 18 m LED film and total 90 m. This means that from every film 4 cables are coming out, so 20 in total. All cables are meeting at the left edge of the glass panel from where they are transferred through the cylindrical component to the power supply and data.
Special consideration was given also to the distance from panel to panel in order to allow enough space for the circulation of the cables as well as for keeping the pixel pitch undistracted.



One glass panel on the facade with the 5 LED films



Pixel pitch 50 mm and gap between panels of 20 mm



The transparent film was chosen to offer an unblocked view for the users in the interior

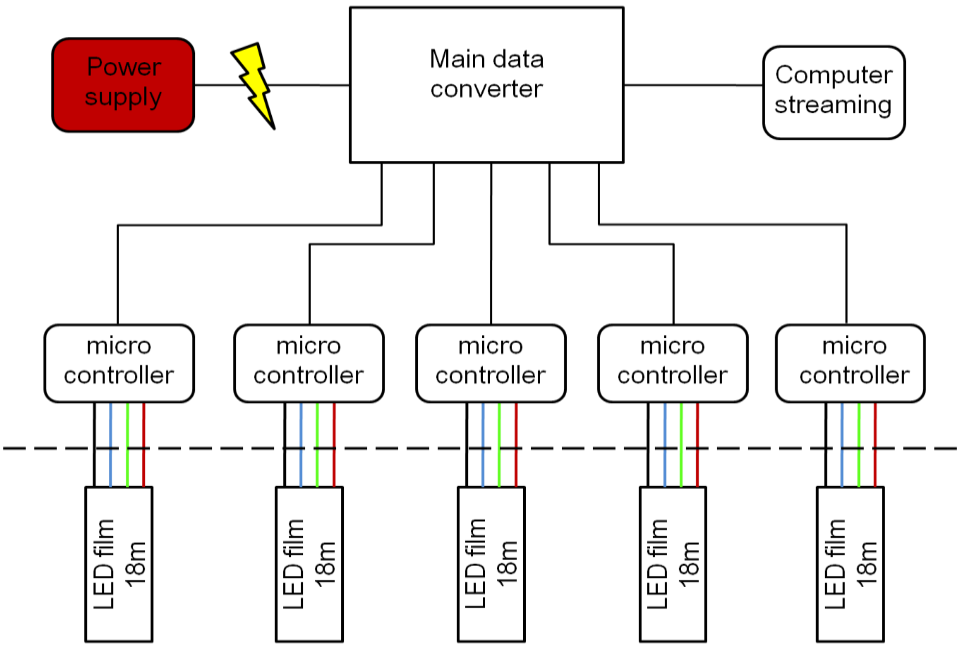
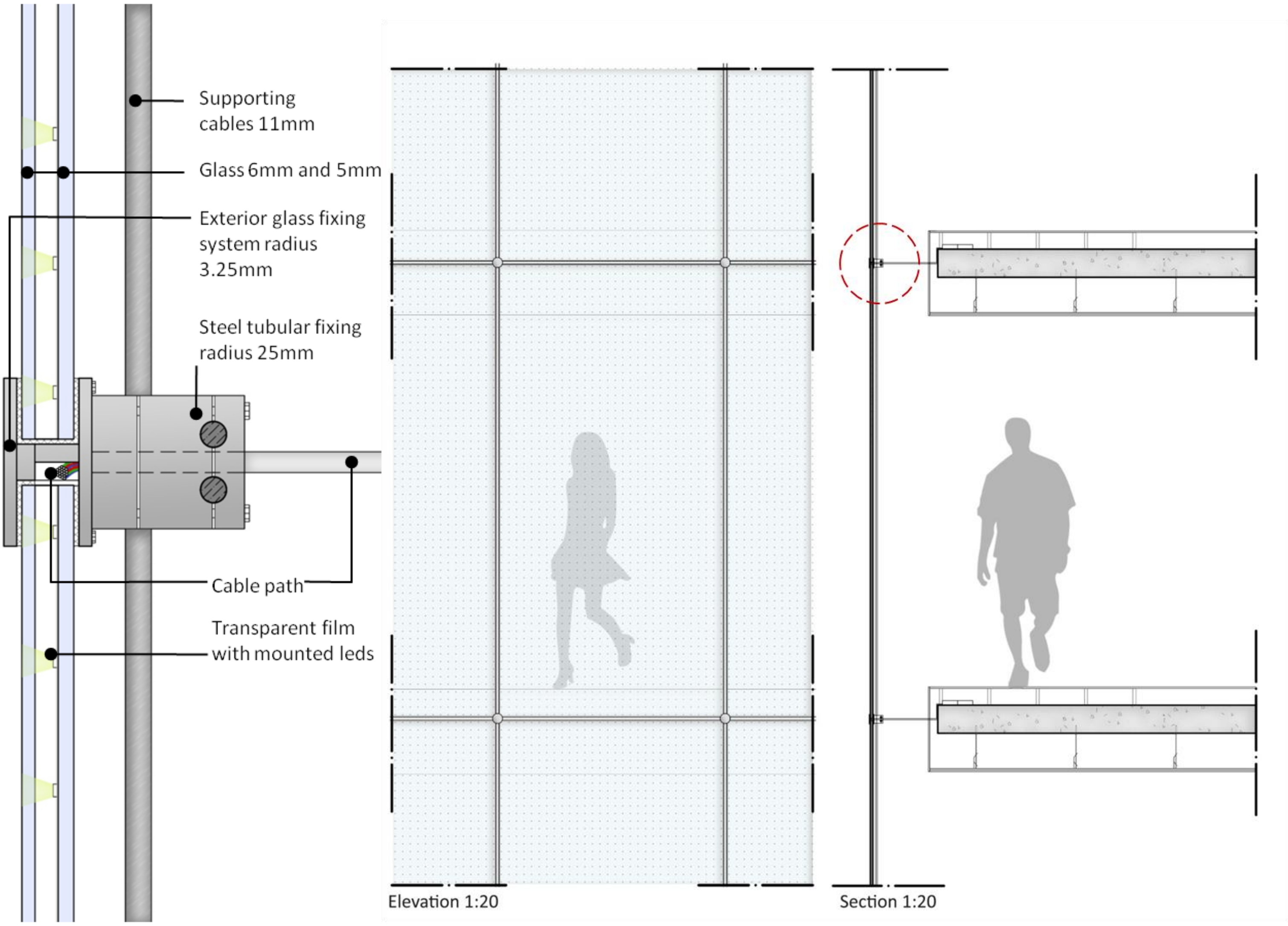


Diagram explaining the connection of the LED films to the microcontrollers and the main data converter. Power supply and computer streaming are connected with the main data converter

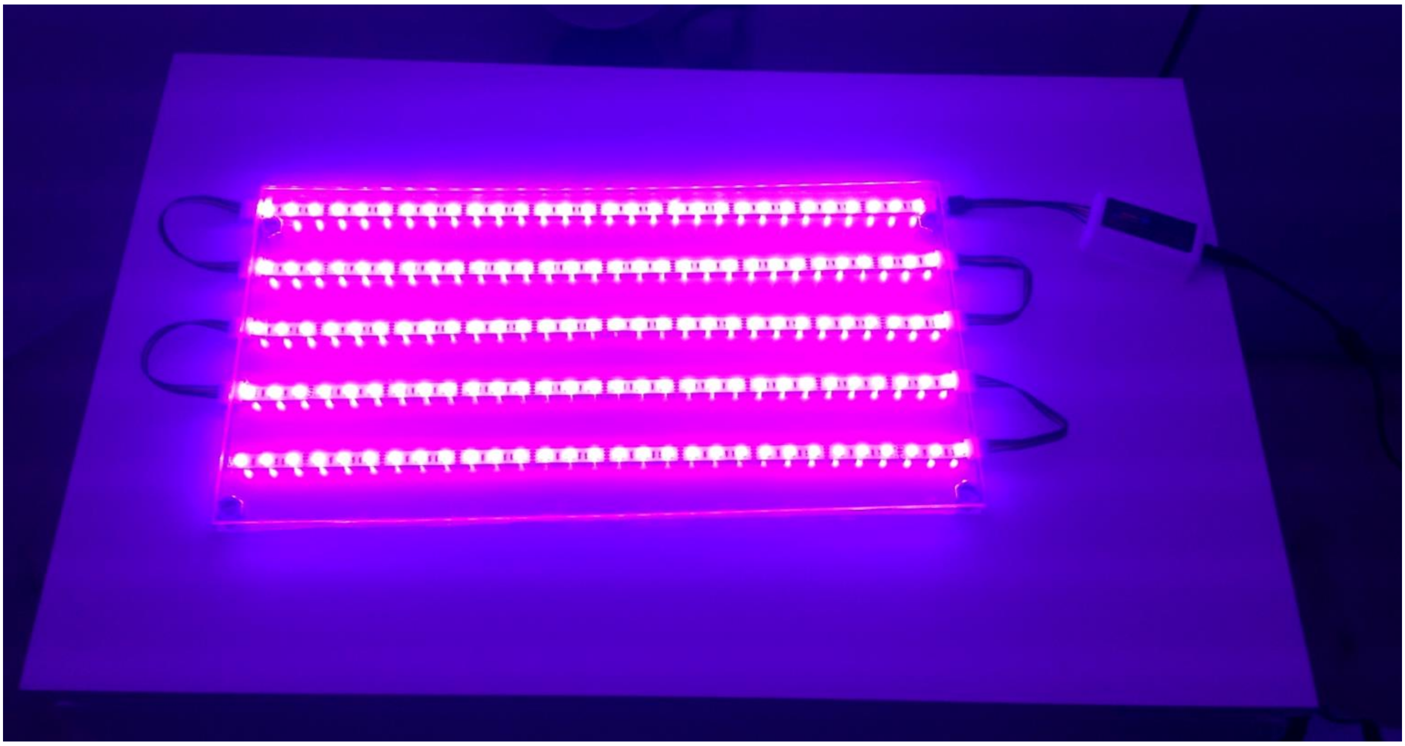


Detail of the component

In order to see how this system looks in reality and work I proceeded with building a small mock-up for my P3. Unfortunately, RGB LED strips are not so common and special suppliers were needed, so in Amsterdam a company (http://ledstrip-specialist.nl/) provided me with these strips of 5 meters. Together with the strips there is a microcontroller, a remote control, a power supply and wifi controller for controlling the LED strips through an application for smartphones. In addition, connecting clips were needed to join the individual strips on the panel because I had to cut the 5 meters in smaller lengths. The panel was made of two pieces of plexiglass. This experience of building a small mock up was very helpful as I had the opportunity to see and feel LED strips closely, the way they work, their light intensity and in general their behaviour and structure. Addressable RGB strips were much more expensive and could not afford them together with their controllers and programmers.

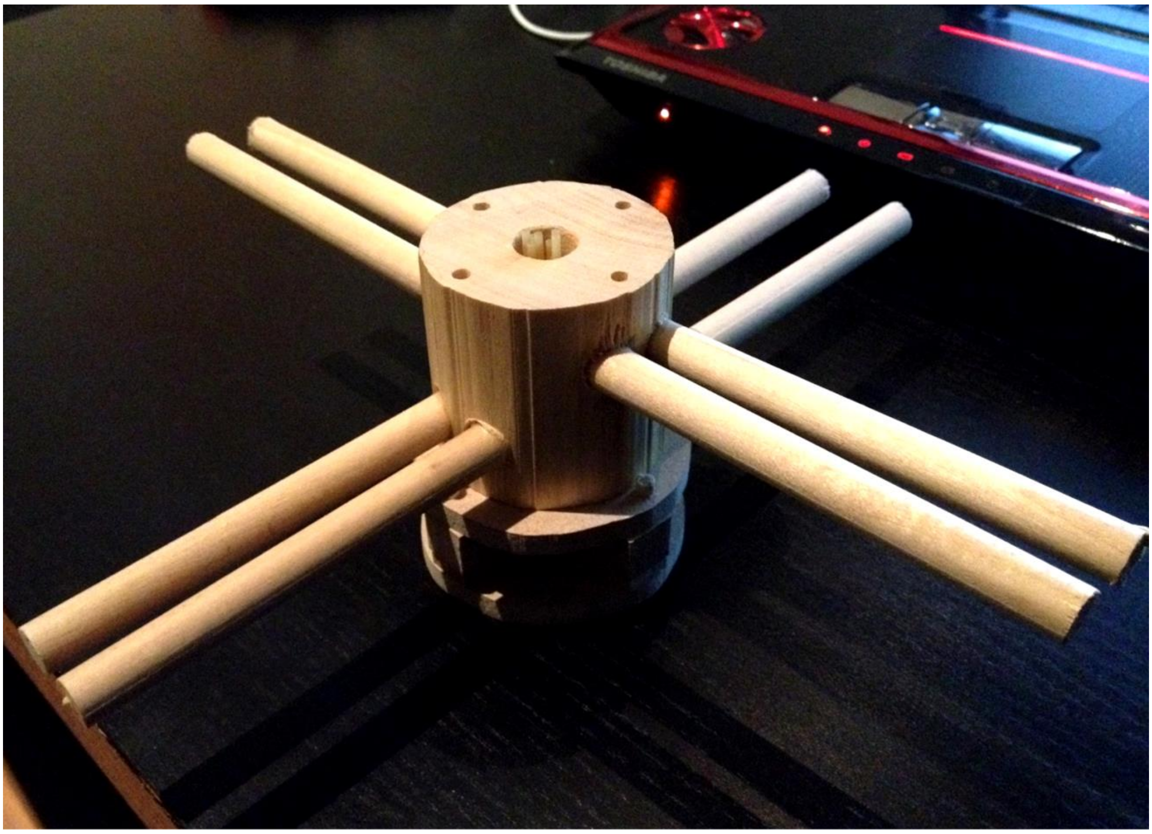
RGB LED strip before division

Maximum intensity at cold white colour

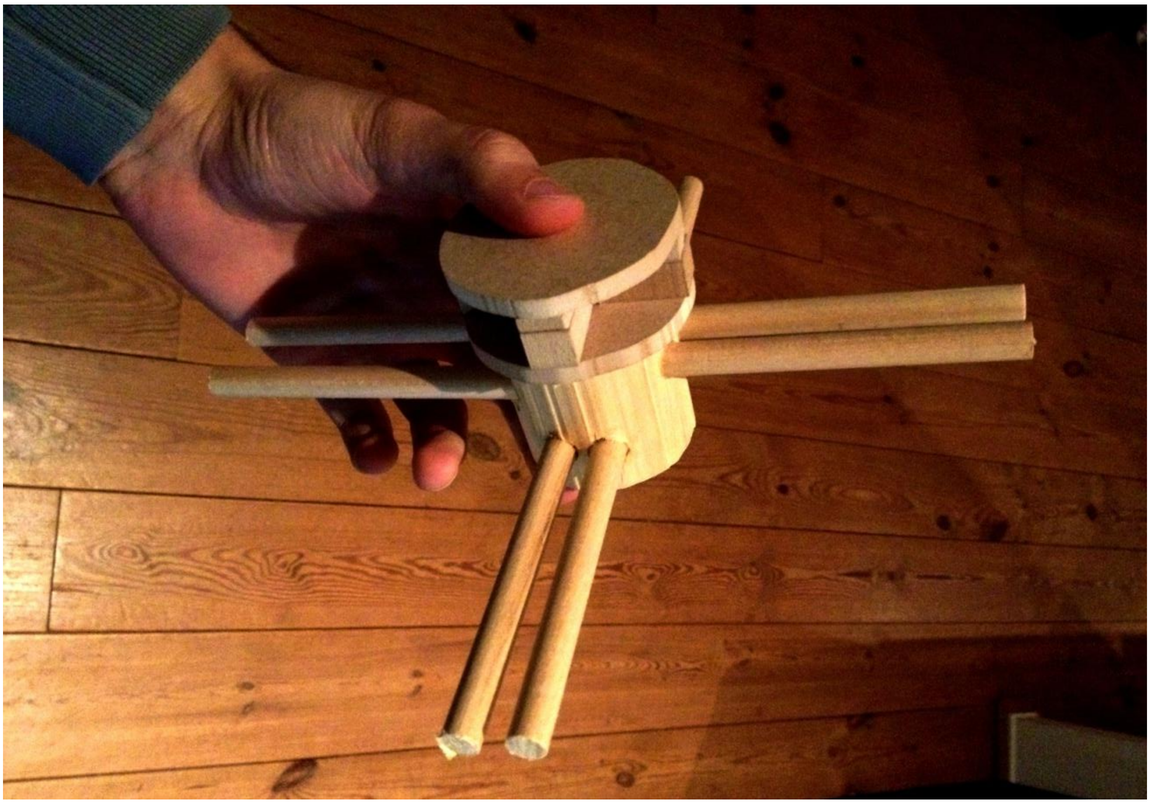


This type of RGB does not have the advantage of controlling each LED individually

Finally, last part of the mock up was the construction of the component. From the 3D model I printed the formulation and then cut the wood accordingly.



The component in scale 1:1



Front part of the 2D planar inox system. Structural rods are 10 mm thick

Final part of this design part was the evaluation of the proposal. In general we could say that the media facade would work with this system but there are some issues which led me to proceed with an alternative solution.
In this design there was a problem with the horizontal cable connecting the component with the slabs. A spider glass facade is under deformation when strong winds occur. The elasticity which is given through the steel ropes allows the movement of the panels indoor and outdoor. Thus the cables needed to be more in length than that from the component to the slabs. Of course this would affect the aesthetics and hanging cables would not be a pleasant view.
Furthermore, the issue with the replacement of LEDs in the glass is not yet solved. Laminated glass does not offer the ability to take out the film, fix the LED and place it back. Therefore, the whole 1,5 x 3,00 m panel needs to be changed. This would be costly and not so efficient.
In addition the sun protection was not integrated in this design. An easy answer would be to add a special coating between the glass or sunshade behind the facade, but that is something common and not aesthetically solving.
Finally, not all facades would have a 50 mm pixel pitch. Maybe a client needs denser or wider grid of pixels. With the wider grid there is no problem on the image created on the glass panels, since the gap of 20 mm between the panes will not still be visible. In case of a denser pixel pitch these gaps would affect the image and create something like the black stripes at King’s Tower in Jeddah.
Thus, the design was not yet successful at many aspects. A different approach needed to be followed which would solve for sure the maintenance issue and the stripe effect on the image of the building.

7.2 PCSS and RGB LED strips

After the research on RGB LED strips and polycarbonate structural sheets I proceeded to the design part where the combination of both would result in a cheap and simple media facade. Firstly, I had to figure out the way of integrating the strips in the sheets, in a way which is reversible so maintenance is possible in case of a LED light being damaged. Another aspect which had to be investigated in the same time was the research on the temperature that the LED strips are having in maximum operation and if they would affect the polycarbonate sheets. One LED chip emits 35 °- 45 ° C at low and maximum operation. Polycarbonate has a glass transition temperature of about 147 °C, so it softens gradually above this point and flows above about 155 °C**.** Consequently, the temperature on the polycarbonate must not exceed 100°C which is very high to be reached.
Furthermore, the reason for combining these two materials is that they do not last for a long time and their lifespan is almost the same for about 10 years. They are both recyclable and thus, environmentally friendly.
Finally, resolution of media facade is important for different scales and viewing distances, so I had to check whether my suggestion is flexible for a variety of pixel pitch or is it a standard design not so much adaptable. In addition, the intensity of the LED lights is important if we want to operate the media facade for both day and night time.

7.2.1 Lifetime of LEDs and PCSS

Many manufacturers claim that their LED strips have a maximum life of 80.000-100.000 hours. This is not true given that the service life of LED strips and the precision of constant current, for the LED chip alone, are tested by the best American company GREE under ideal conditions in laboratory. Consequently, this data could not be regarded as the actual life span of LED strips. The operating principles and working environment of LED chips determine that the actual lifespan of LED products is around 40.000- 50.000 hours.
Since now, LED strips have been widely applied in indoor and outdoor lighting industry. As they are constant current elements, products from different manufacturers may have different constant current effects and the lifespan is also different. As users and customers we should have a clear understanding about this. A detailed analysis about the service life of LED strips is chosen to be given following, since it is one of the basic elements in a media facade.

a. The temperature coefficient of the volt-ampere characteristics

LED is a semiconductor diode and it has volt-ampere characteristics. Consequently, the volt-ampere characteristics have a temperature coefficient which means when temperature rises, the volt-ampere characteristics are decreasing.

b. The lumens depreciation of LED strips

Most white LEDs are created by illuminating yellow fluorescent powders of blue LEDs. There are mainly two reasons which cause the lumens depreciation: The first one is because of the decrease of the blue LED itself, which is faster than red, yellow and green LED.
The second one is the lumens depreciation of fluorescent powders, which is affected intensively in high temperature. LEDs of different brands have different kinds of lumens depreciation, which is related with their junction temperature. The junction temperature refers to the temperature of the semiconductor P-N junction and the higher the junction temperature, the more intense the lumens depreciation. Thus to extend the lifespan, we need to lower the junction temperature first by the use.

c. Extend the life of LED strips effectively

Nowadays, usually the service life of strips is announced as 50.000 hours while in reality this value is influenced by many factors. With the constant development of LED technology, continuous decrease of LED cost and improvement of LED performance, RGB strips are performing better. Their long lifespan, high efficiency and energy conservation have been greatly noticed and studied.
How to extend the lifespan of LED products can be addressed following.
Firstly, the encapsulation technology is very important. There are different encapsulation technologies which have influences upon the quality of LED strips. In the same environment, the light intensity degradation of LEDs encapsulated by common primer is 76% higher than

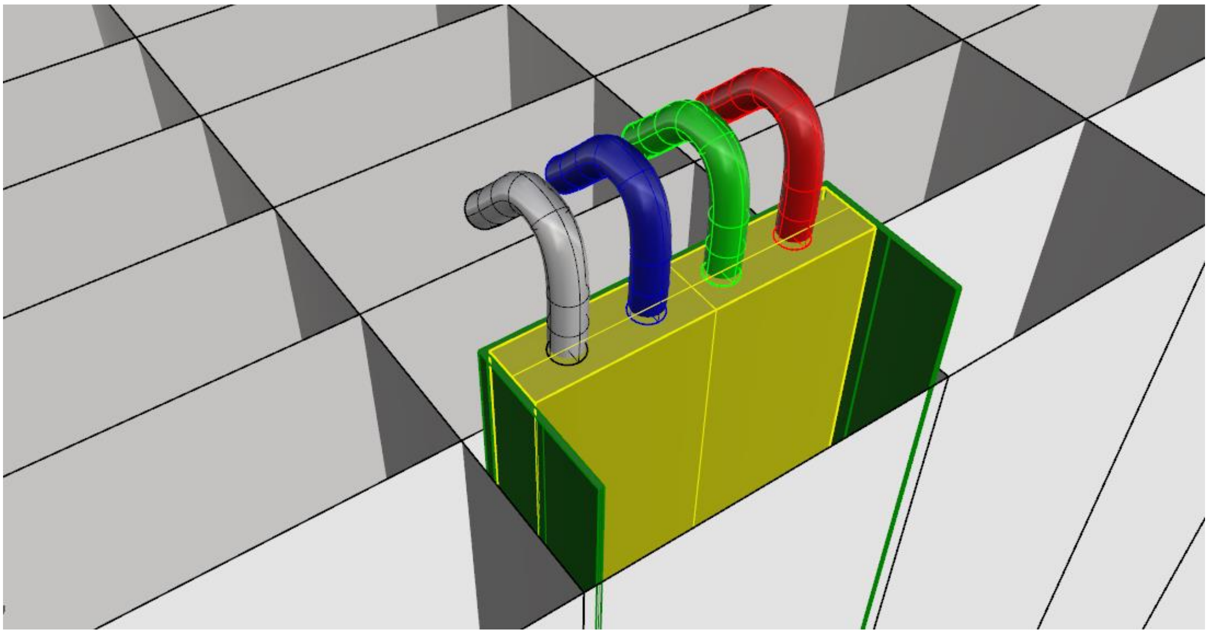
LEDs encapsulated in A-grade glue. Therefore, good encapsulation process will greatly extend the lifespan of LED products.
Secondly, when LED lamp beads are working the heat production is small and the temperature of frame is less than 45°C. At this time, the lifespan of LED strips is ideal.
The key to extend the lifespan is to lower the junction temperature of LED strips and thus a good heat sink could radiate heat away in time. (http://www.chineselight.com/) AGICO ELECTRONICS
In summary, the temperature is essential for the lifespan of LED strips. The higher the temperature is the shorter the lifespan. The ideal working temperature of LED products is around –5°C to 0°C, which is impossible. Thus customers need to understand the performance during purchasing LED lighting fixtures. At the same time, reasonable protection is also needed to guarantee that LED strips could give full play and obviously amount of use time. For a media facade, the hours of working during day and night is critical for the lifespan of the LEDs.
As far as the polycarbonate structural sheets are concerned the lifespan of them is becoming longer nowadays and can reach 20 years. But, as it was mentioned in previous chapter polycarbonates have the disadvantage that they start to degrade after 10 years (chapter 5.4). All manufactures offer a guarantee till this period after when sheets start yellowing by the UV radiation. Someone can say that this is a good reason to replace the polycarbonate sheets in parallel with the LED strips which are also lasting for the same amount of years.

7.2.2 Maintenance and recyclability

One of the basic problems I faced during the design process was the issue of maintenance of the LED lights if they are integrated in the media facade elements. The concept with the LEDs integrated in laminated glass didn't succeed in this part. It was still impossible to replace a burned LED without destroying the whole facade glass panel. Thus, the polycarbonate sheets seamed ideal with the partitions between to fit the led strips along the panel.

The thickness of the champers was proofed to be perfect for integrating the 12 mm LED strips being attached in plastic bars sliding in the chambers.

In addition, the click system of the panels, chosen for the design, offers the reversibility of the facade by taking out the panels and fix the LED strips in case of failures. With the same way of assembling the facade they can be put back in place.



The LED strip (yellow) attached on the plastic U profile (green) fits in the chambers. Cables from the top are transferred to the power and data supply

This system fits to all requirements of pixel pitch and allows light transmission to the interior from the chambers not being filled with LEDs.

In terms of recyclability, this solution is totally environmentally friendly because everything is fixed with dry joints and as it is assembled it can be disassembled. Polycarbonate sheets can go for recycling and used in the new products.

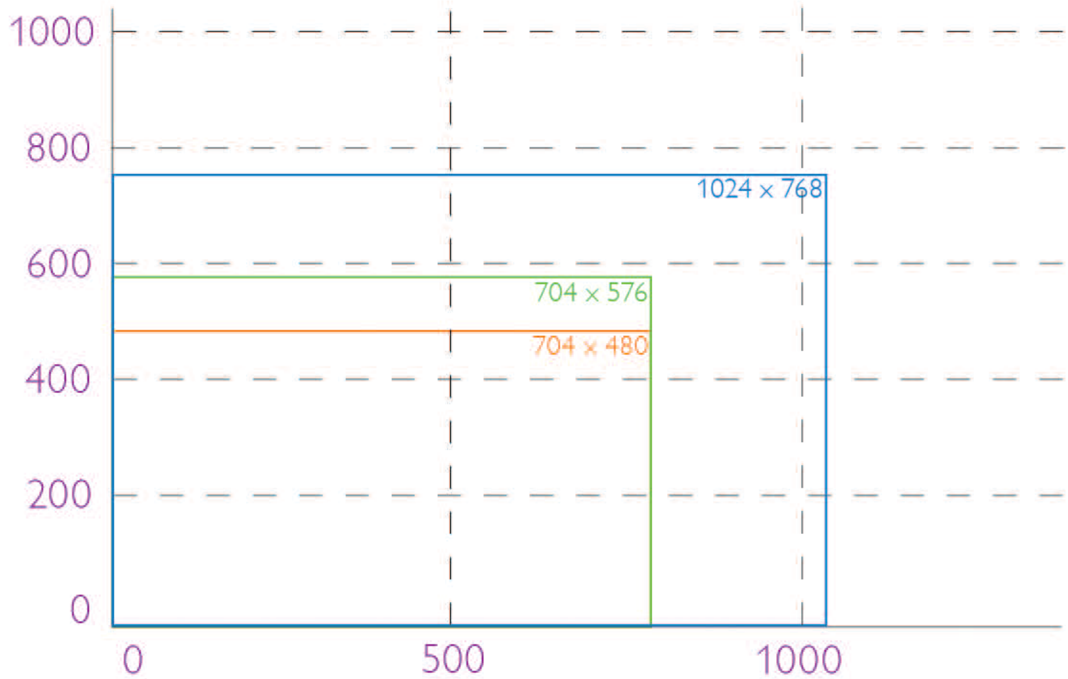
Lexan is another manufacture colossus of polycarbonate sheets. During manufacturing, Lexan sheet offers environmental advantages over glass. Typical operating temperatures during the sheet extrusion process are in the 240^{o} C range. Therefore the energy used during the extrusion process in which polycarbonate resin is converted into polycarbonate sheet, is just a fraction of the energy needed to manufacture the flat glass that goes into the same building & construction applications. During extrusion process, up to 15% of recycled content is used to produce virgin material.

LED flexible strips are composed of a flexible circuit and LED bulbs have a circuit board on the inside. LEDs are electronic components and like PCBs they can be recycled. They are recycled in order to reclaim any precious metals. LED light fixtures and lights contain no hazardous chemicals and fully comply with the Restriction of Hazardous Substances directive, which limits the use of lead, mercury and four other hazardous materials in electronics. LEDs contain trace amount of a few different metals including copper, Pb, nickel and silver but not enough to pose a serious threat on contact. This is the way of recycling the LEDs.

In general, this concept offers the versatility of changing the facade every 10 years according to the needs. By recycling the facade materials you have positive results in the cost of construction and the energy savings.

7.2.3 Media facade scales (pixel pitch, resolution, intensity)

When designing a media facade planning for video displays involves special considerations such as pixel pitch, minimum and maximum viewing distances, sampling and display resolution. Images on a LED video display appear to be sharper to the human eye as the distance to the display increases. Similar, images appear less visible as the distance decreases. The spacing between pixels (pixel pitch) determines the minimum and maximum viewing distances for discernible video output. Pixel pitch is measured center-to-center.
The following calculations offered by Philips are general guidelines for determining minimum and maximum viewing distances, based on video displays using grids of evenly spaced pixels.
To determine minimum viewing distance, we have to multiply pixel pitch by 1000 distance units. For example, if the pixel pitch is 50 mm, the minimum viewing distance is 50 m.
On the other hand, to determine the maximum viewing distance for discernible video, we have to multiply the screen height by 20 distance units. For example, if the screen height is 10 m, then the maximum viewing distance for recognizable video is 200 m.
In general, LED screens are visible beyond the maximum viewing distance for discernible video. To determine the maximum viewing distance that still creates visual impact, we have to multiply the screen height by 50 units. A screen 20 m high will continue to create visual impact at 1.000 m.
The resolution of a LED video display equals the total number of vertical and horizontal pixels — the greater the pixel count, the greater the resolution.



Resolution increases as the pixel number increases (Philips iColor FLEX manual)

By comparing the input of Citiled (pg.49), GKD (pg.53) and Philips for minimum viewing distances we can conclude that to determine the minimum viewing distance where the image is not pixelated we have to multiply the size of pixel pitch by 700 mm to have the optimum result. After constructing and testing the mock up though, the variety of 700 changed to double size at 1400. The mock up has a pixel pitch of 25 x 20 mm and still from the 30 m the image was pixelated. It is safer to reach a good image result multiplying the pixel pitch by 1400 and determine the minimum viewing distance. Therefore we have the following board.

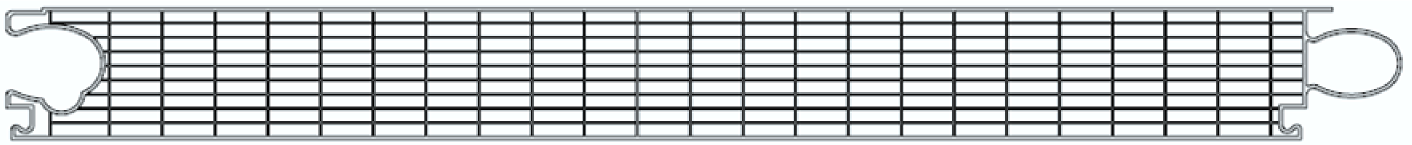
Pixel pitch (mm)	Minimum viewing distance(m) Multiply by 1400 mm
12	17
25	35
35	50
50	70
65	90
80	115
95	135

Brightness is another important factor of the media facade especially for exterior applications. For outdoor use, 2.000 cd/m² is required for most situations at least, whereas higher-brightness types of up to 5.000 cd/m² cope even better with direct sunlight on the screen. Generally we can conclude that an outdoor LED sign is visible when it generates a minimum of 5.000 nits (cd/m^2) when sun emits approximately 4.000 nits.
Indoor use requires a much less brightness of 600 cd/m² which is about 10 times less than outdoor use.
LED lights on the strip 5050 which is chosen for the design emit 14 lumens per LED. With a 50 mm pixel pitch and 400 RGB LEDs/m^2 our facade emits 5.600 nits. For 25 mm pixel pitch and 1681 RGB LEDs/ m^2 the facade has an intensity of 23.534 nits which is very high. With special adjustment light intensity can be decreased to save also energy. Consequently, this type of LED pitch and strips is appropriate even when sun is shining on the facade.

7.3 Polycarbonate media facade with vertical straight panels

The first design has chosen to be for a shopping centre, similar to this from Reiss in London. Shopping malls do not require direct sunlight on the interior. In contrary they need to be less lighted to keep the clients in a constant environment with indirect and artificial lighting. On the ground floor there will be the entrance and shops. Second level till the top of the building a straight facade of 9 meters height and 18 meters width, made of polycarbonate is being suggested.

Therefore click panels of 50 mm thickness, similar to these from Rodeca, were chosen with a U value 0,83 W/m^{2}K. This click system is time and cost efficient. For functional reasons in combination with the LED strips panels will be 1 m wide and 9 m height. They have 10 walls and 9 chambers. Due to the technology offered nowadays the polycarbonate sheet will be clear on the exterior wall for better resolution of the media facade, while the other walls will be translucent.

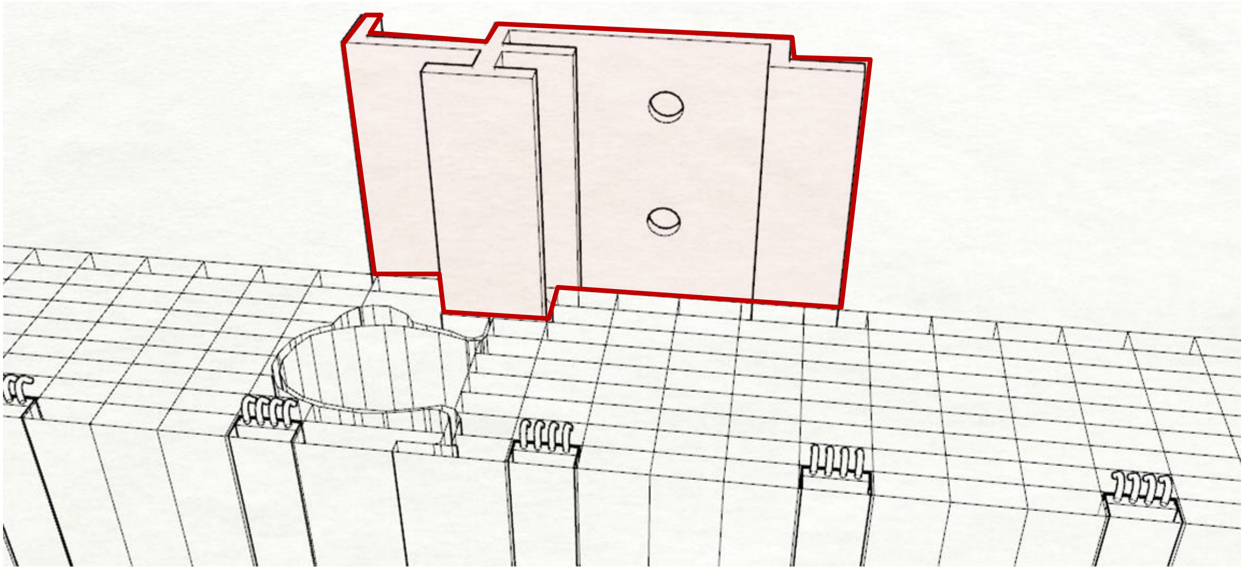


The panel used for the facade

As far as the LED strips are concerned, they will be slided in the last chamber to the exterior surface through plastic U profile bars which will stop at the bottom of the panel. By placing the LED strips every four chambers a 50 mm pixel pitch grid will be created. Out of every 9 m LED strip four or three cables are coming out: GND = Ground (close the circuit), Di= Data in (data input for the controller chips), (Ci= Clock in (to synchronize different parts of the circuit)) and +5V= Volts (power supply).

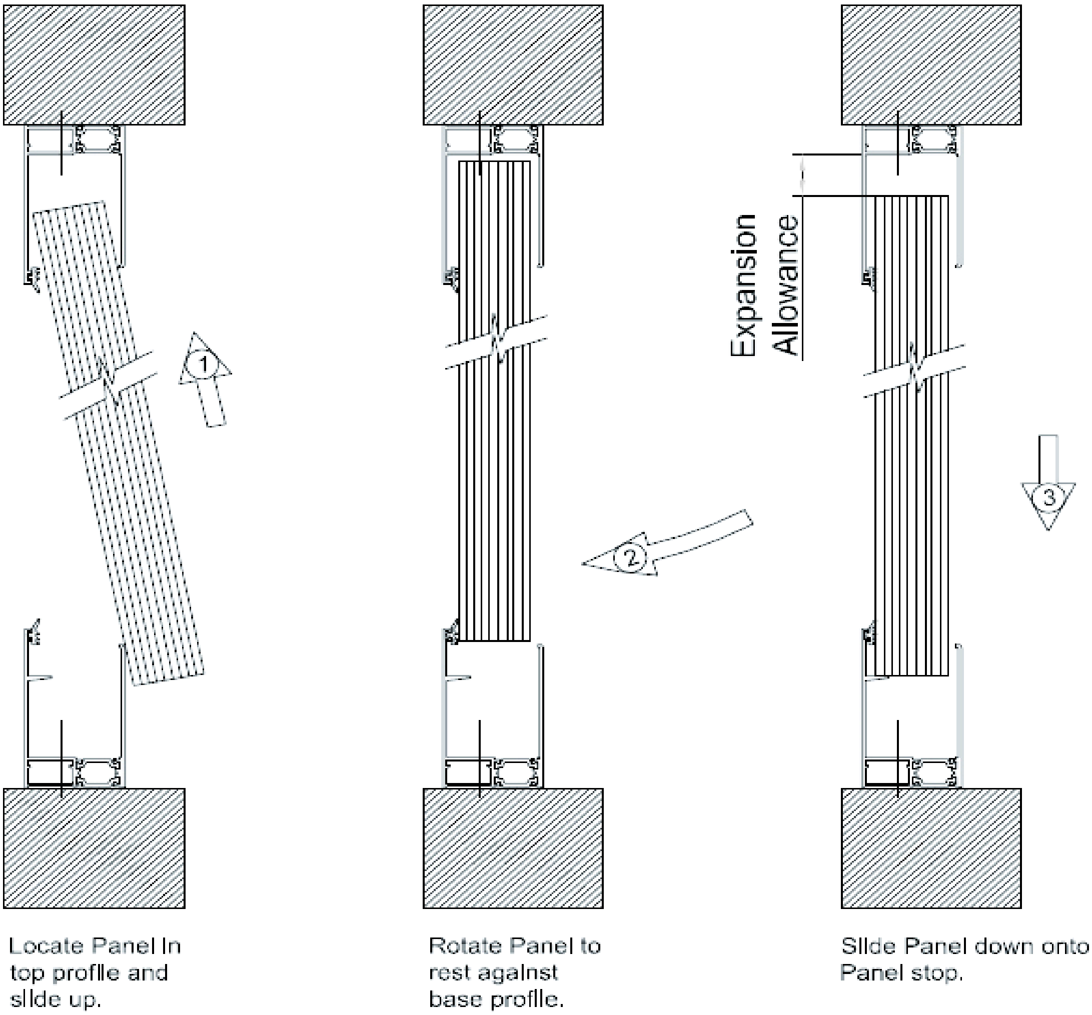
These cables are ending to a central hole with 20 mm diameter on the aluminium profile in the middle top of every panel of 1 m wide. In case the pixel pitch is denser or wider, the hole should be adjusted accordingly to fit the cables. Special consideration is given by allowing 50 mm extra cable due to thermal expansion of the polycarbonate sheets. Microcontrollers and data converted are mounted on the ceiling and covered with a suspended ceiling.

Polycarbonate facade needs a substructure to hold the panels in position. Vertical steel columns of H profile 100 x 100 mm are placed every 3 m along the interior of the facade. Intermediate horizontal bars of U profile 100 x 50 mm are fixed on the steel columns every 1,5 m. Without these bars polycarbonate panels would bend by wind pressure and weight. A special aluminium clip fixed with screws on the horizontal bars is used to keep two panels in position.



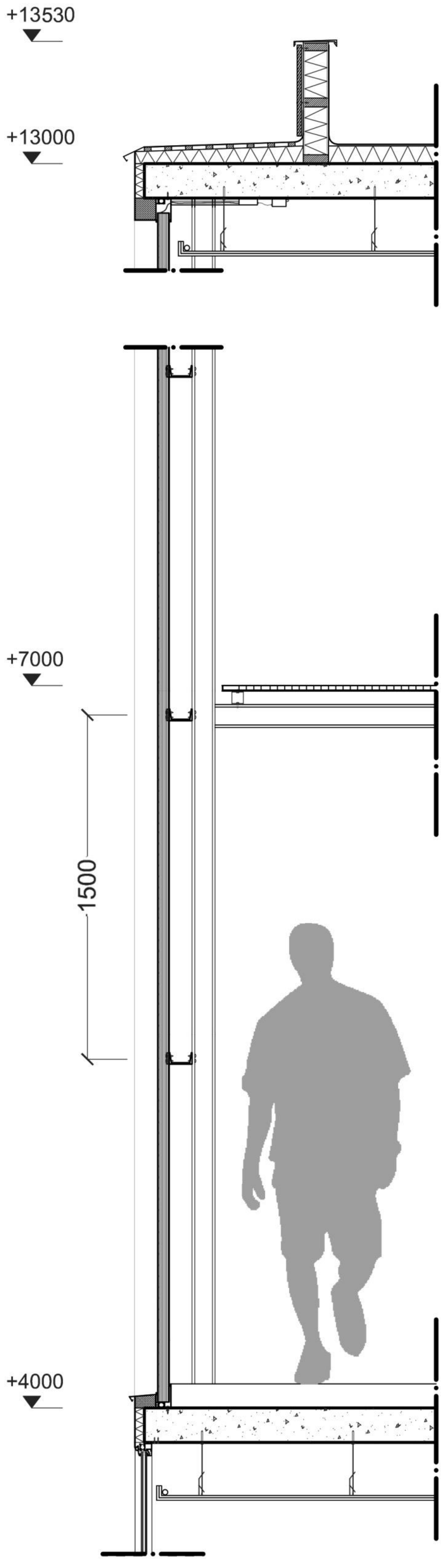
Two panels connected to each other and the component which keeps them attached to the horizontal bars

The way of assembling the facade panels can be done in 3 steps.

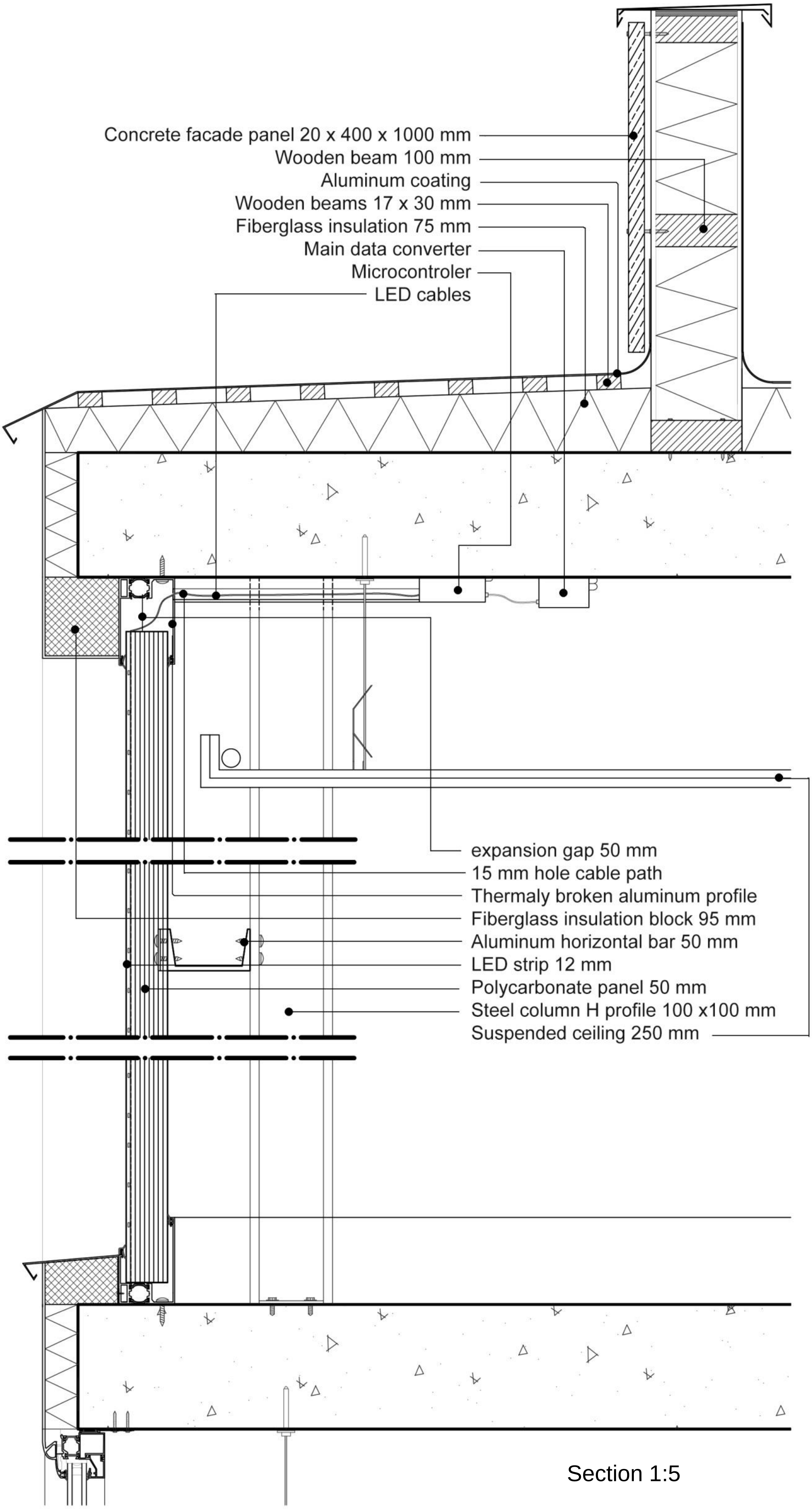


The three steps of installing the panels described by Marlon company

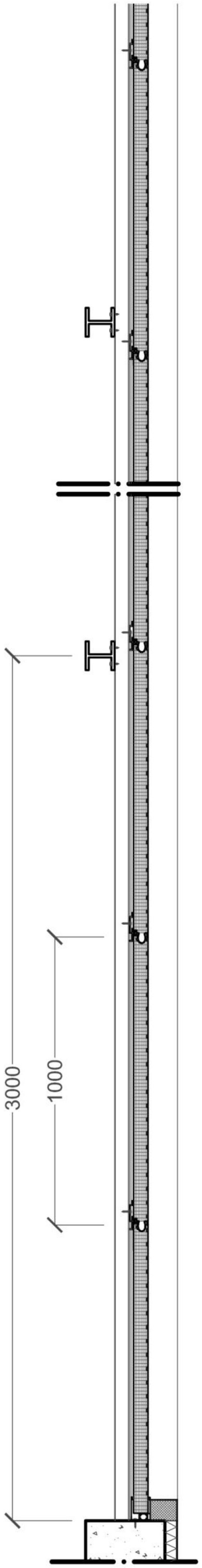
For best energy performance of building's skin thermally broken aluminium profiles 105 x 70 mm are chosen for the design. The down profile has the one edge lower in order to allow the sliding of the panel. The roof is covered with the proper insulation. In case a LED light is damaged, polycarbonate panel can be unclicked and LED strip taken out of the chamber to be fixed.



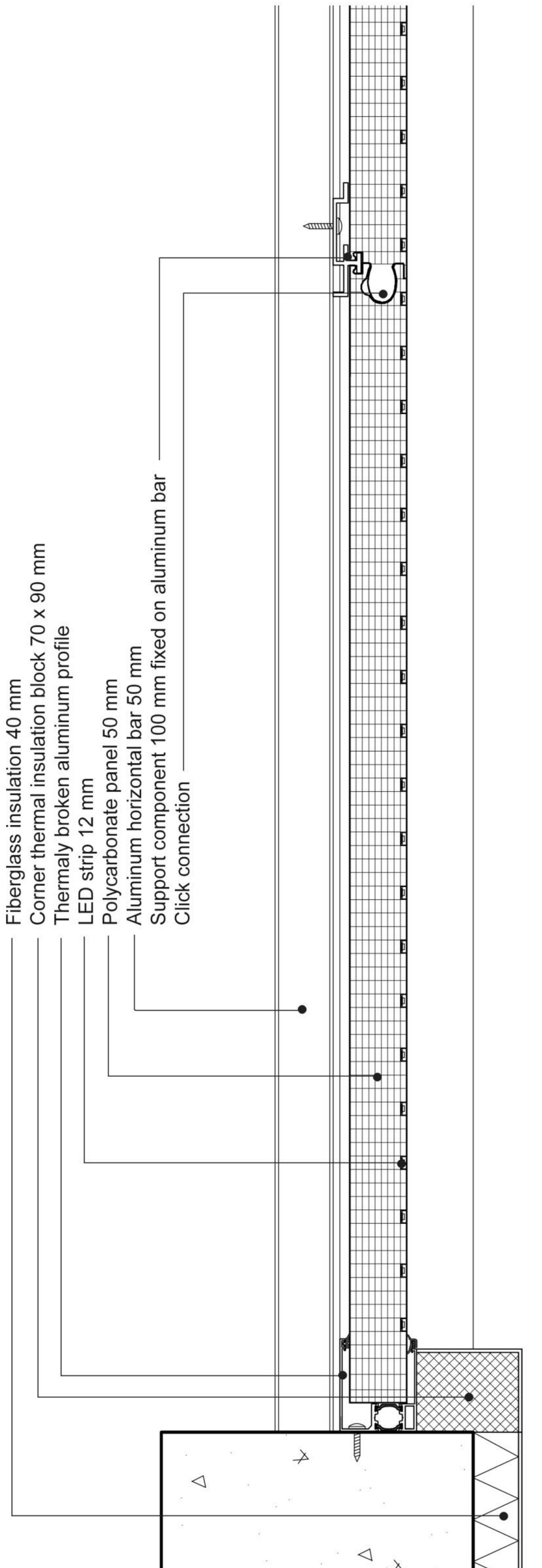
Section 1:20


Concrete facade panel 20 x 400 x 1000 mm
Wooden beam 100 mm
Aluminum coating
Wooden beams 17 x 30 mm
Fiberglass insulation 75 mm
Main data converter
Microcontroler
LED cables
expansion gap 50 mm
15 mm hole cable path
Thermaly broken aluminum profile
Fiberglass insulation block 95 mm
Aluminum horizontal bar 50 mm
LED strip 12 mm
Polycarbonate panel 50 mm
Steel column H profile 100 x100 mm
Suspended ceiling 250 mm

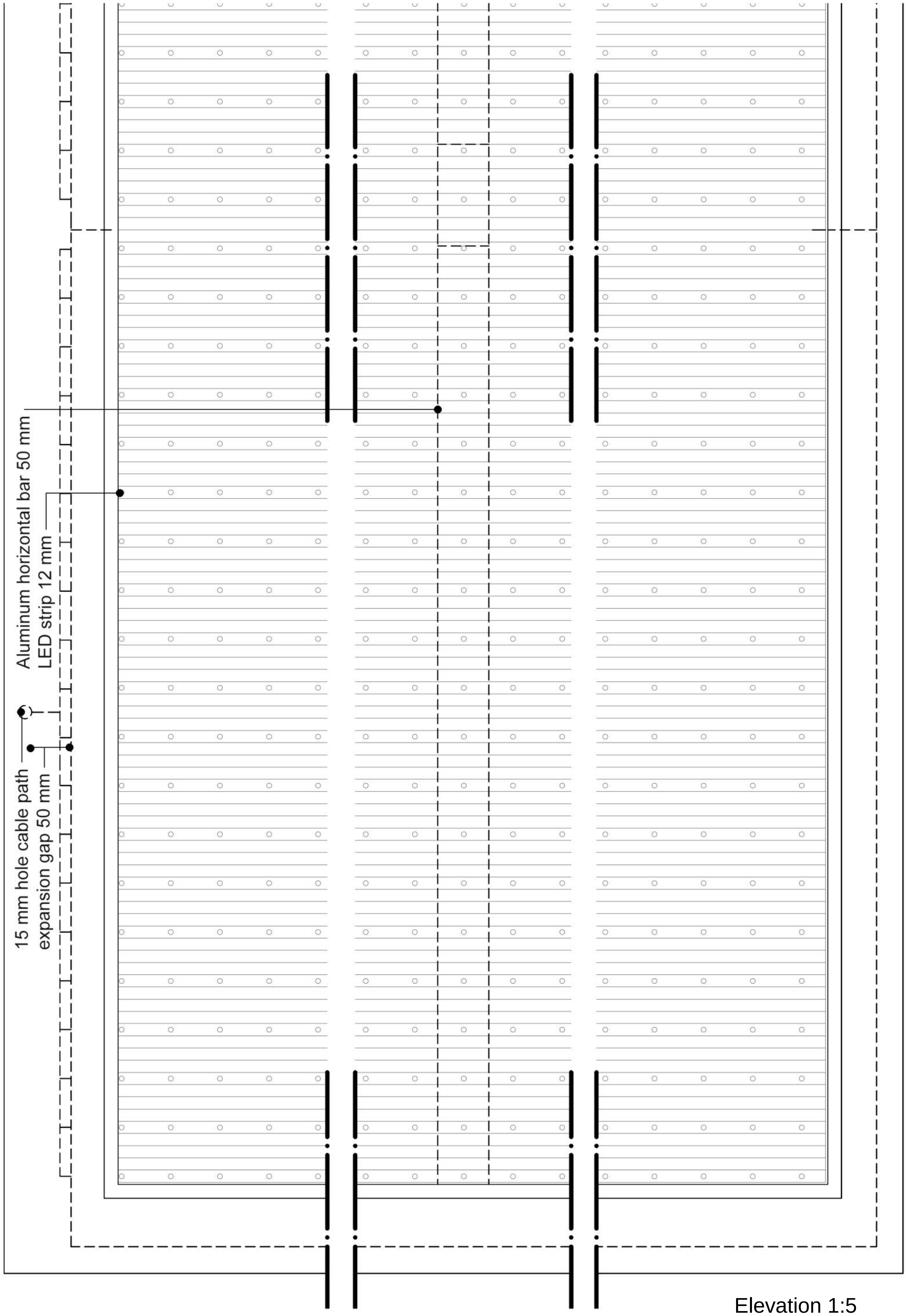
Section 1:5



Floorplan 1:20

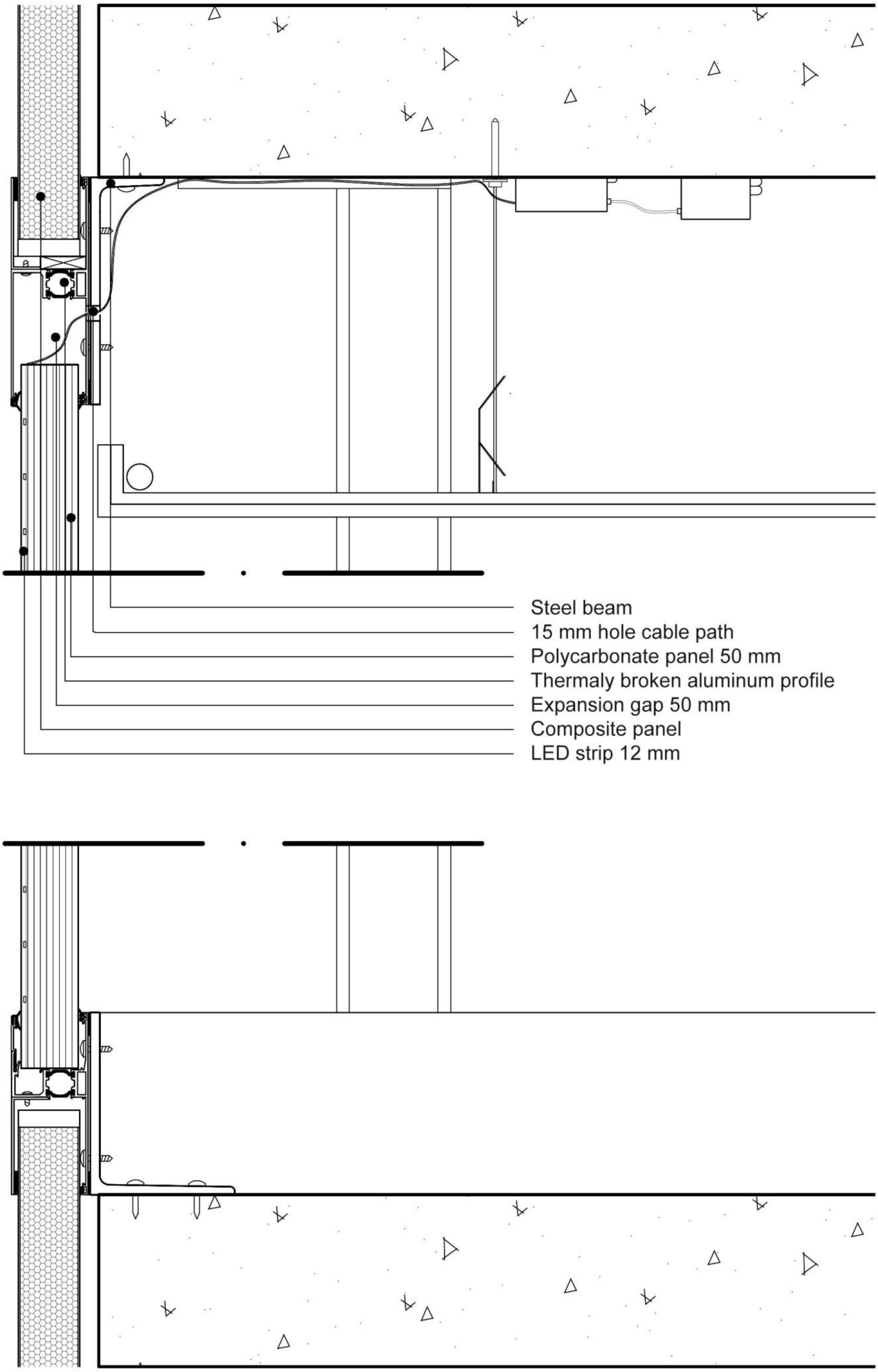


Floorplan 1:5

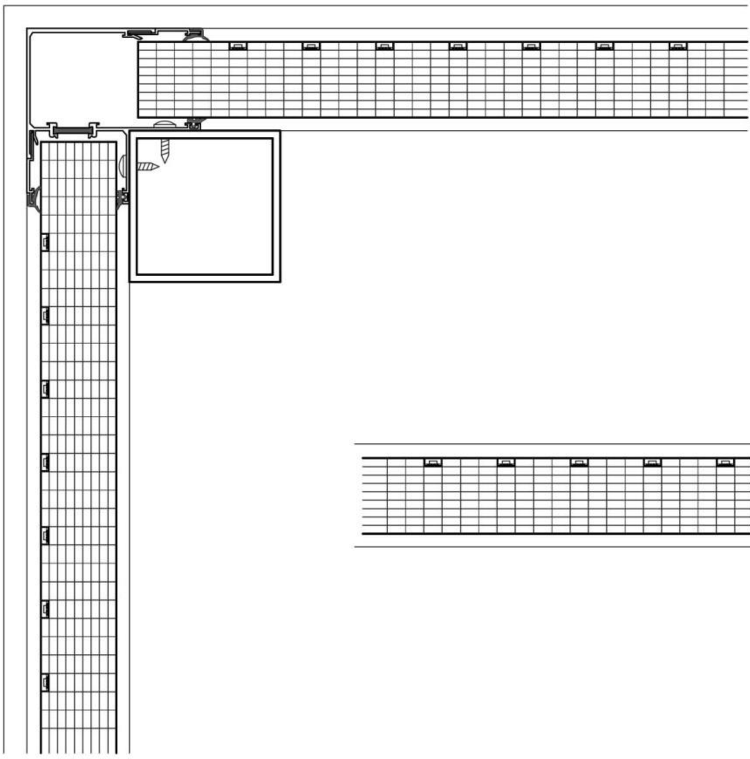


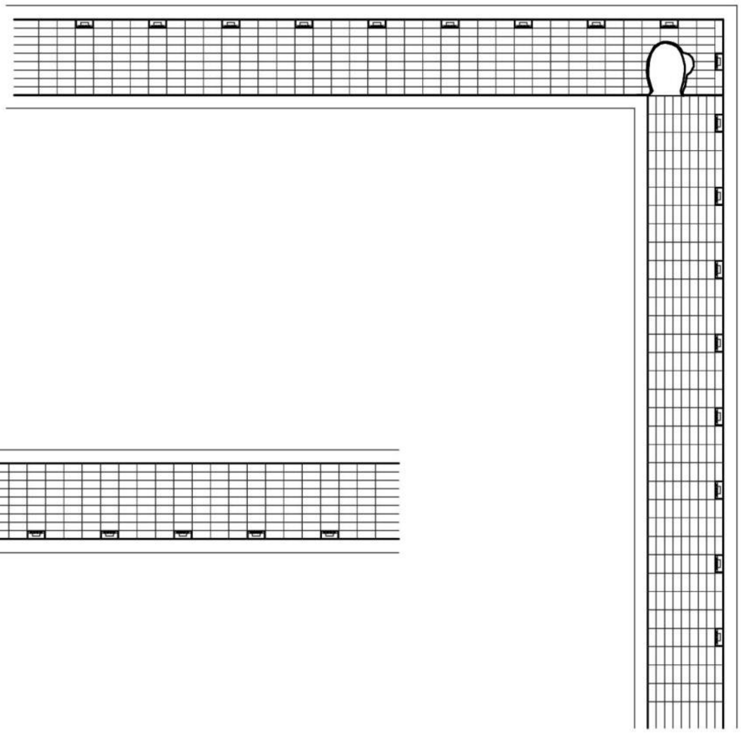
Elevation 1:5

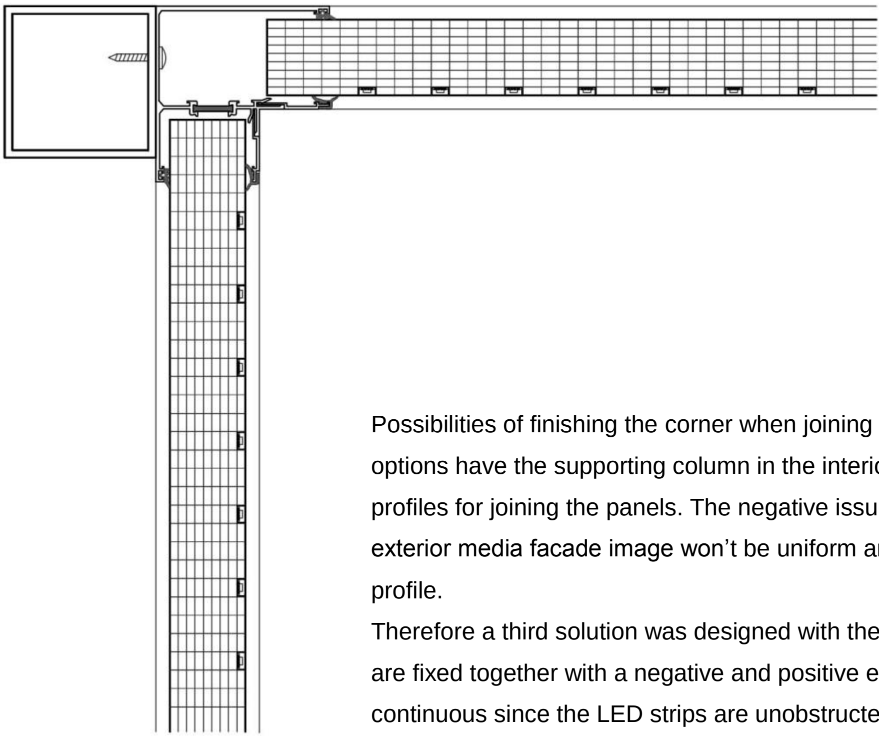
Combination of polycarbonate media facade panels and composite panels.



Section detail 1:5







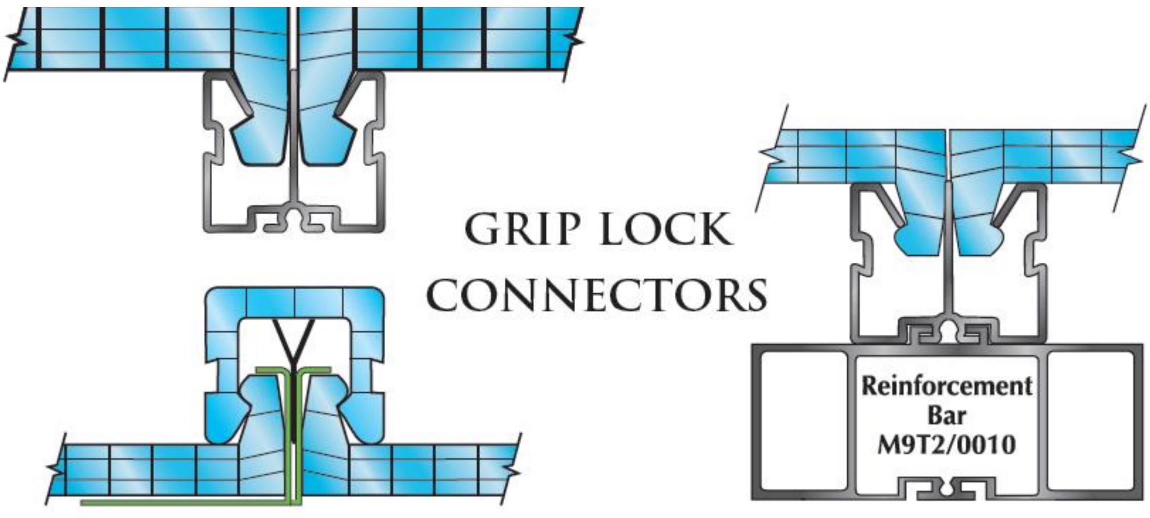
Possibilities of finishing the corner when joining two panels in 90 degrees angle. Two options have the supporting column in the interior and thermally broken aluminium profiles for joining the panels. The negative issue about these solutions is that the exterior media facade image won't be uniform and it is interrupted by the amulinum profile.

Therefore a third solution was designed with the click fix system where the two panels are fixed together with a negative and positive end. With this type the image is continuous since the LED strips are unobstructed by corner aluminium profiles.

Corner details 1:5

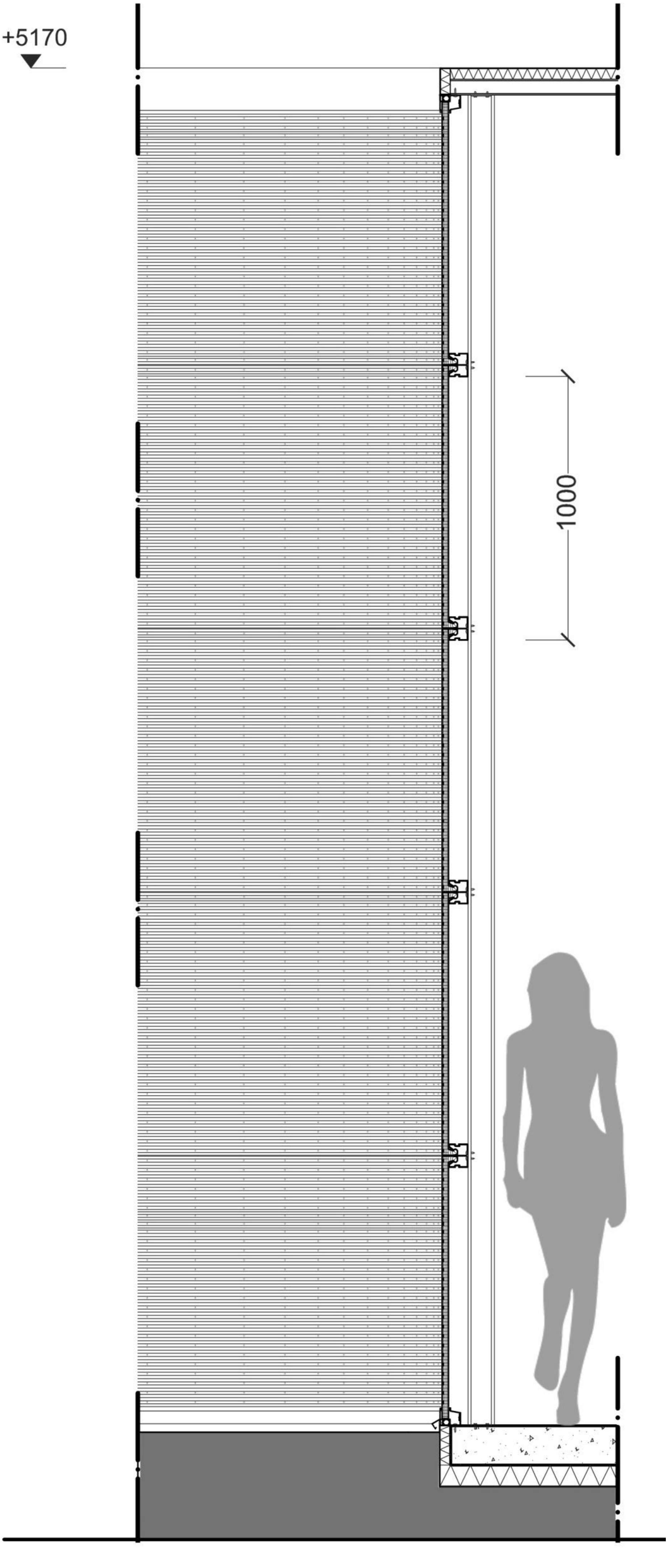
7.4 Polycarbonate media facade with horizontal curved panels

The second design was added to my thesis to prove that media facades are not only for vertical straight walls but also for curved. The main benefit of using curved screens for visual displays is that for known viewer position, a screen with the same physical screen size produces a wider field of view for a curved screen than a flat screen. This is because as the edges of the screen move closer towards to viewer, the field of view increases.
This effect provides a greater sense of immersion in the display environment and can improve visual perception due to the increased area of peripheral vision achieved. (http://www.immersaview.com/resources/why-curved)
Because of the curvature in the facade thinner panels were chosen for the media facade. 25 mm thickness can have a minimum bending radius of 8 m. So the panels have 1 m width for functional reasons again and length of up to 18 m because LED strips can be powered correctly only until this length. A different system is used here the ''grip locked''. In this system PCSS have from both sides on the edges two extrusions which are locking in aluminium, steel of polycarbonate profile. Aluminium profile is chosen because it can be produced curved continuously. These profiles are in every 1 m height and fixed on supporting columns H profile 100x100 mm every 3 m.

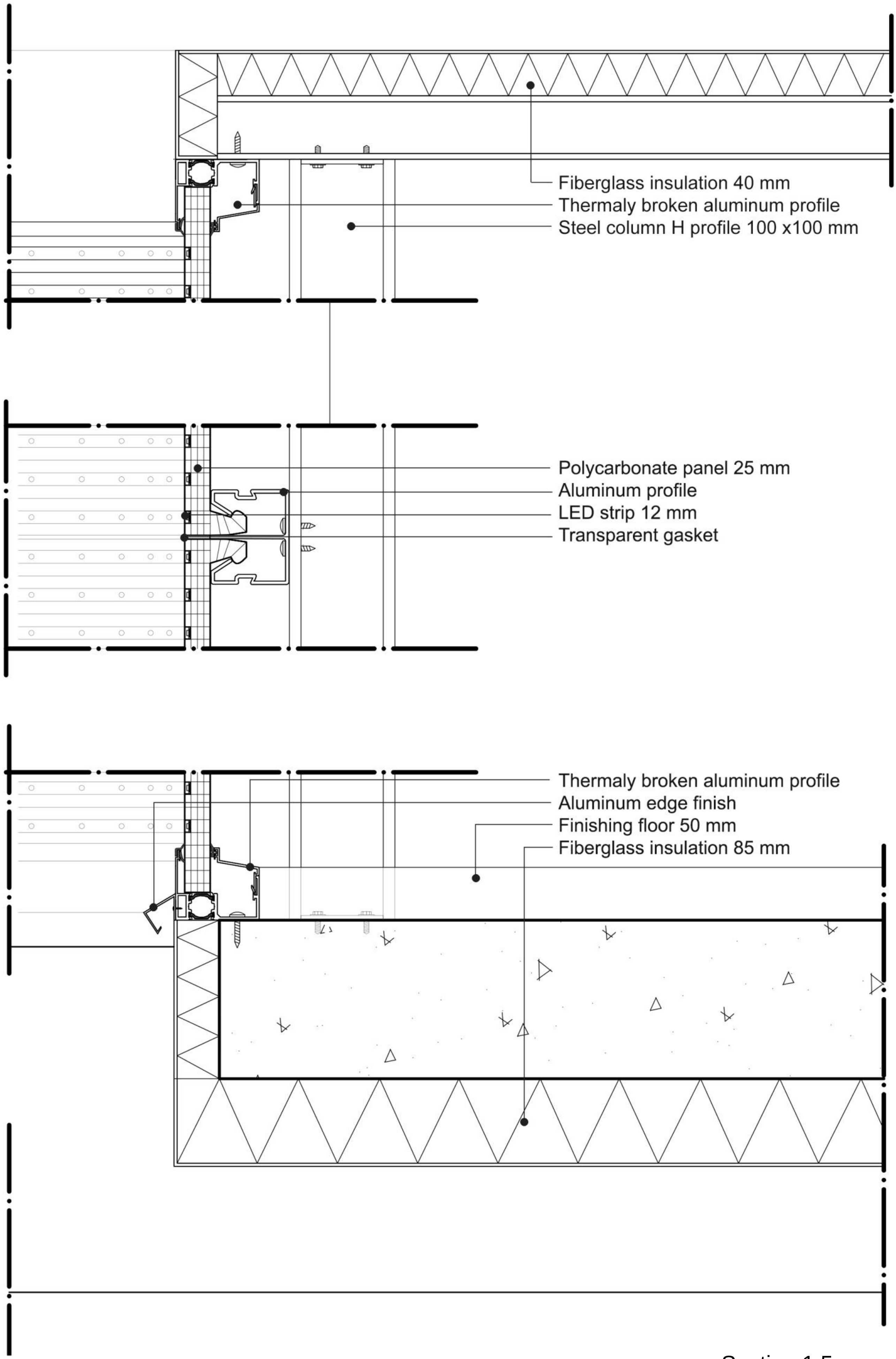


System illustrated by CO-EX Company

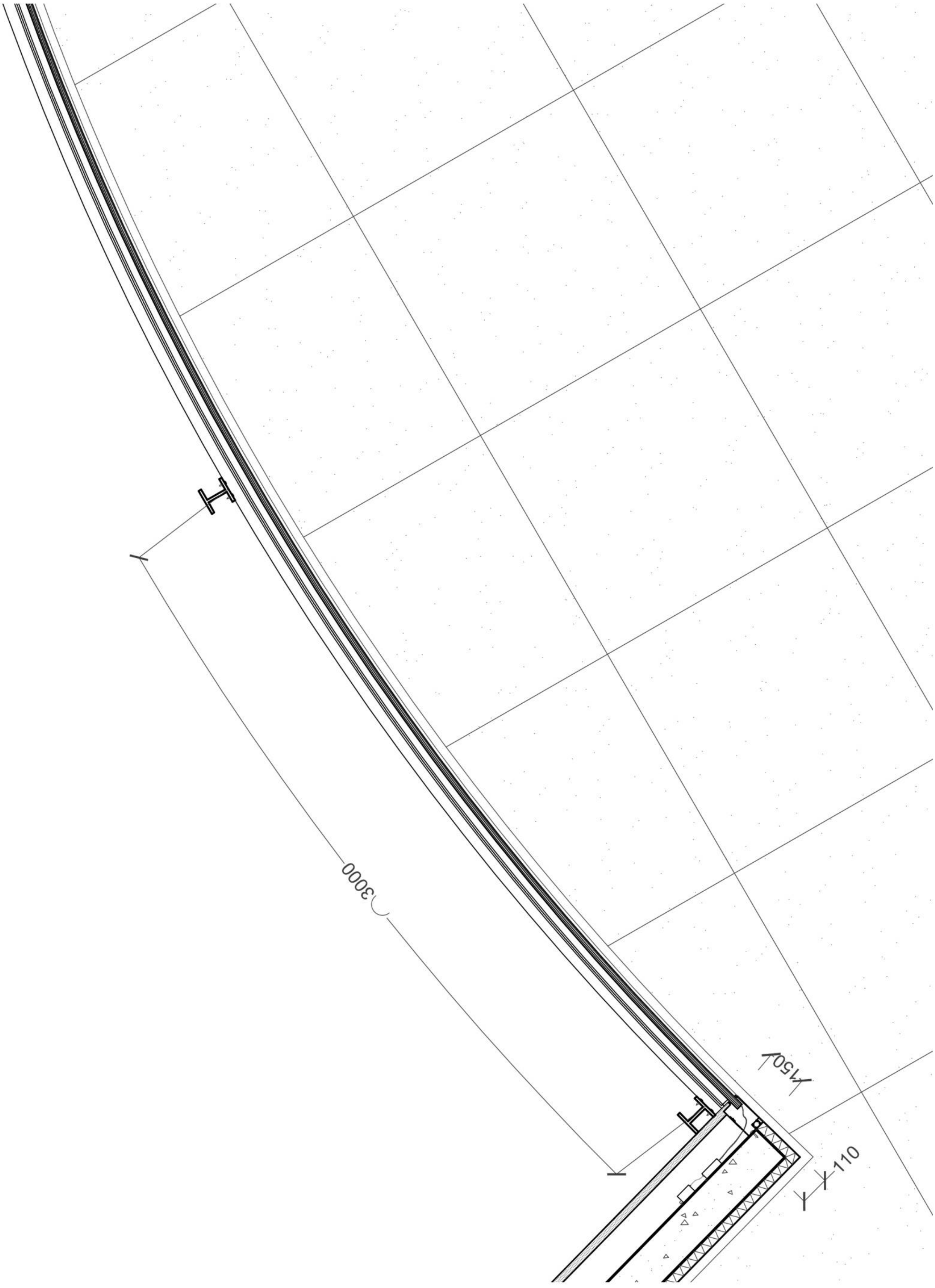
As far as the LED strips are concerned, here they run horizontally in the polycarbonate chamber. Cables and devices are on the side of the facade and covered with a gypsum board for aesthetic reasons. In this example the pixel pitch chosen is 25 mm because the facade is on the ground level and people are reaching it easily. Consequently, the minimum distance they can reach to have a clear image is 25 x 1400 = 35 m.



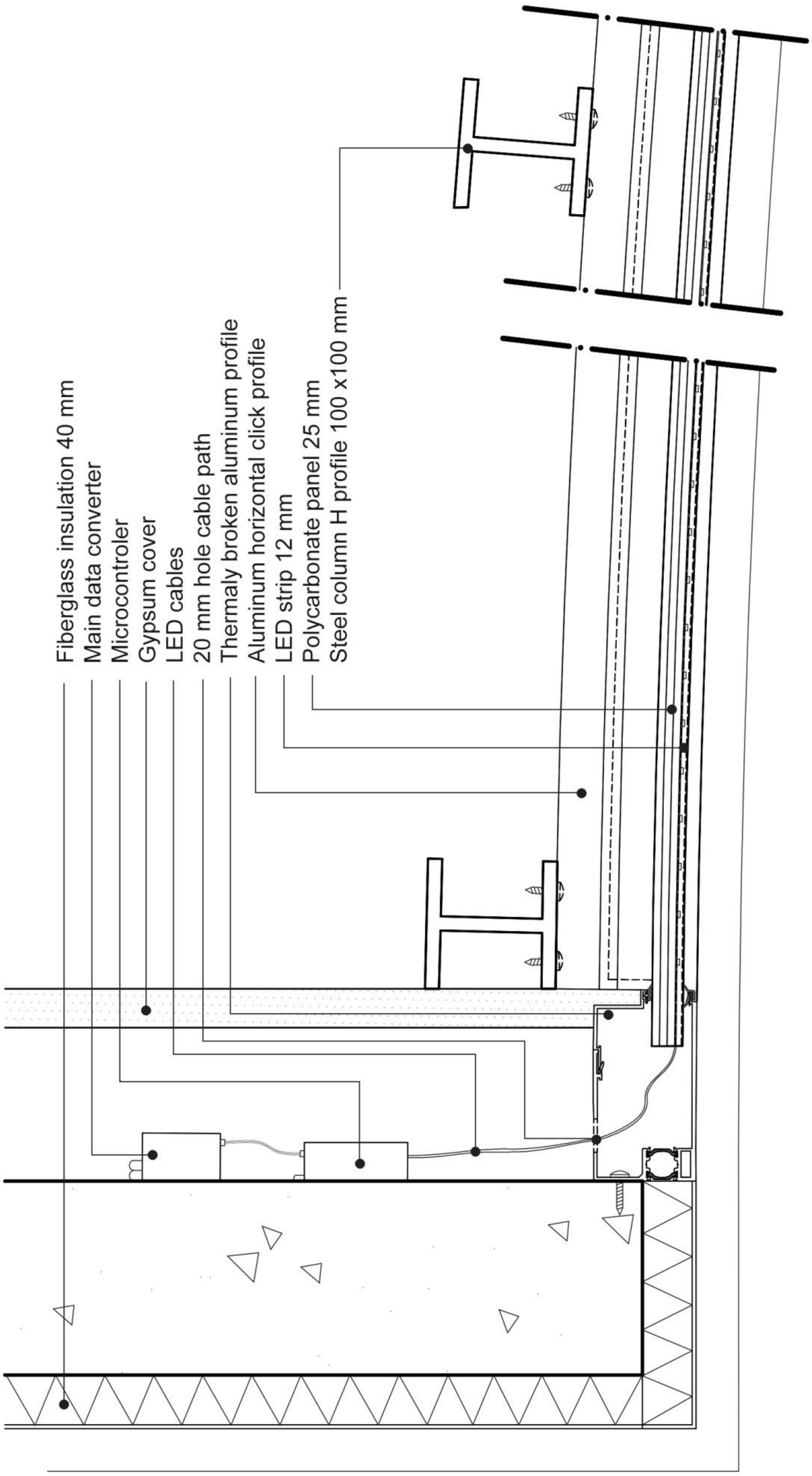
Section 1:20


Fiberglass insulation 40 mm
Thermaly broken aluminum profile
Steel column H profile 100 x100 mm
Polycarbonate panel 25 mm
Aluminum profile
LED strip 12 mm
Transparent gasket
Thermaly broken aluminum profile
Aluminum edge finish
Finishing floor 50 mm
Fiberglass insulation 85 mm

Section 1:5



Floorplan 1:20



Floorplan 1:5

7.5 Visualisation-Sketch designs

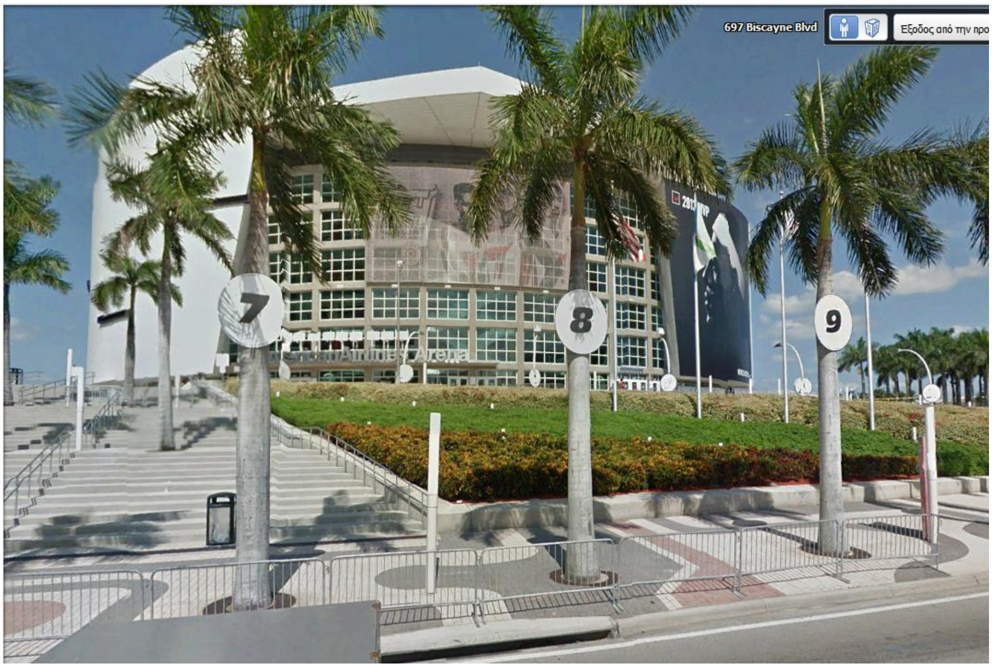
7.5.1 Rollecate warehouse in Staphorst

The first sketch design and visualisation is according to the technology used for the 50 x 50 mm pixel pitch. By comparing media facades with the same pixel pitch and light intensity like in Miami and Milan made by GKD we tried to illustrate the result in a supposed warehouse of Rollecate in their base in Staphorst. The media facade could be used for social and cultural messages promoting the local tradition as a touristic attraction.

Media mesh facade using 50 x 50 mm pixel pitch in Italy by GKD
(http://www.gkdmediamesh.com/applications/mediamesh.html)

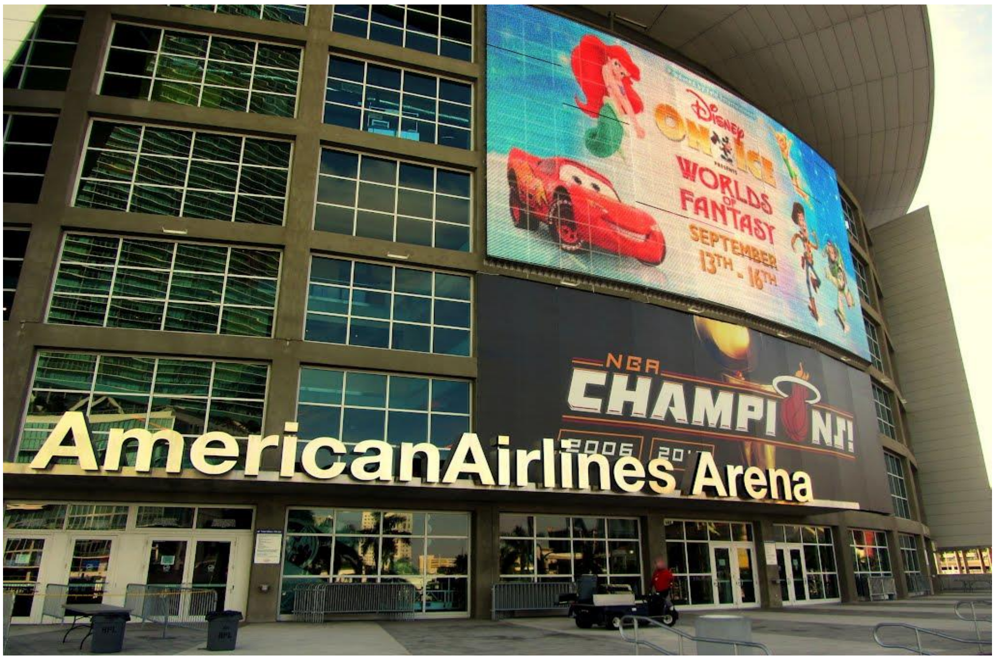
Media mesh facade using 50 x 50 mm pixel pitch in Miami by GKD view by 20 m
(http://www.gkdmediamesh.com/applications/mediamesh.html)

Miami American Airlines Arena
(6000 nits) west facade
50 mm pixel pitch from 70 m
viewing distance-direct sunlight



Miami American Airlines Arena
50 mm pixel pitch from 90 m
viewing distance afternoon

Miami American Airlines Arena
50 mm pixel pitch from 35 m
viewing distance afternoon



Day situation of the suggested facade advertising buildings made by Rollecate. Viewing distance 50m

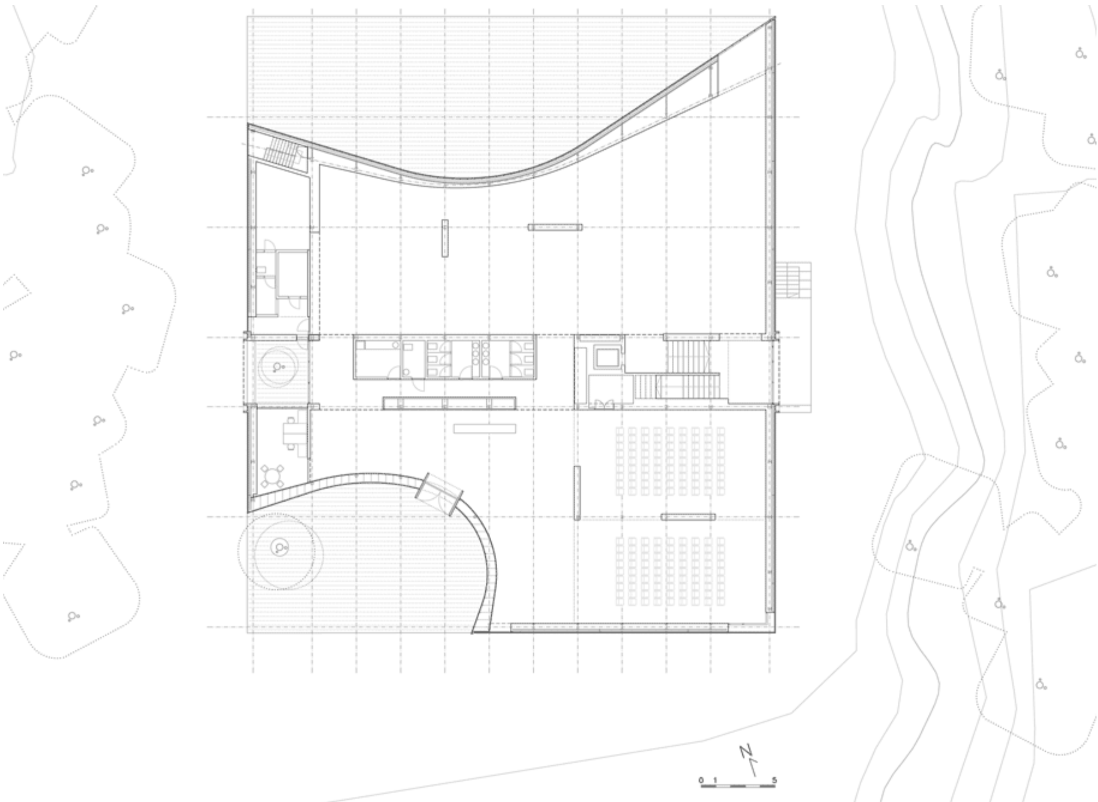
Night situation of the suggested facade advertising culture of Staphorst. Viewing distance 50m

Possible application in the case study office building in Staprhorst. View from the motorway which means 120m viewing distance

7.5.2 The Museum of Energy, Spain

The second design is based in a curved facade of polycarbonates. The building in which we chose to represent the 25 mm pixel pitch is the ‘’Museum of Energy in Spain’’. Designed by Girona studio Arquitecturia, the museum near Tarragona is wrapped in vertical lengths of black-painted steel and features a tall window framing a central row of double-height rooms. Two curved terraces dissect the rectangular plan to create the two concave walls, which are clad in translucent polycarbonate.

Elevation view of the museum with the curved surface of polycarbonates (http://www.dezeen.com/)



Floorplan of the museum with the two curved polycarbonate facades (http://www.dezeen.com/)

Media facade with denser pixel pitch of 25 mm because users are getting closer to the screen. Viewing distance 30m

7.5.3 Picadilly Circus, London

Piccadilly Circus was surrounded by illuminated advertising boards on buildings since the early 1900s. The earliest signs used incandescent light bulbs and in the 2000s there was a gradual move to LED displays, which completely replaced neon lamps by 2011. The number of signs has reduced over the years as the rental costs have increased. As of 2014, the site has six illuminated advertising screens above three large retail units facing Piccadilly Circus on the north side and a mix of smaller retail, restaurant and office premises fronting the other streets (http://en.wikipedia.org/wiki/Piccadilly_Circus).
A place like this was chosen to visualise the concept of polycarbonate media facade in a crowded place with curved buildings which are forming a square. In a similar way with the second design suggestion, the only difference is the mirroring of the aluminium profiles with the curve to the exterior; an interesting media facade can be created.

The illuminated signs of Piccadilly Circus by day, January 2014 (http://en.wikipedia.org/wiki/Piccadilly_Circus)

25 mm pixel pitch polycarbonate media facade in Piccadilly Circus. Viewing distance 30m

8. CONCLUSIONS

8.1 Evaluation of the design

After completing the design stage we can come in some conclusions concerning the final product of the polycarbonate media facade.
First of all this media facade is environmentally friendly. The ability to separate LED strips from the polycarbonate sheets easily by just sliding them out does not require special procedure, technique like integrated LEDs in laminated glass. The process of extruding multiwall polycarbonate involves very low energy consumption and has a minimal impact on the environment. Polycarbonate is an energy-efficient solution and is 100% recyclable at the end of its life. The use of multiwall polycarbonate can also qualify for LEED credits (http://www.bpf.co.uk/).
In addition, the problem of the maintenance being solved is very important. By simply pulling out the LED strip from a panel damages can be fixed without the need of replacing a whole panel or follow a difficult procedure. The click-fix system offers a reversible solution.
Furthermore, it is obvious a cheaper solution compared to all the other types of media facades, except projection. By using cheaper material, polycarbonate instead of glass, lighter material which means less structural system supports and profiles, simplest and quicker assembly procedure which saves cost and time it can be characterised as a cheap media facade solution.
In order to prove the cheaper advantage we made some calculations relating to the construction of the media facade and compared it with the results of the research we made in the beginning.

Straight panels media facade 50 mm thickness and 50 mm pixel pitch
Addressable RGB LED strips from 3 Dutch suppliers cost 20 €/m (http://ledstripcenter.nl/), (http://ledstrip-specialist.nl), (https://www.ledstripxl.nl/)
Polycarbonate facade panel from Rodeca PC 2550-10 costs 100 €/m^2 (installations included)
In 1 m^2 of our facade we have 21 m of LED strips so a total cost of 21 x 20= 440€/m^2
The plastic U shaped channels are also 21 m and they are very cheap while searching for suppliers. A representative price is 0,5 €/m so 21 x 0,5= 10,5 €/m^2 (http://www.joymace.com/)
Consequently for our facade 100 + 440 + 10,5 = 550,5 €/m^2
Our facade is 9 x 18 m = 162 m^2
So a total price would be 89.100 €

- If we compare it with GKD a typical price for a mediamesh façade will be 5.000 – 6.000€/m².

The results are impressive giving that our product is 10 times cheaper.

- If we compare it with Leurocom a price for over 42 mm pixel pitch is 4.500€ /m²

The results are again impressive giving that our product is 8 times cheaper.
Going to Rollecates offers and costs we saw that Philips for a 50 mm pixel pitch offered 212.688 €.
With our product in the 13 x 8 m facade or Rollecate's building it will cost 104 x 550,5 €/m^2 = 57.252 € which is almost 4 times cheaper.
With the pixel pitch of 25 mm which means 2 times better resolution than the previous example the polycarbonate facade for Rollecate would cost 104 x 1110= 115.440 € which is again cheaper than the 42 x 45 mm pixel pitch offer by Brakel Atmos = 150.000-200.000 €. Almost 35 % less price for bigger area on the facade than the 32 m^2.

Curved panels media facade 25 mm thickness and 25 mm pixel pitch
The cost of the Addressable RGB LED strips is the same but the pixel pitch is denser so double strips per m^2 so 550,5 €/m^2 x 2 = 1101 €/m^2
Polycarbonate facade panel from Rodeca PC 2625-5 costs 75 €/m^2 (installations included)
The cost of the U shape is also doubled so 10,5 €/m^2 x 2 = 21 €/m^2
Consequently for our facade 1101 + 75 + 21 = 1197 €/m^2
Our facade is 5 x 18 m = 90 m^2
So a total price would be 107.730 €
Another privilege of the design is the versatile concept of adjusting the pixel pitch according to clients' needs easily. LEDs are independent from the polycarbonate structural sheets, as long as the interior chambers are more than 12 mm wide. Pixel pitch can be adjusted starting from 12 mm horizontally. The resolution compared to other materialised media facades is very good given that the LEDs at full brightness emit 14 nits and the pixel pitch is enough for a clear image like the media facades in Miami, Milano or New York.
The versatile character of this media facade can be also observed in the variety of geometries and dimensions in which PCSS can be produced. This offers the ability of curved inwards or outwards surfaces, straight facades or under an angle.
Polycarbonate structural sheets have many applications in Germany, the Netherlands and in USA. This means that it is a product under demand and being used often for cheap facade solutions. Rodeca, which is one of the leading companies in PCSS, has materialised only in Holland more than 50 projects. By integrating LED strips the product is upgraded and can add more value to the market.
As the technology evolves, both polycarbonates and LEDs can have a bigger lifespan which will add value to the product. Already in the PCSS the addition of special UV protection layers increases their lifespan from 10 to 20 years and the LEDs have proven under ideal

conditions that they can reach 100.000 hours working life. So in the future we expect better performance.
On the other hand, this design has some facts which cannot be change and avoided. The most profound is the issue of transparency. Compared to glass polycarbonates do not offer a clear view even in the transparent state. The daylight pass in the space is restricted and this affects the users when it is especially an office building. This is a clear excuse for a client to not prefer polycarbonate compared to glass.
Moreover, the life expectancy even if it is 20 years it has a limited use time. After this period, the facade must be replaced like it happens with the LEDs. This might be a mixed blessing because in twenty years from now the technologies will have change dramatically and new products in the electronics will be available.
Finally, a clue that proved to be difficult to define is the relationship between pixel pitch (resolution) and users viewing distance on the media facade. Citiled and GKD are giving almost the same number of meters for viewing distances for the same pixel pitch while Philips demands longer viewing distance.
Thus, only a testing model of 1:1 scale would give the answer to the problem, something also that the media facade companies are suggesting to the clients always.
All in all, the result of the evaluation comes out positive by presenting a product competitive to the market and realistic. It was achieved to create a cheap and simple solution for the media facade world.

8.2 Rollecate's feedback on the design

During my graduation project Rollecate's experts and especially, Products Manager Daniel Nijboer and Project Leader Siebe Wassenaar, were close to me by offering their crucial feedback on my design and their knowledge on the facade engineering aspects. Therefore, I considered very helpful of them to give an overall critic to my design.

After a close discussion they were positive about the whole idea in terms of feasibility and reality. They addressed that it is important that a cheaper product for media facades has being invented but though with some limited characteristics.

As a facade company Rollecate has never used PCSS for their projects considering glass superior. Polycarbonate is a material which is not ideal for high-rise buildings with facades which need to cope with strong wind loads. Structural glass is more in favour for such applications.

On the other hand the idea of using the polycarbonate media facade for logistics, storage houses and low rise buildings is more appropriate. By integrating LEDs in the PCSS the product is upgraded and attracts clients' attention to try it.

Furthermore, there were comments in the technical part of the design. The horizontal beams which are supporting the facade polycarbonate panels are fixed only with bolts on the click fix components. The addition of 3M VHB tape between polycarbonate panels and horizontal beams would improve the loading distribution by wind pressure. 3M VHB structural bonding tape is a pressure-sensitive adhesive tape that bonds on contact and when heat-cured develops a structural strength bond.

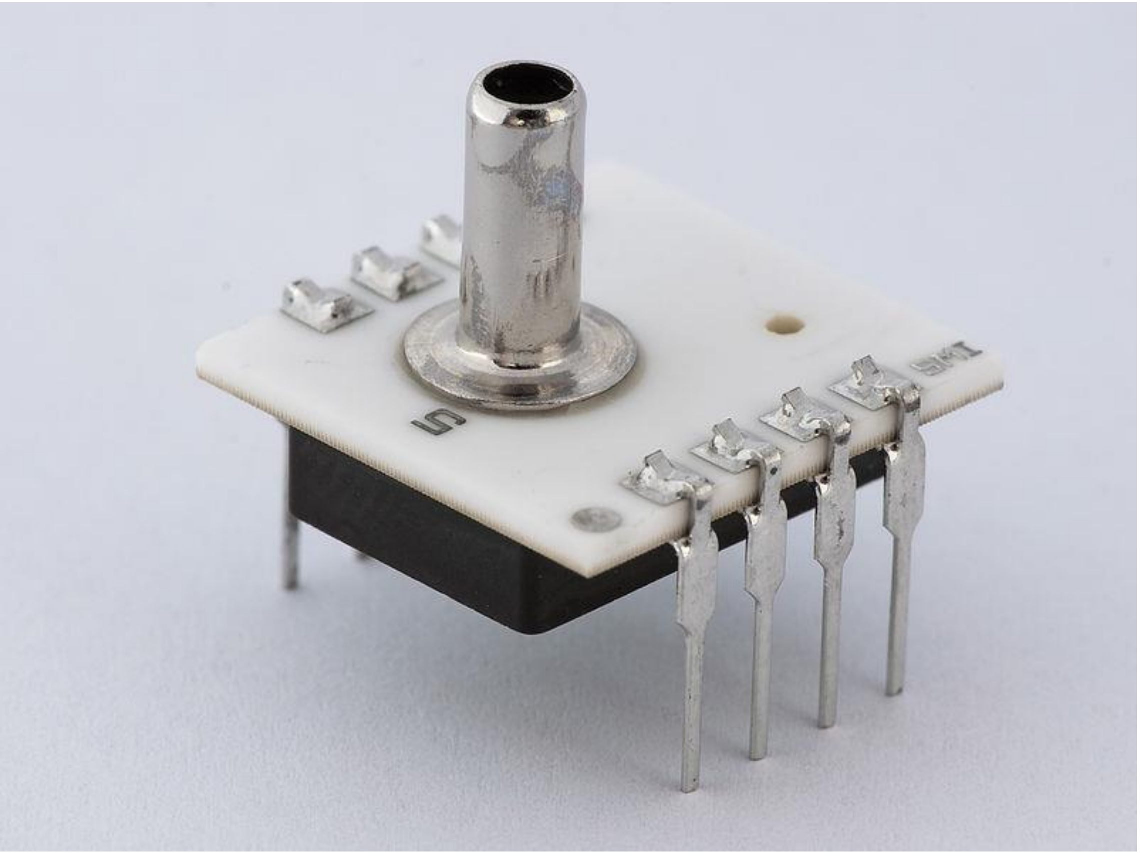
Another aspect which needs special consideration is the condensation which might occur in the chambers of polycarbonate due to temperature differences out of and in the panel, if the facade is not ventilated properly. The air in the polycarbonate would be warmer than that on the outside so maybe a special tape on top and bottom to close the panels, or a special cap will do the job. This though is affecting the free exit of the cables.

9. FURTHER SUGGESTIONS - NEXT STEPS

In order to complete this master thesis, I considered important to include in my report further suggestions for improvements on the final design product which can broaden the market demand. For me it was a new experience to get involved in the world of electronics with LED and OLED lighting. Furthermore, the most challenging was the integration of them in a facade component.

It is reasonable that things which are explored and tested for years and being solved after many difficulties in the media facade industry cannot be produced in a six months period to a perfect extent by a student who is researching the topic for the first time. There is always space for next steps which would upgrade the product.

The first suggestion can come from inspiration by projects with LED interactive tiles. These are interactive LED elements that react to the location and movements of objects and persons using pressure or motion sensor technology. The first technology is based in pressure sensors which measure pressure usually of gases or liquids. Optical pressure sensing techniques include the use of the physical change of an optical fibre to detect strain due to applied pressure. This technology is used in challenging applications where the measurement is highly remote, under high temperature, or may benefit from technologies inherently immune to electromagnetic interference. Another analogous technique utilizes an elastic film constructed in layers that can change reflected wavelengths according to the applied pressure (https://www.repository.cam.ac.uk/handle/1810/225960).

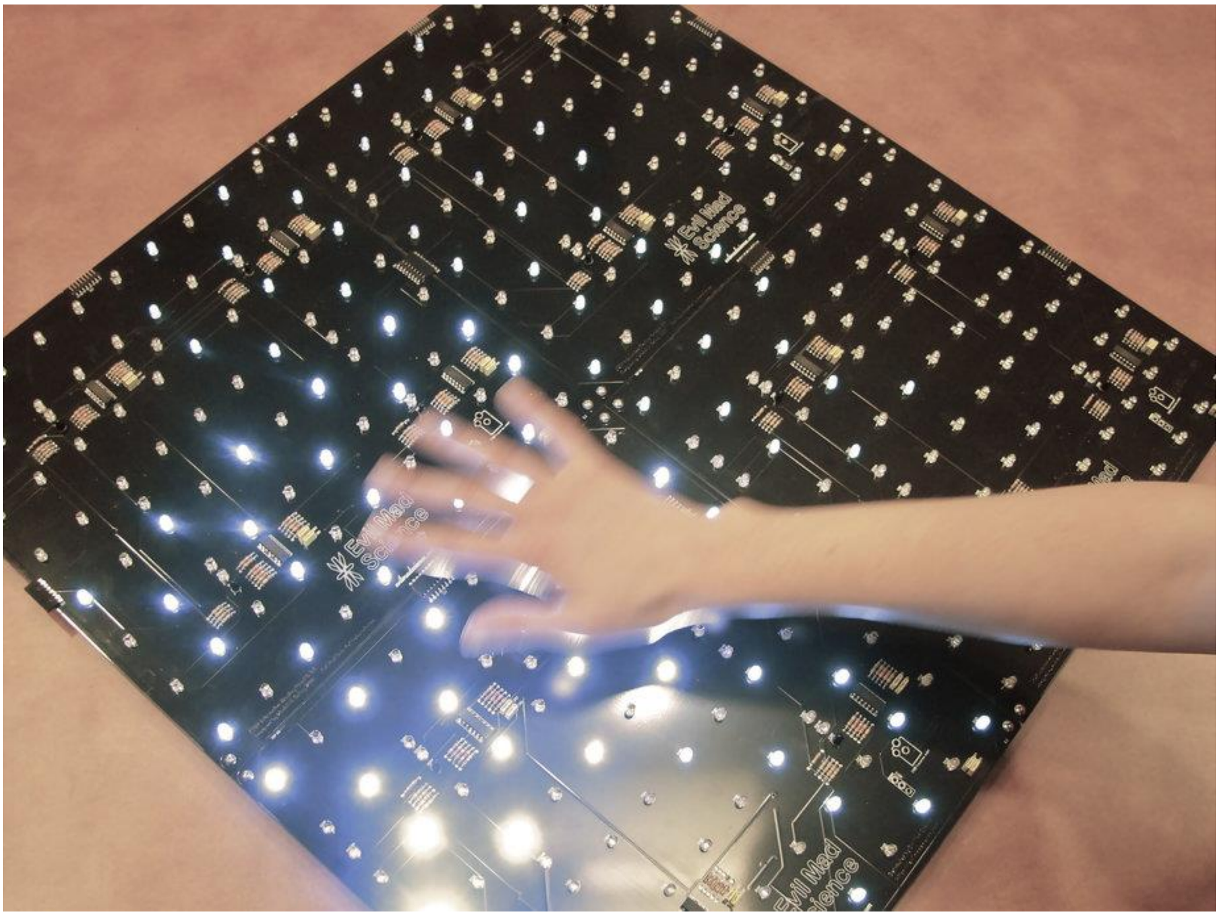


Digital gauge pressure sensor for medical purposes from Silicon Microstructures (http://en.wikipedia.org/wiki/Pressure_sensor)

Coming back to the LED tiles they measure 100 x 100 mm and have integrated software that allows accessing each individually. By touching the wall the tile responses to the pressure by illuminating light.

Interactive LED wall with touching concept (http://www.futurefeeder.com/)

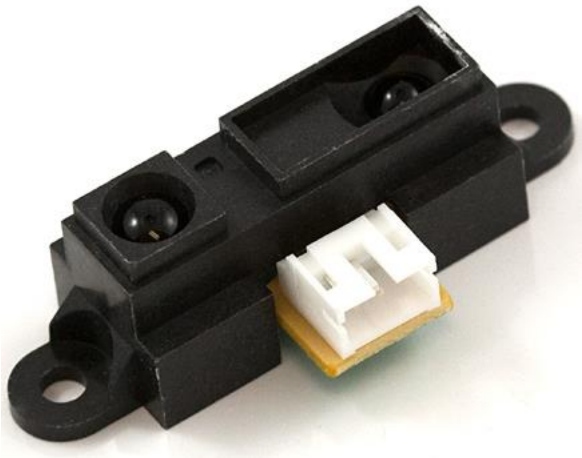
Another example of interactive facade tiles is this with motion sensor nodes. These panels are 305 x 305 mm, with 80 ultra bright white LEDs arranged on a regular grid. Each has four motion sensor nodes which control the 80 LEDs.



Four panels connected together to form a screen (http://shop.evilmadscientist.com/productsmenu/majors/46)

Closer view of the panel with the connection chips and the motion sensors (http://shop.evilmadscientist.com/productsmenu/majors/46)

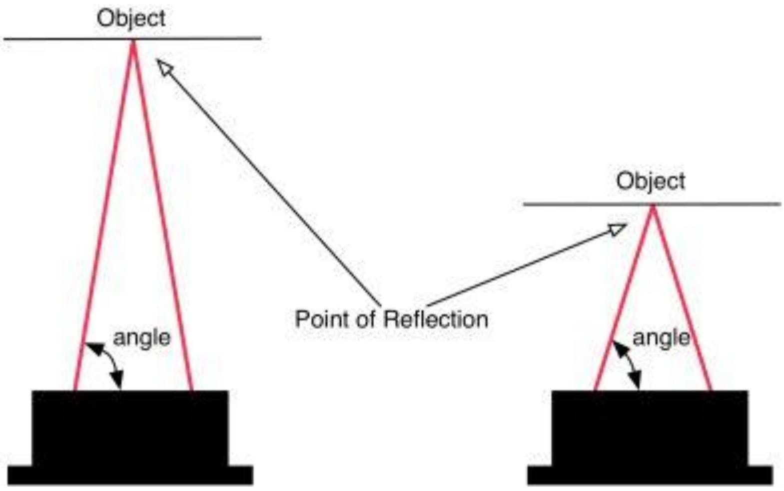
Usually there are two types of motion sensors used in applications for capturing people's presence. The first type is the infrared proximity sensors which are having one IR emitter and one IR receiver. An infrared emitter is a source of light energy in the infrared spectrum that is used in order to transmit infrared signals from a remote control. The light rays emitted are reflected on the object and then the IR receiver gets the signal for the presence of the object by translating it to a command for LEDs.



An IR proximity sensor (http://www.robot-domestici.it/)

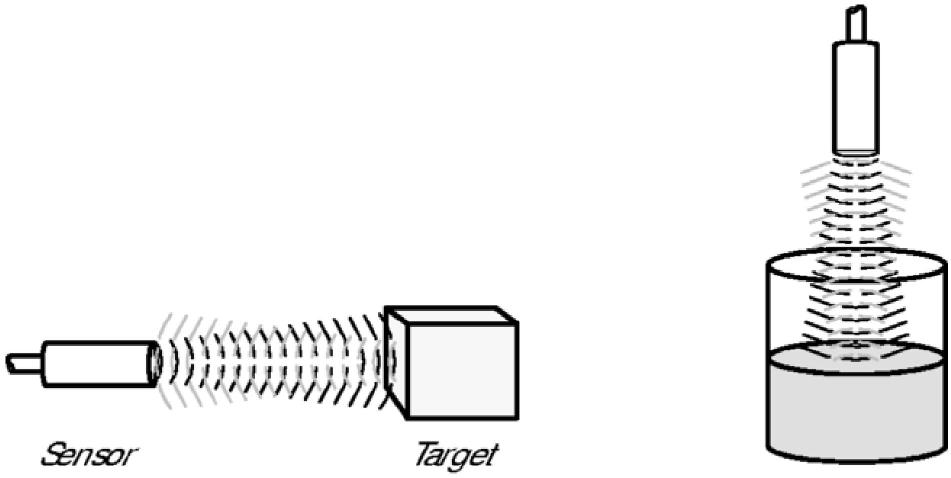
A PIR proximity sensor which can be mounted on a LED strip (http://www.instructables.com/)

The limitation of the IR proximity sensors is that they are appropriate only for short distance motion detections, usually lower than a meter.



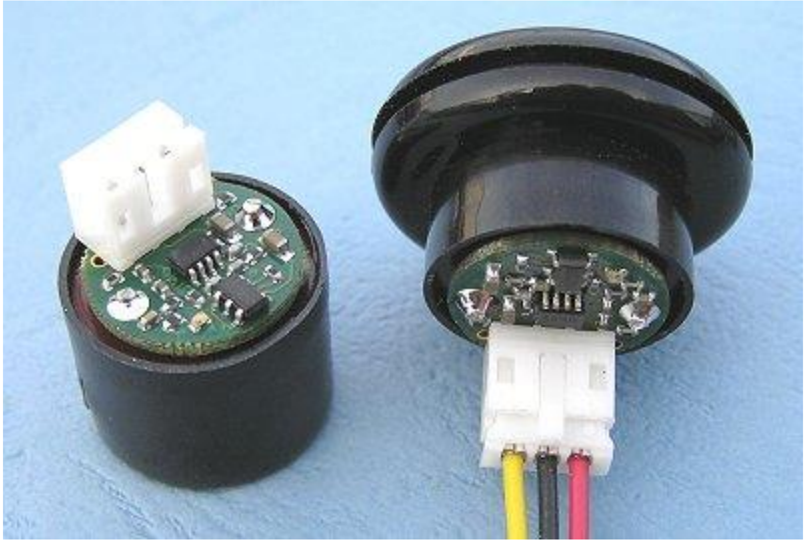
Sharp IR detector angle of reflection arrival for near and far object (http://www.acroname.com/)

The second type of motion sensors is that of ultrasonic proximity sensors. They use a piezoelectric transducer to send and detect sound waves. The transducer generates high frequency sound waves and evaluates the echo by the detector which is received back after reflecting on the obstacle. Sensors calculate the time between sending and receiving the echo to determine the distance of the object. When the object enters the operating range the output switches.



Sound waves echoing off of solid and liquid targets (http://ab.rockwellautomation.com/)

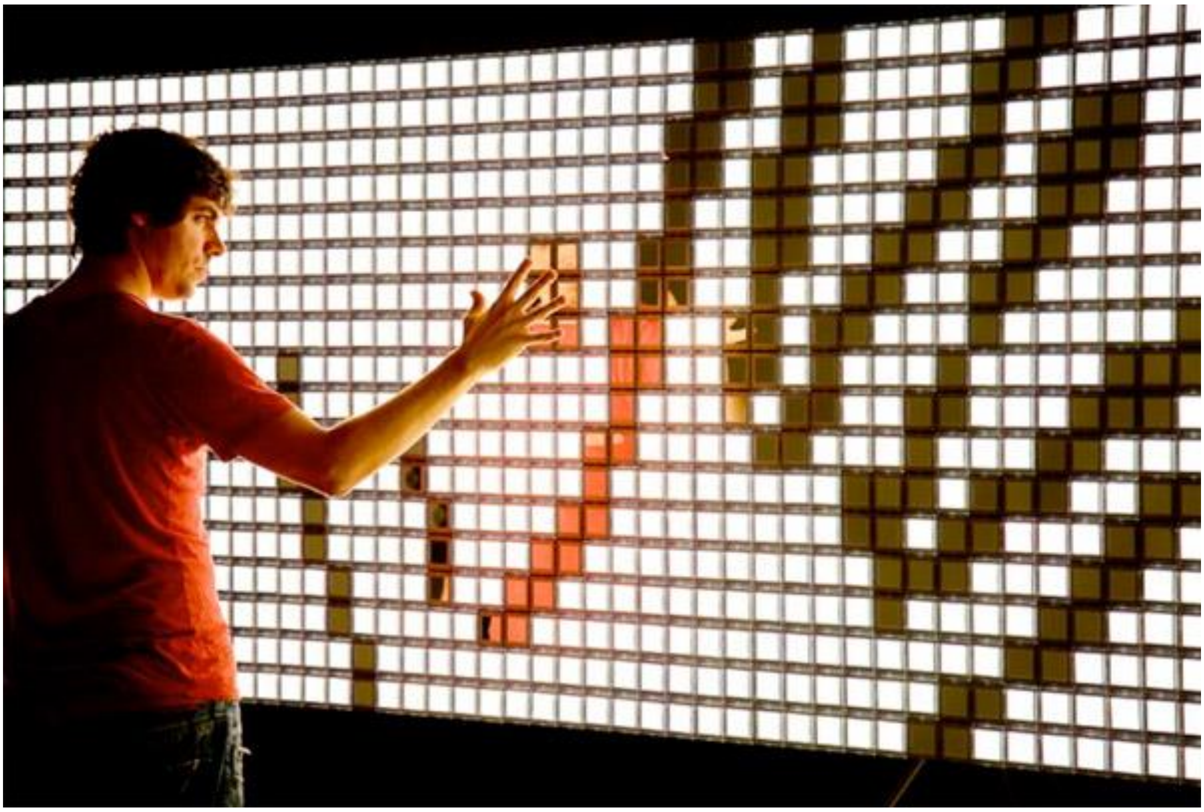
This type of sensors is more accurate and appropriate for small and long distance motion detection which can reach 6 to 10 meters easily.



SRF01 Ultrasonic range finder with dimensions which can fit in a LED Strip (http://www.robot-electronics.co.uk/)

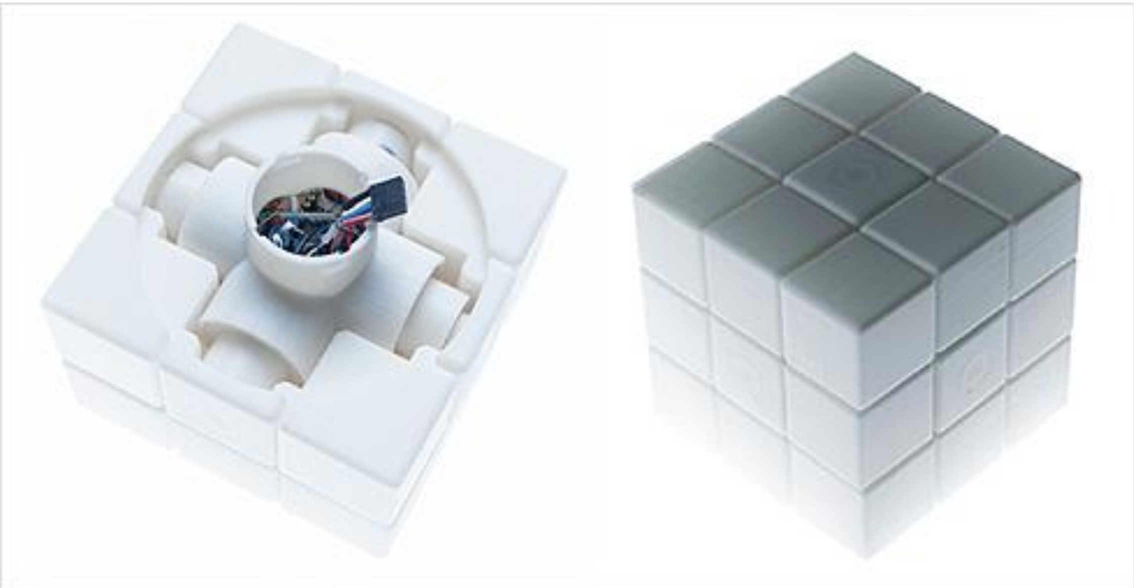
Such systems for interactive facades are becoming more and more common usually for interior applications. It would be a challenge to integrate this technology in a media facade open to the public which could act both for advertising and entertainment. The technology already exists but the assembly of all the components is not materialised yet.

The second suggestion for improvement comes from a project that Philips materialised with an interactive facade made of OLEDs. We have found through the research that OLEDs have many advantages but also a lot of space for improvement. There are still many basic issues which should be solved like the changing of colours in an OLED panel. Colour variety is restricted for these panels and currently is under research. The Philips LivingShapes



Interactive wall by Philips (http://technabob.com/)

interactive wall has over 1.152 Lumiblade OLEDs built into 72 OLED panels. Through computer control a camera in the centre of the installation records each movement in front of the wall which it then translated into impulses that light up specific individual OLEDs.
The cost of a product 2,70 x 1,30 m by Philips costs 140.000 € which is the cost for a media facade offered to Rollecate for example. The suggestion for our project to be improved would be to combine the sectors where OLEDs are superior to LEDs, like thickness, efficiency, contrast, surface temperature and maybe replace LEDs with OLEDs. It is a big issue which will be solved in the future according to the technology evolution.
Finally, the third suggestion for improvement would be to add the wireless concept in the media facade. As we saw in the first design proposals the wireless power transmission works better with the direct contact of the receiver and the sender. Consequently, there is no way of powering the LEDs on the facade without direct electricity input. On the other hand the possibility of controlling the LEDs wirelessly is possible. This is proven in a recent project the ''Puzzle Facade'' in Austria. Spanish designer Javier Lloret designed a building cube which can change colours by remote control of LED lighting.
The player interacts with the designed interface-cube. The interface-cube holds electronic components for keeping track of rotation and orientation. This data is sent over Bluetooth to a computer that runs the Puzzle Facade designed software. This software changes the lights and colour of the large-scale Ars Electronica's media facade in correlation to the handheld interface-cube. (http://interactive.javierlloret.com/puzzlefacade/)



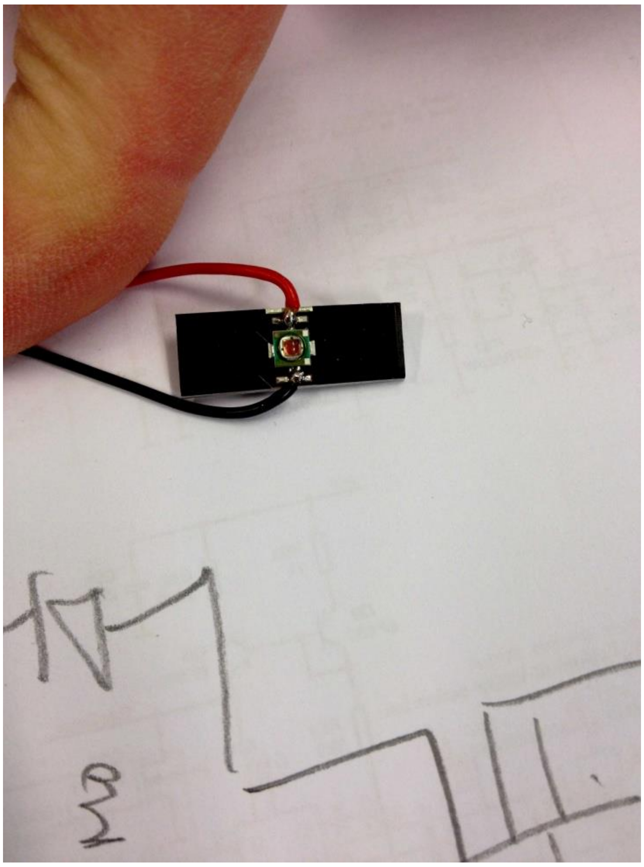
The controlling joystick cube connected with the computer (http://www.lednews.org/puzzle-facade-building-led-cube-austria/)

Movements on the small cube translated on the building's facade (http://www.lednews.org/puzzle-facade-building-led-cube-austria/)

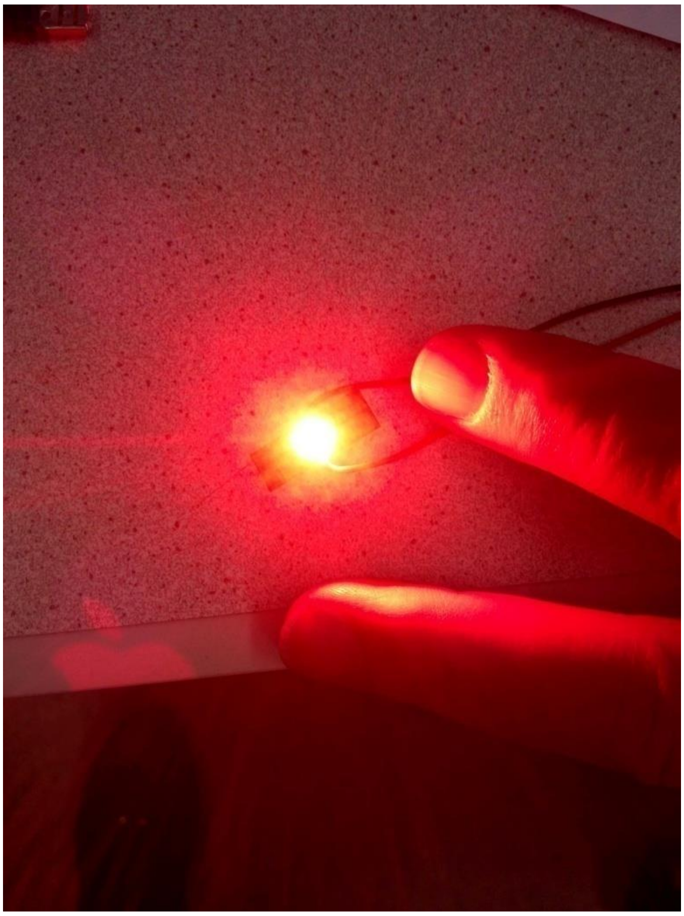
In our project LED strips are connected with cables to the microcontrollers and the main controller which is then connected to a computer with the data. Here only by using a wifi network and bluetooth system you can control the whole facade. The subject though becomes more complicated when you have to project videos and advertisements. The response of sender and receiver should be direct to allow good graphics. However this technology is promising and will add value to the polycarbonate media facade if we manage to program wirelessly the LED lights. Of course there should be a closer collaboration with specialists from the electronic world.

The technology of LEDs is very promising for media facades because strong lighting LEDs already started to be in the market. My privilege of working my mock up in the EWI was that I was in contact with specialists in the field of microelectronics and components. Recently they developed a project of a small PCB with almost 200 LEDs mounted on it which can produce seven times the light of sun. These LEDs come from Cree with the name XLamp® XP-e LeD. The XLamp® XP-e LeD combines the proven lighting-class performance and reliability of the XLamp XR-e LeD in a package with 80% smaller footprint. The XLamp XP-e LeD continues Cree's history of innovation in LeDs for lighting applications with wide viewing angle, symmetrical package, unlimited floor life and electrically neutral thermal path (http://www.cree.com/)

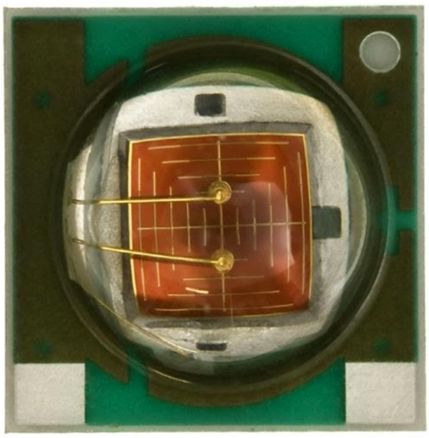
PCB made of aluminium due to the high temperature emitted by the LEDs



LED from CREE mounted in aluminium plate

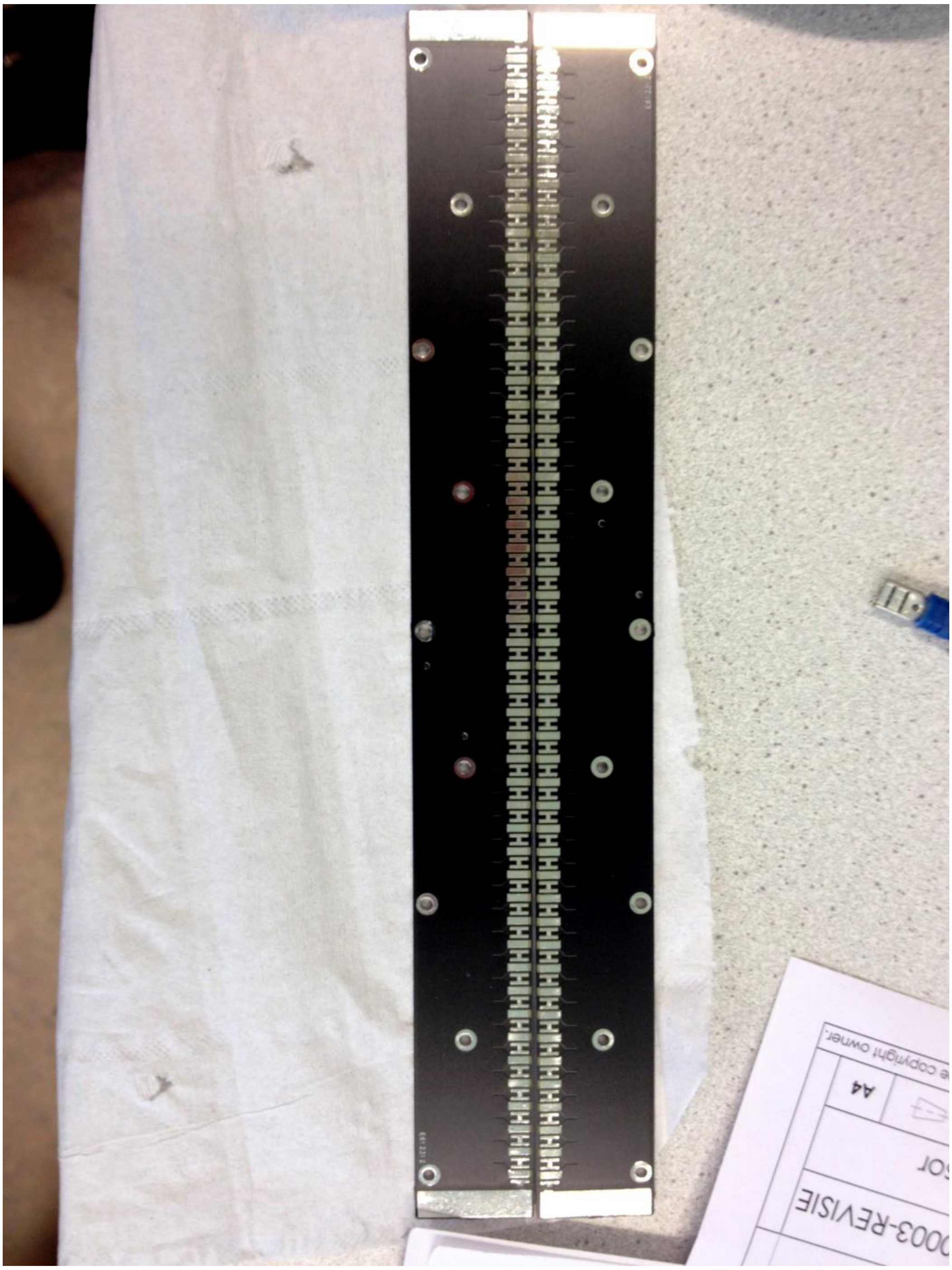


Red LED from CREE illuminated. White colour emits up to 1079 lm



XLamp® XP-e LeD

One of the issues that these strong LEDs have is the fact that they rise very high temperature on the back. Therefore, only strong materials like aluminium are possible to support them. PCBs offer a tremendous variety in the application of mounted LEDs. Same people from EWI developed a LED strip by joining two aluminium plates and by using special LEDs they are aiming to reach 27 times the light intensity of sun.

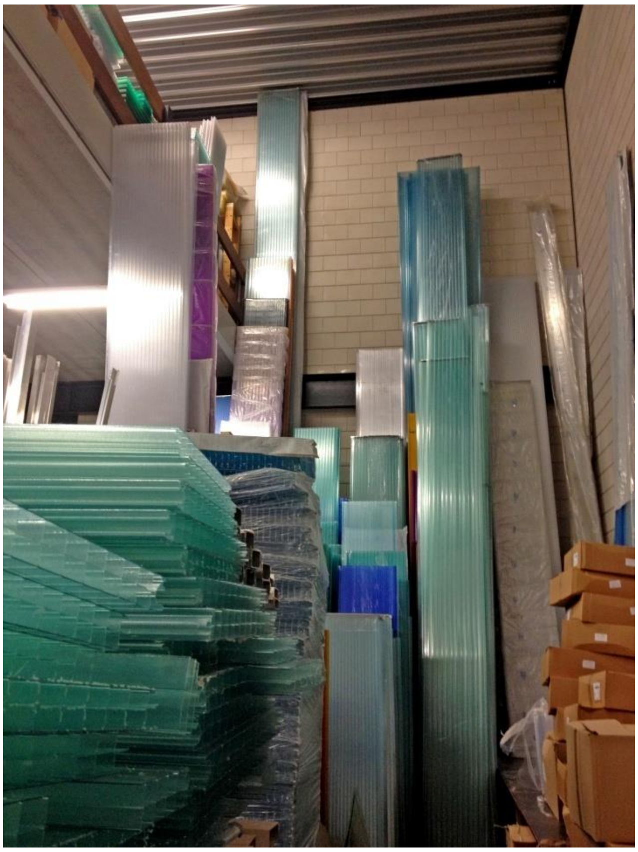


PCB made of aluminium with very close distances between mounted LED positions

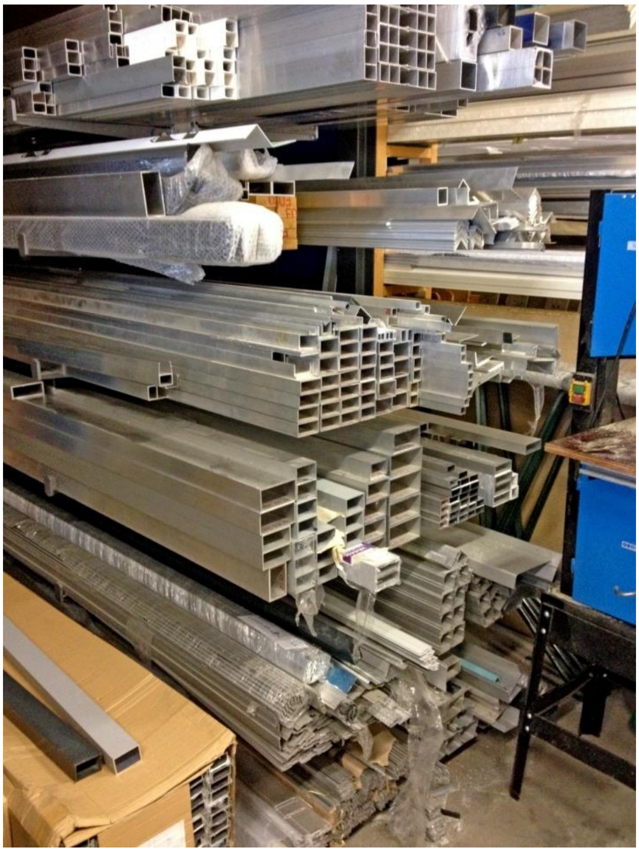
10. POLYCARBONATE MEDIA FACADE MOCK UP

In order to show the result of the suggested design it was decided to build a representative mock up of the polycarbonate media facade. In this way I could see the light quality emitted by the led strips in the polycarbonate, the connections of the LED strips, the programming and the pixel pitch resolution in several distances.

Therefore, firstly I visited the warehouse of Rodeca in Alphen aan den Rijn.

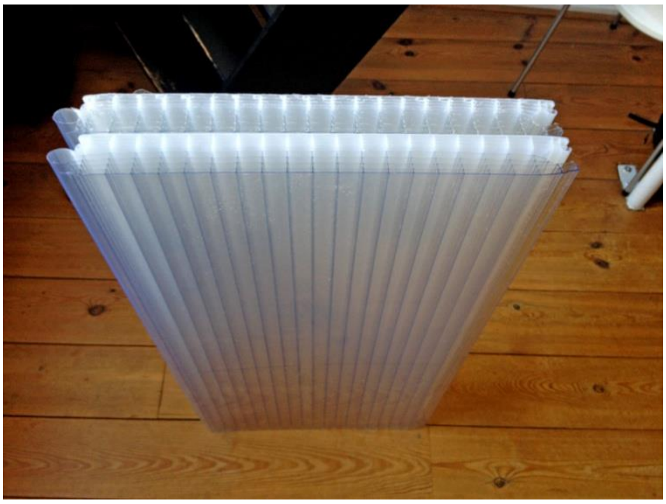


Storage of different types of PCSS in the warehouse

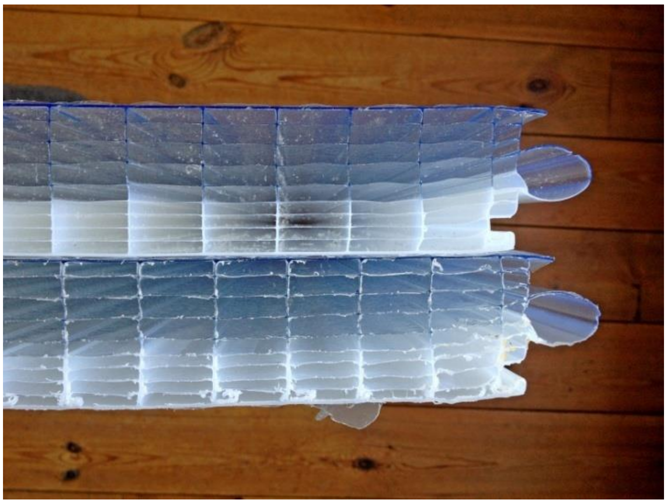


Aluminium profiles for the PCSS

There I was supplied by two polycarbonate panels of 500 x 1000 mm, with the click system, a thickness of 50 mm and U value 0,83 W/m^{2}K. Half of the panel is translucent and the other half transparent as they are mentioning in their possibly colouring combinations. In addition they offered me a sample of aluminium profile, no thermally broken and some gaskets for making it watertight. Here I have to thank the company for its support by offering me these materials free of charge, since I was a student.

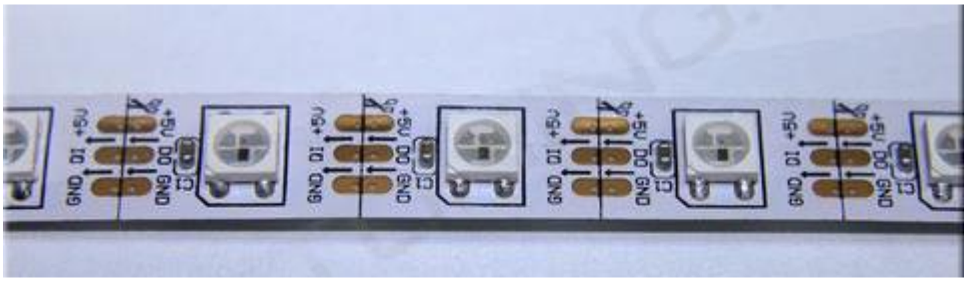


Two panels of 500 x 1000 mm



Top view of the section of the panels

After being supplied with the polycarbonate panels I searched for the LED strips in order to illuminate the facade panel. I decided to make the best possible resolution of 25 mm pixel pitch for the 500 mm wide panel. The chambers here are a bit wider compared to the 1 m panel. This panel of half meter has 19 chambers so we need 19 m of addressable RGB strips. The type of strip used is LED Strip WS2812B Digital RGB Indoor High Power (5 Volt, 60 Leds per meter, 5050, IP20). RGB LED chips and microcontroller are integrated in the housing SMD 5050 and together they form a complete digital controllable full-colour pixel.



LED Strip WS2812B with 60 LEDs per meter (https://www.ledtuning.nl)

In order to power up the LED strip we need a power supply Open-Frame, 5 Volt 70A 350 Watt. Some recommendations from the company are to always take care that there is sufficient free air circulation to keep the power supply cool enough. Also, environmental operating temperature should not exceed 40 °C and it must not be used near hot objects or near objects that radiate a lot of warmth.

Power supply (https://www.ledtuning.nl)

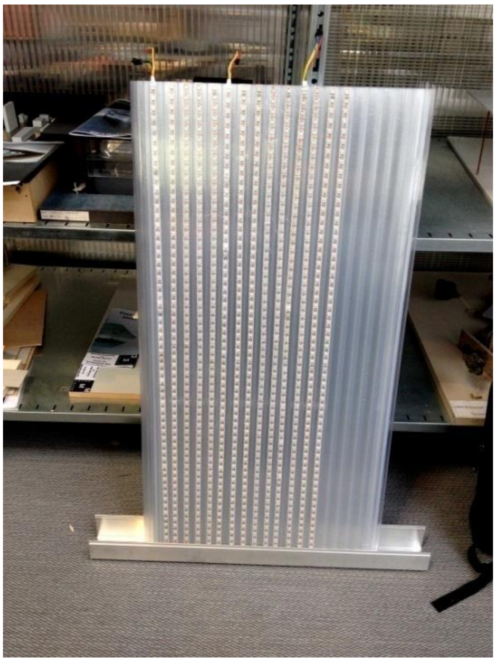
Finally, we need the main controller to control the RGB strip. WS2812 Controller for 5 Volt Digital WS2812 LED strip is the solution. There is also computer software available which creates files, stored on the SD card which is readable by the controller. The controller forwards the information, text, colour effect, video animation to the WS2812 LED strips.

WS2812 Controller with SD card (https://www.ledtuning.nl)

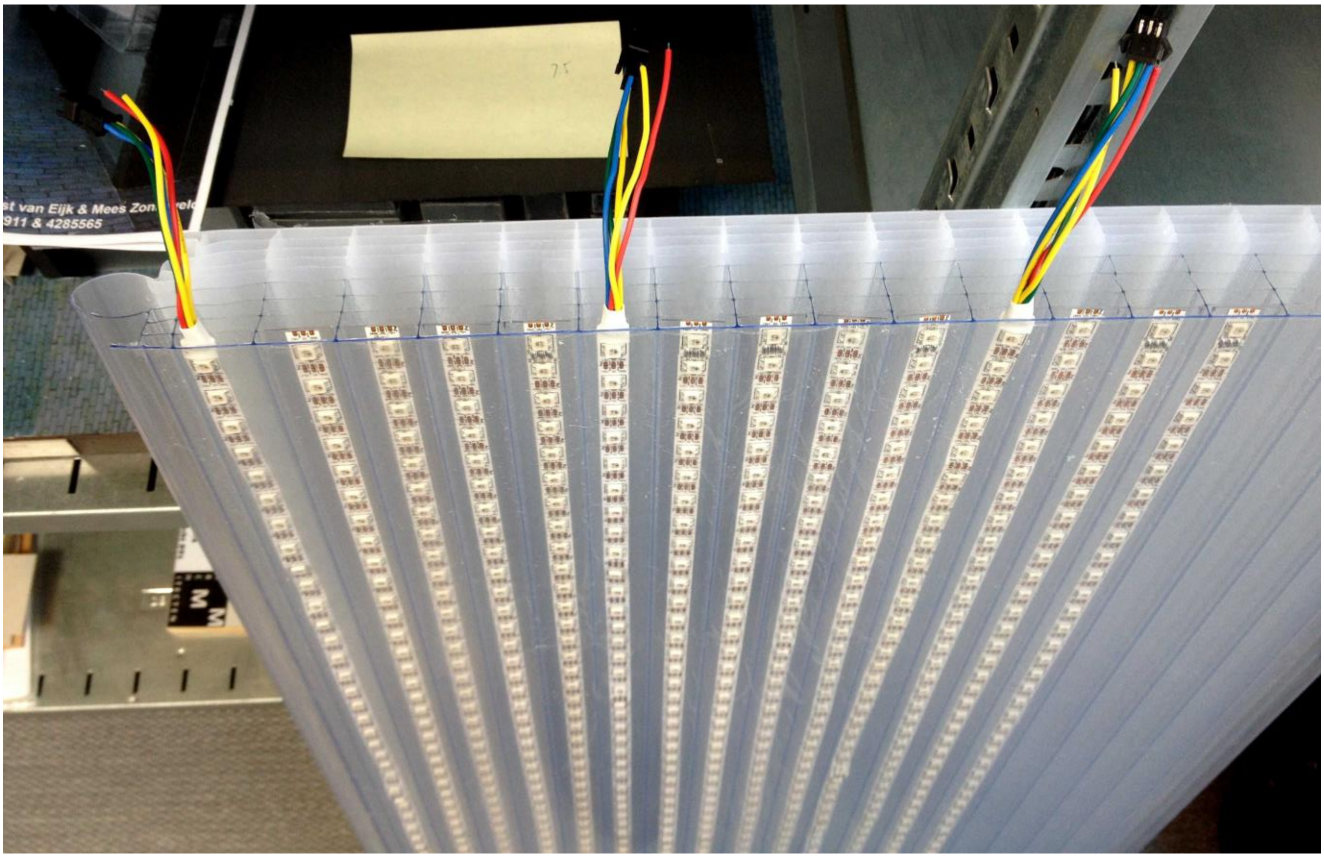
The construction of the media facade panel started by cutting the plastic transparent stripes of 23 mm width. Afterwards, the led strips were glued on the plastic ones in order to adjust easier the pixel pitch and align the LED chips.

Cutting the plastic lanes

Cutting the LED strips

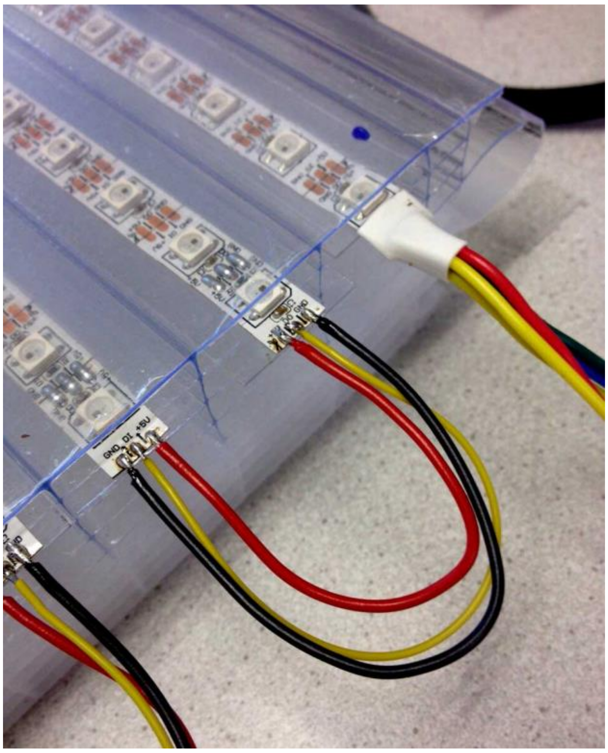


Sliding the strips in the panel

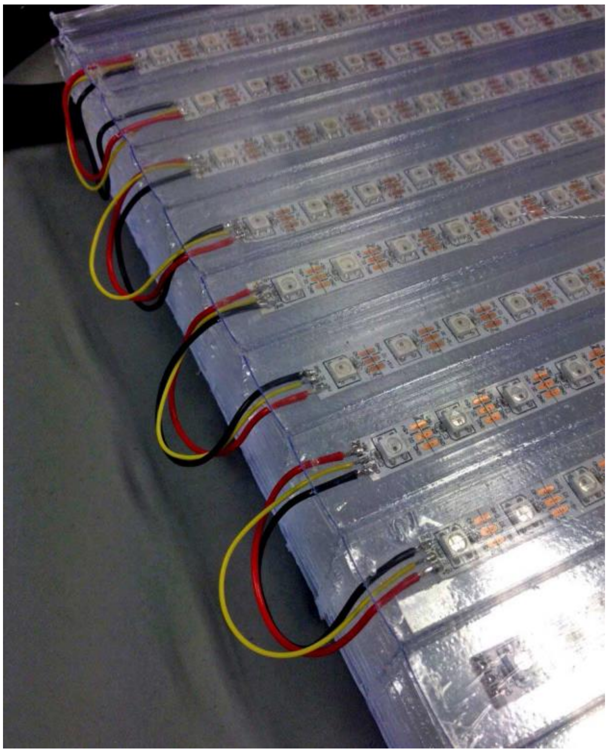


Closer view of the panel with the LED strips in the chamber

In this system due to the fact that the strips are every one meter we needed to join them together and the best solution is the soldering. From every strip 3 cables are coming out, GND, +5 V and Di. On the strips there are arrows which are showing the direction of the data transferring the commands for the chip controllers. Consequently, it was important to join them properly. After going to EWI in TU Delft, with the help of technicians and the appropriate equipment I started soldering the strips.



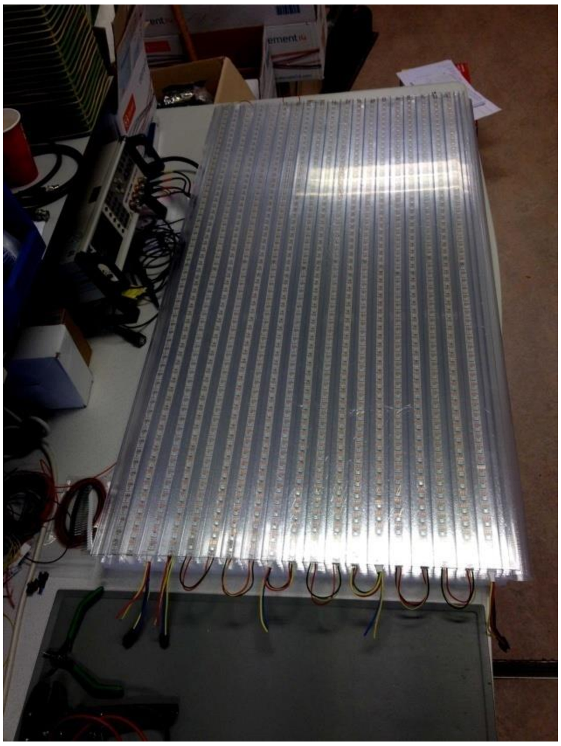
Closer view of the soldered wires on the edge



Joining the stripes in a closed circuit

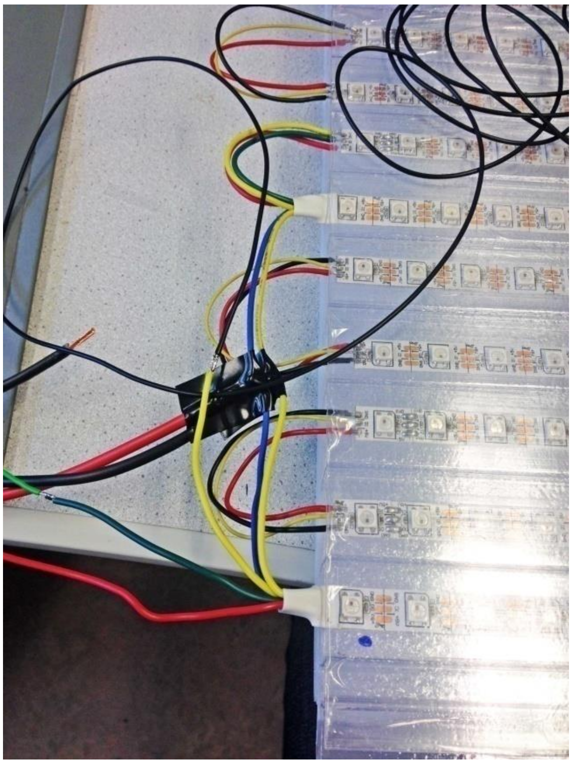
After soldering every stripe I was checking with an LCD Multimeter the electrical resistance between the cables in order to avoid damages on the circuit and the led strips by overlapping metals. Always the price of Ohms should be different from zero between three cables so the circuits are ok.

Machine measuring the volts

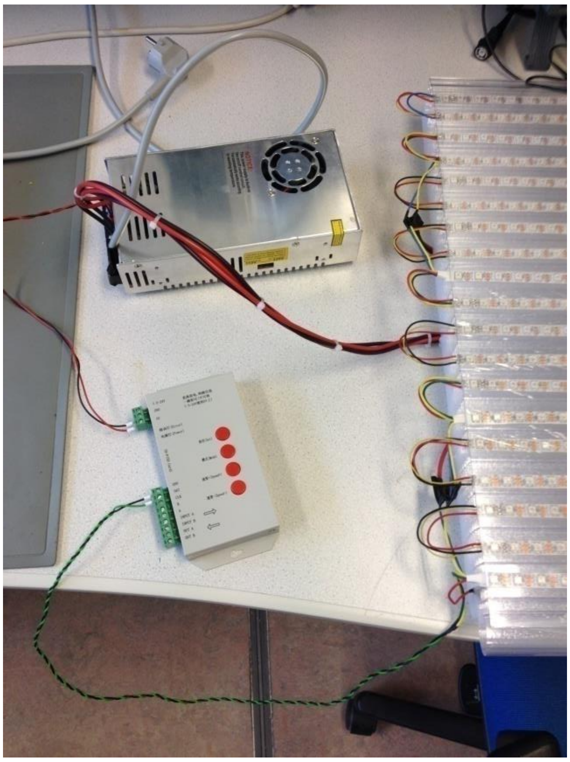


Overview of the panel and the connections

After soldering all the stripes together I proceeded by connecting the controller and the power supply to the LED strips.

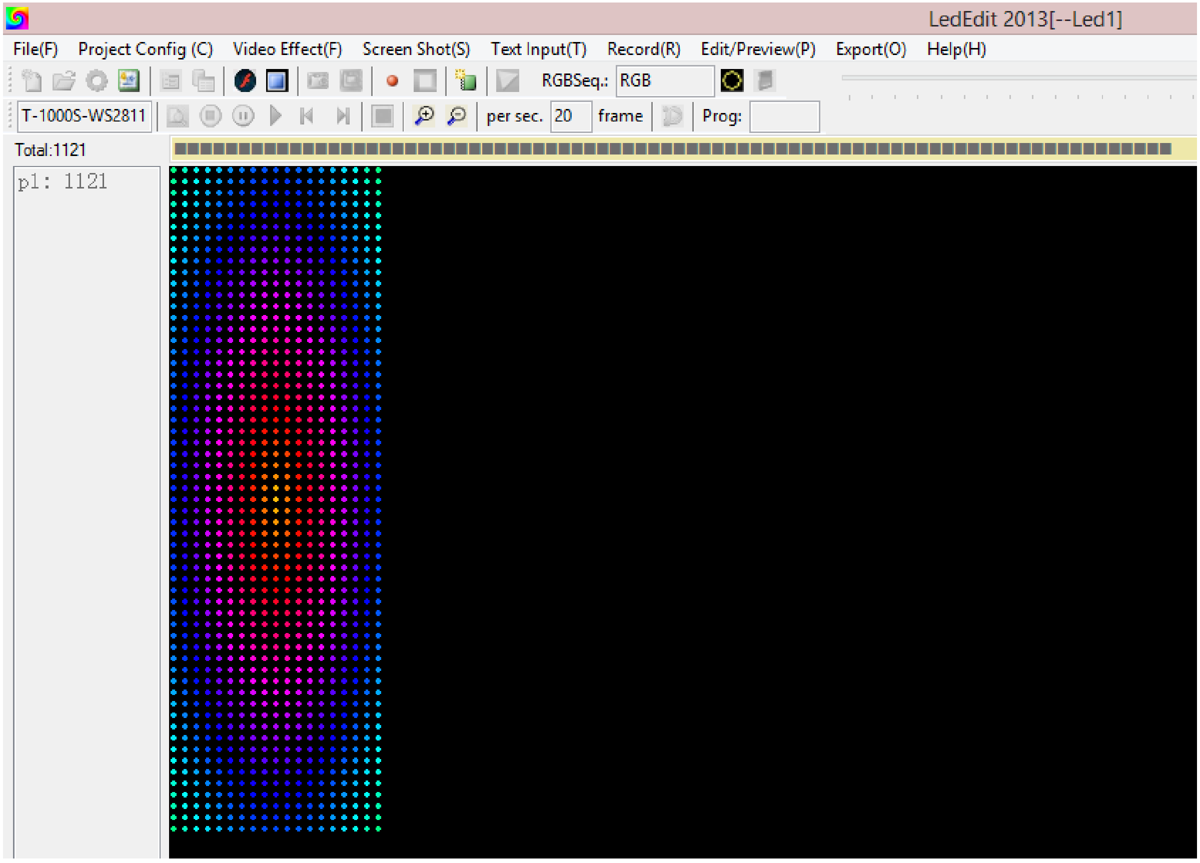


Detail of the connection with the cables



Power supply and microcontroller

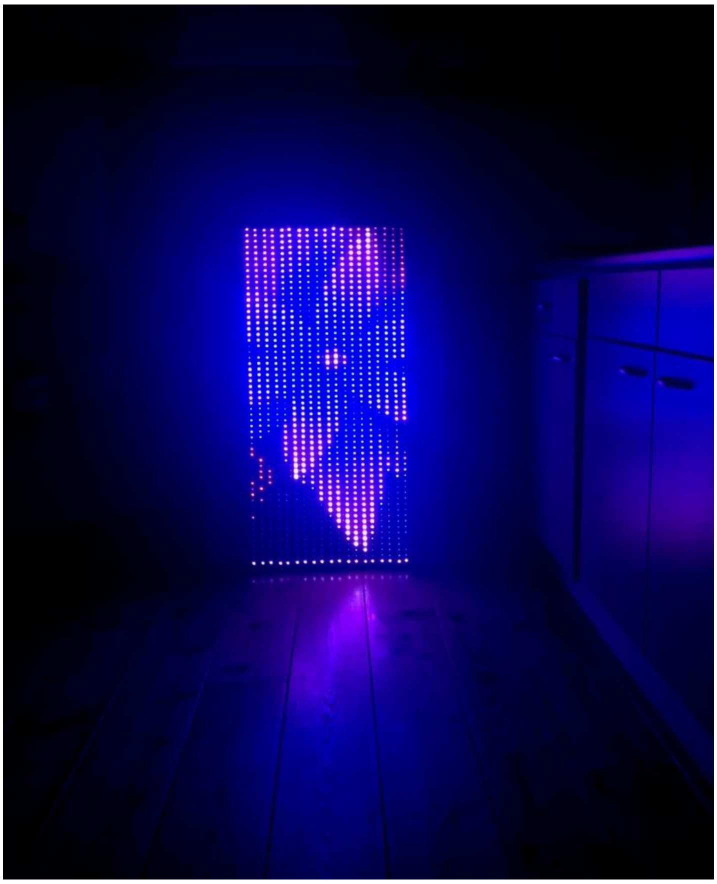
As far as the software LED Edit 2013 is concerned it has many options to design your LED screen by commands. You start by building the LED display with vertical and horizontal pixels in the environment and then adding effects. After recording the effects on the LED grid you export the file and save it in the SD card. Finally, by plugging the SD card in the controller you have the video effects on the screen.



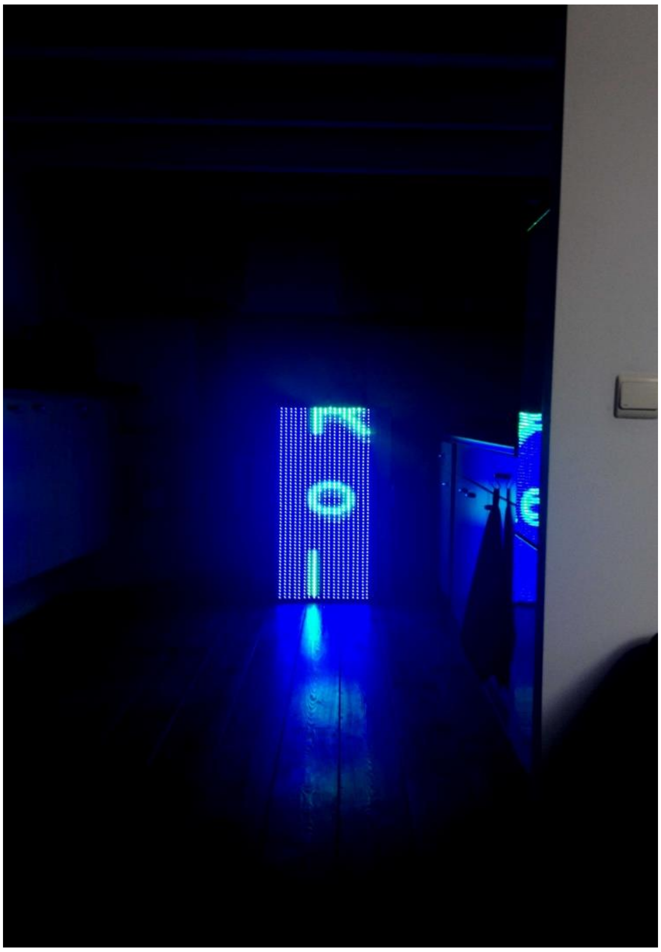
Screenshot of the software with our grid of 19x59 pixels and 1121 in total

The effect of the pixel pitch in the panel cannot be captured in images through the appropriate distance since it doesn't appear on the screen. Therefore only images from about 5 meters can illustrate the result of the panel. It was observed that with a pixel pitch of 25 mm horizontally and 20 mm vertically at the distance of 30 m the image started to get rid of the dot pixels. The observer needs to go close to 35 meters in order to see the panel clearly as a unified image. Consequently the multiply factor of 1000 distance units by Philips is closer to reality for a clear image. If we say that with a 25 x 20 mm pixel pitch the image is clear close to 35 m then the factor should be increased and be 1300-1500 distance units. The brightness is high and expected like in reality. If you look at the facade panel for much time it is annoying for the eyes. All in all the expectations were correct, except the minimum viewing distance.

Prof.dr.ing. Ulrich Knaack on the screen from 3m viewing distance



Flower effects



Fonts with a stable background colour

Coloured background with black fonts

11. LITERATURE

Books:

- Ashby M., Shercliff H., Cebon D., *Materials: Engineering, Science processing and design*, Butterworth-Heinemann, 2009
- Brookes Alan J., *The making of facades*, Delft University of Technology-Faculty of Architecture, 2006
- Haeusler M.H., *Media Facades – History, Technology, Content*, avedition, 2009
- Haeusler M.H., *New Media Facades – A Global Survey*, avedition, 2012
- Knippers J., Cremens J., Gabler M. & Lienhard J., *Construction manual for polymers + membranes*, Institut für international Architektur-Dokumentation, 2011
- Margolis J., *Engineering plastics handbook*, McGraw Hill, 2006
- Meijs M., Knaack U., *Components and connections-Principles of Construction*, Birkhauser, 2009
- Tscherteu G., Tomitsch M., *Media Architecture Biennale 2010 Exhibition Catalogue*, Künstlerhaus, 2010

Websites-Articles:

Leds-Oleds

- Amir Naeimi, *OLED Display with SG-TFT*, Master Thesis, TU Delft, 2011
- http://articles.ides.com/design/2010/plastic-electronics.asp
- http://dl.acm.org/citation.cfm?doid=2493432.2493486
- http://en.wikipedia.org/wiki/Mean_time_between_failures
- http://hr.wikipedia.org/wiki/Pozdrav_Suncu
- http://inhabitat.com/croatian-harbour-town-celebrates-natural-forces-with-beautiful-public-art-installations/solar-installation-zadar-croatia/?extend=1
- http://inhabitat.com/philips-develops-a-transparent-energy-gathering-oled-car-sunroof/clear-oled-car-roof-2/
- http://inhabitat.com/researchers-develop-the-worlds-most-efficient-flexible-oled/
- http://inhabitat.com/solar-oled-tiles-transform-skscrapers-into-zero-energy-displays/
- http://www.chineselight.com/
- http://www.hendyconsulting.com/
- http://www.idtechex.com/research/articles/oled-vs-led-lighting-is-there-room-for-oled-lighting-00005477.asp
- http://www.led-professional.com/technology/light-generation/eu-funded-manucloud-project-combines-oled-and-organic-photovoltaic-in-a-facade-module
- http://www.ledsmagazine.com/index.html
- http://www.luxmagazine.co.uk
- http://www.murs-photovoltaiques.com/urban-tiles-mur-photovoltaique-oled-facade-lumineuse-ecologique
- http://www.philipslumileds.com/technology/led-glossary
- http://www.prnewswire.com/
- http://www.radio-electronics.com/info/data/semicond/leds-light-emitting-diodes/lifespan-lifetime-expectancy-mtbf.php

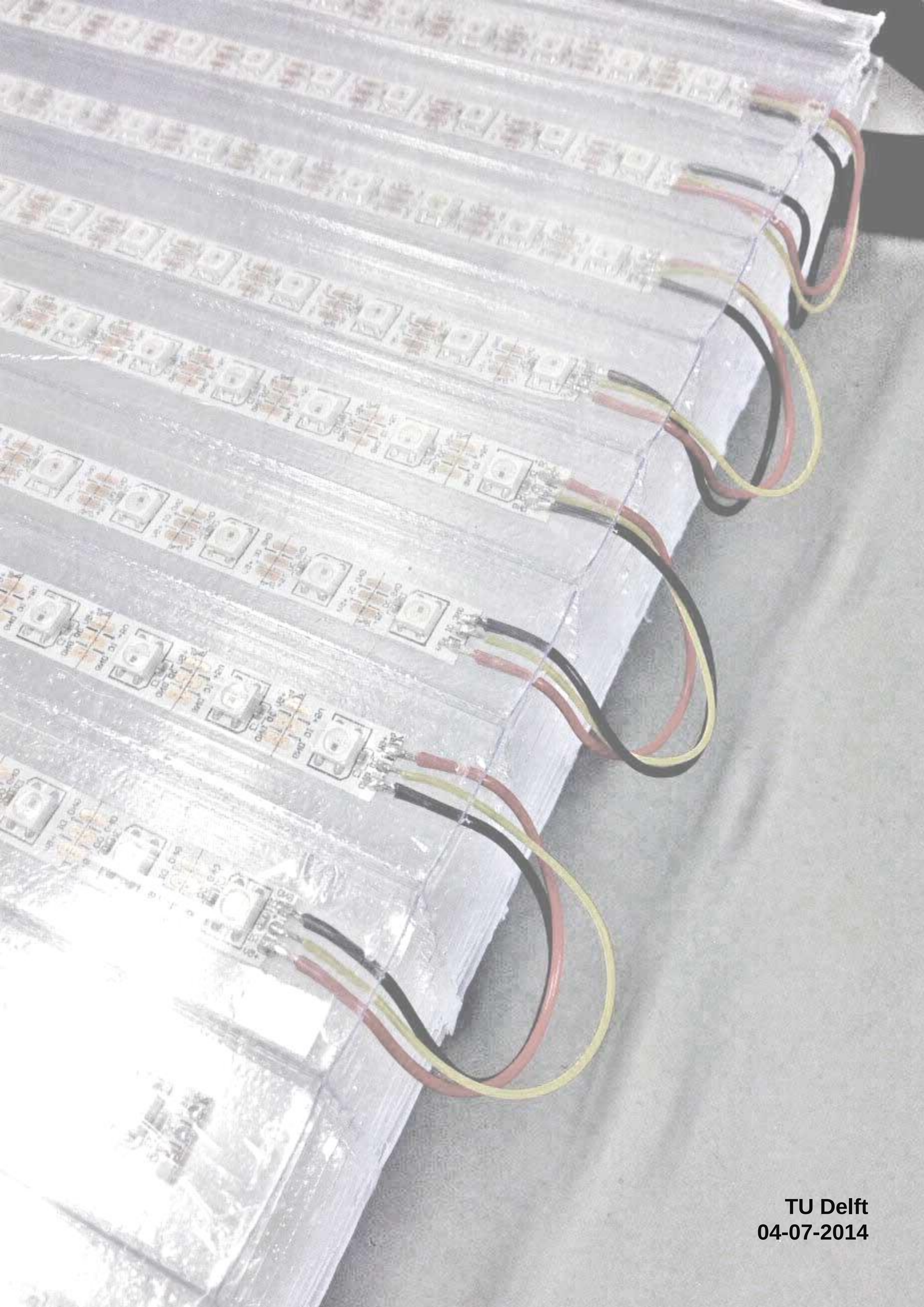
- http://www.radio-electronics.com/info/data/semicond/leds-light-emitting-diodes/lifespan-lifetime-expectancy-mtbf.php
- http://www.tofoled.com/En/shownews.asp?id=192
- http://www.tue.nl/en/university/news-and-press/news/color-of-oleds-can-now-at-last-be-predicted-thanks-to-new-modeling-technique/

Media facades

- http://mariuswatz.com/2012/02/07/arcs-rockheim/
- http://www.agc-glass.eu/
- http://www.alucobond-media.ch/gallery
- http://www.citiled.com/#/projects/project-portfolio-1/souk-entertainment-centre-21/
- http://www.colorkinetics.com/
- http://www.electronics-tutorials.ws/diode/diode_8.html
- http://www.gkdmediamesh.com/
- http://www.leuro.com/en
- http://www.louvreled.com/
- http://www.mediaarchitecture.org/kings-road-tower/#more-4705
- http://www.onlyglass.de/en_us/pictures.html
- http://www.realities-united.de/#SHOWINFO,1,1
- https://www.schueco.com/web/lightskin_en/lightskin

Polycarbonates

- http://continuingeducation.construction.com/article_print.php?L=307&C=913
- http://facadesconfidential.blogspot.nl/
- http://www.bpf.co.uk/
- http://www.co-excorp.com/mac.html
- http://www.extechinc.com
- http://www.glasscon.com/
- http://www.ontwerpburo-roza.nl/
- http://www.rodeca.de/?L=1
- http://www.sepitalia.com/
- http://www.whowithwhat.com
- https://kluedo.ub.uni-kl.de/home



TU Delft
04-07-2014