# Index

1. Introduction (DI studio)  
2. Context (Location & Problem Statement)  
3. Analysis Houston  
4. Analysis Downtown Houston  
5. Analysis reference project  
6. Design  
7. Climate design  
8. Construction  
9. Façade  
10. Paper Thermal comfort in warm urban spaces
Delta interventions is an interdisciplinary studio which deals with the development of delta areas worldwide. Not only does the delta offer great conditions for settlements and trading, there is also the threat of the water. The studio focuses on research and design projects that not only result in more safety and better water systems, but also in stronger spatial identities and new cohesions of cities and landscapes; in a new, strong and beautiful urban delta landscape. The central question of the studio is how safety, new cohesions and identity can be combined in innovative designs.

The scale of the design can vary from buildings, constructions and public works to urban areas, landscapes and regions.

The border between water and land is fit for different kinds of activities: fishing, agriculture, trade, commerce and industry. This has a big attraction on people.

In 2014-2015 the Houston–Galveston Bay Area was topic of research of the van Eesteren Chair at the Faculty of Architecture and the Built Environment of the Delft University of Technology.
All over the world water is becoming a bigger problem: because of a lack of water, or just too much of it. With the ongoing growth of the world population, people world-wide move to areas formally not suited for urbanization. Many of these areas are flood plains. The risk of living in these kinds of areas increases because of the climate change; the sea levels will rise and storms are getting more intense. This calls for adaptation for urban and architectural development. Instead of fighting water, designing with water is the future.
The Houston metropolitan area has about 6 million inhabitants. It is the most populous city in Texas and the fourth city in the United States. The city was founded in 1836 on the banks of the Buffalo Bayou. The city is connected through the Buffalo Bayou to the Galveston Bay. This big brackish bay is in turn connected to the Gulf of Mexico.

In 1901 oil was discovered. New industries settled in Houston and the city grew rapidly. Without any zoning laws, Houston got an interesting composition with mainly suburbs and some concentrations of high rise buildings around attractors like Texas Medical Centre and Downtown Houston.

Through time the border between water and landscape shifted due to the low altitude and marsh like landscape and the tropical storms.

In a short time road infrastructure increased rapidly. Train tracks were a mean of transporting goods, but after the introduction of the car it got neglected.

In 1850 Houston was not yet the centre of the region, but due to several storms and the shifting of the coast other towns vanished or lost their leading position. After the destruction of Galveston in the early 20th century due to a hurricane, the industry, trade and harbour were shifted inland to Houston.
Flooding: Because of the rapid population growth, the city's expands its new neighbourhoods onto low areas vulnerable to flooding. At the same time, the new city structures distort the natural landscape, making the natural runoff systems fail, making the flood risks even bigger.
“No one really shares Houston”

Lars Lerup (2011),
former dean of the faculty of architecture,
Rice University

“All of us have a unique view of the city (Houston red.) we inhabit. But some cities are more conducive to undisturbed personal perception than others. Houston is such a city – the absence of shared space sees to this. Predominantly motorised and individualised, Houston limits pedestrian and public experience to interior spaces – be it mall, arena, church or parking garage. Exterior space is dominated by the movement through it: whether parking tarmac, freeway, cloverleaf, frontage road, cul-de-sac. Houston is mine (and everybody else’s), rarely to be shared, merely an extension of my driveway.”

Lars Lerup (2011),
former dean of the faculty of architecture,
Rice University
The river landscape is mostly flanked by industrial areas. The river banks consist of hard lines and is not dynamic. The industry is mostly petroleum related. It consists of refineries and harbours. But there are some green areas around the riverbanks as well. The flood risk in this area comes mostly from flooding of the river through extensive rainfall.

This marsh like area consists of several lakes, wetlands and the Trinity Bay. Here the Trinity River flows into the bay. The line between water and land is in this area quite obscure. The flooding risk here comes from the river as well as the water build-up from the storms from the sea.

One of the striking features of this area is the open lake on both sites of the peninsula. The open water, in combination with the wetlands attracts wildlife. The flood risk of this area comes mostly from storms from the sea.

This site features the sea front and the sandy beaches. Here the thread from the sea is imminent. This area does not have a sufficient sea defence.
POPULATION HOUSTON

In cities like Detroit or New Orleans the population is declining. In Houston, on the other hand, the population is still growing, even during the crisis. (Forbes, 2012) In 1910 the population of Houston was 78,800. In little more than a 100 years, in 2012 the population of the metropolitan area of Houston was 6,177,035. The population grew by 31.0 % since 2000 and a 2.1 % growth since 2011. Forbes ranked Houston as the No. 4 growing city. Here is a potential of lot of encounters between different people.

Houston lies on an extensive plain, sloping at a rate of 1 in 5000 from the centre of Houston to the Gulf of Mexico. There are not many natural boundaries like big rivers or mountain or hills limiting the growth of city.

With a population of about 6 million, it has a low density. This has its impact on the way people travel in Houston.

Population Growth

The population of the Houston metropolitan area is growing rapidly.

03 ANALYSIS

The population grew by 31.0 % since 2000
It is the No. 4 growing city in the US

Source: Forbes 2012
Houston is one of the first cities where the use of the car really took off. At the beginning of the 20th century oil was found in this part of Texas. Because of the oil winning in this area, the usage of cars is fairly cheap. The city of Houston is thereby totally focussed on motorised vehicles. Trains are merely used for transport of cargo. At this moment there is only one tram line in use and two more under construction (this for a city of over 6 million). There is an extensive bus network, but the local and state government does not support further extension of the public transport network.

Having a car is absolutely essential in Houston. The car is a highly individualised way of transport. Because of the low density and the usage of the car Houston is highly individualised.
Lars Lerup divided Houston into mega shapes. Slow zones (the zoohemic canapé area with the room underneath, people public space, but no one knows this), speed zones (highway, people move faster, but real estate changes faster as well. Closer to the speed zone, the higher the speed.), Downtown area, Texas Medical, Uptown.

Zoohemic Canopy Part of the American Dream is living in a single family house that lies on a plot of land with a green lawn. Most of the Houstonians live like this. In Houston there are no zoning laws. Developers therefore build small cul-de-sac suburban neighbourhoods with a low density, ever extending the borders of the city.

Downtown Houston is the location of choice for my project. Although Downtown Houston has high rise buildings up to 320 meters, it has a medium density: 30 to 40% of the surface of Downtown Houston consists of paved parking lots.
Downtown Houston Despite of the high rise, Downtown Houston does not have a high density due to on surface parking lots. This does not promote street life.

Downtown Houston does not have a big diversity of functions. Most of the buildings are offices.

Most activities take place during day with the working people. After working hours there is a small dip in activities while the working people go home. Then there is another spike, as the cleaning people move into downtown Houston.
Beside a lot of parking lots Downtown Houston has several different district and attractors. The main districts are the Theatre District, the Historical District, the Public Service District, Skyline District and Main Street.
Climate Houston has a humid subtropical climate with hot summers and mild winters. From May until half September the high average temperature is above 30°C, peaking to 34°C.

In warm countries most of the time the outside space is as important as the inside space, promoting street live. Not in Houston. In Houston people do not take advantage of the climate when the outside temperature is within the comfort zone.

Tunnels Downtown Houston
To avoid the warm months, air conditioned tunnels have been made to replace the street, leaving the streets empty and bare. There are almost no trees and a lot of hard surfaces in Downtown Houston, making the micro climate there uncomfortable hot.
The goal of the Houston Downtown Development Framework is to revitalise Downtown Houston, making it livelier. Here are some points of the Framework:

- Making DT Houston denser by replacing on surface parking with residential buildings, shops and offices.
- Making Downtown Houston denser will help Downtown Houston become a pedestrian friendly place where people can share Houston.
- Revitalisation of Main Street and introduction of the Metro Rail
- Extension park and development of the waterfront
- Expansion Theatre District and restoration Historical District.
Most venues in the Theatre District are high-end, high threshold venues like Opera, Ballet, Symphony etc. The venues are mostly focused on on group. All program are during the night.

**“High-end” venues**

- Alley Theatre
- Hobby Center for the Performing Arts
- Jesse H. Jones Hall for the Performing Arts
- Wortham Theater Center

**“Low-end” venues**

- Bayou Place
Literature studies of the Houston Downtown Development Framework show a few points that will add complement the existing venues. The development framework gives the following points:

- Make continuous effort to ensure that Theatre District facilities do not lag behind national counterparts in quality or capabilities.
- Add smaller-scale performance venues and support spaces that provide room for spontaneous, energy and urban diversity.
- At Bayou Place Phase II, consider arts-related uses, high-rise residential development and removal of the overhead structure above Bagby so that the street can become a key civic corridor.
- If Buffalo Bayou improvements and U.S. Postal Service plans allow, redevelop the existing post office site as a mixed-use extension of the Theatre District along the bayou.

Similarly, examine the Bob Casey Federal Courthouse site as a potential location for performance venues or support spaces if a new federal courthouse is built.

Study the potential for creating a cultural park for the Theatre District by closing Texas Avenue and Pinckie Street (made possible by a redesigned I-45 corridor) while improving access to public garages.

Work with property owners to add entertainment, such as an IMAX theater, to the area around the Downtown Aquarium.

Develop hotels on the market's ability.

- Increase the hotel room count.
- Broaden the range of hotel products offered.
- Plan for a second major hotel near the convention center.

Continue improving Allen’s Landing and the Sunset Coffee building.

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The design location is located on the north side of Downtown Houston next to the Buffalo Bayou, between the historical district and the theatre district. It is a crossroad between nature and city, recreation and work. The new design will replace a gas station on a square street block of 75 by 75 meters.
The river bank along the Buffalo Bayou at the north side of Downtown Houston is neglected. There is no place for the river in the rigid road system. The urban landscape acts as if the natural landscape does not exist, thereby creating two worlds. One world, the upper world consisting of streets and buildings is far more dominating than the lower world, the Buffalo Bayou. The two worlds do not interact, it is almost a no go area. The only time these two worlds come together is when the Buffalo Bayou floods the urban area of Downtown Houston.
Flooding Downtown Houston

Tropical storms will always come from sea, from the Gulf of Mexico. The water will be pushed up the bay. At the same time extensive amount of rain is falling in the city. Houston lies on a moist prairie. Water cannot easily penetrate through the gumboil soil, so moves laterally. So when it rains water should be stored temporarily and then pushed into these bayous, which are very ancient. They are not rivers, but they are runoff systems (research this). Nowadays, there are many concrete bayous. Bayous had an ecological richness. With increased asphalting and hardening of the surface and shed roofs, can’t store the water. The runs to the bayous rapidly, filling them. The water cannot be flushed into the Galveston Bay because of all the water getting pushed to the mouth of the river, resulting in flooding of Downtown Houston. Houston should have flat roofs, so you can store the water for a couple of weeks. Prairie had hog wallows who could store water for several weeks. If you shed the water down the river, you will get real flooding problems.
As a threefold assignment with the Bostan, Mahalle and Market hall, we see the market hall as the link between the three notions. We see the market hall as a place not limited to the commercial aspects of a market, but a public sphere where an exchange of ideas and interaction takes place. To reinforce the identity of the Mahalle Duvari the market hall has to be integrated in the neighbourhood.

**Flooding Downtown Houston**

The design location lies in a 1 in 50 year flood plain with water levels of 0.79m. Can rise up to 3.5m. The design location lies in a shallow flood plain. The flooding usually lasts hours, rather than days.

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**Water level of flooding:**

- In 50 years: 0.79m
- In 100 years: 1.79m
- In 500 years: 3.44m

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**Flood Risk**

1. **Floodplain Types**
   - **Type A: Valley Floodplain**
     - Generally located in the northwestern portion of the county.
     - Ground in the area is more “defined,” with creek valleys.
     - Flooding can be very deep and usually extends for a few days.

   - **Type B: Major River Floodplain**
     - Only one major river floodplain in Harris County. Along the San Jacinto River.
     - Large, deep and swift, and flooding conditions may sometimes last a week or more.

   - **Type C: Shallow Floodplain**
     - Exists throughout much of the county and affects thousands of residences and businesses.
     - Channel capacity is exceeded, resulting in flooding that usually lasts hours, rather than days.

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**Research//Houston Downtown// Bubu Cao   20/11/2014**

**AR3DI020   Delta Intervention**

**Flood Risk**

The diagram below shows coastal flooding when unusually high tides or hurricane surge can flood low-lying structures. Ground subsidence can result in more frequent and severe coastal flooding. This type of flooding isn’t restricted to any one area of the county. It can happen anywhere. When in-tense local rainfall exceeds storm sewer or roadside ditch capacity, the water can “pond” in the streets deep enough to flood residences that are not near a creek or bayou. The water will seek a path to the channel by flowing overland (sheetflow). When residences and other structures are in the path, additional flooding occurs. This type of flooding is not identified on Flood Insurance Rate Maps, which is another reason why flood insurance is so important to everyone.

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**Type D: Coastal Floodplain**

* Fifth flooding Scenario

**Ponding/ Overland Flow**

- **Short duration**
  - **Subsidence**
  - **Tidal surge**

- **Longer duration**
  - **Stream flooding**

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**04 ANALYSIS DT HOUSTON**

21/90
Challenges
- 1 in 50 year’s flood risk
- No one shares Houston
- Exterior/ outside is considered hostile, unwanted, therefore is not being used
  - Big difference between inside and outside climate, therefore no usage of the outside/ streets
- Low interaction and accessibility

Opportunities to take advantage of
- Extensive population (6 million potential encounters)
- Skyline of Downtown Houston (Views and atmosphere)
- Climate
- The new master plan (Revitalization, densification)
- Location (Close to Main Street, next to the Buffalo Bayou and the Historical District, part of the Theatre district)
SESC Pompeia

So what kind of program will be suited for my design location.
A reference project: SESC Pompeia. I studied in SP for six months.
A building you must visit is the Pompeia leisure center,
designed by Lina Bo Bardi. It is a place of freedom, to do what you want to do.
A welcoming place, a place to experience.

Marcello Ferraz, an architect who worked alongside Lina Bo Bardi described the center in 2012 as following:

“Who doesn’t have a fond recollection of this place from all the years spent living in our densely-packed metropolis? The music shows, circuses, festas juninas, multi-ethnic festivals, memorable exhibitions – or even just meeting up with someone and doing very little, sitting on the public sofas beside the water or the fire…”

So what are the qualities of SESC Pompeia?

A solution for Houston?

Leisure Center SESC Pompeia (1986), São Paulo - Lina Bo Bardi

“Who doesn’t have a fond recollection of this place from all the years spent living in our densely-packed metropolis?”

M. Ferraz (2015),
One of the architects of SESC Pompeia
The Inner street makes the leisure centre function as a city within a city. It gives the visitor the freedom to move freely from program to program, from hall to hall. Because every function comes back to this street, the street will always be busy with people. It is a place to pass through, but also to stay, to rest, to watch people pass by.
A comprehensive program attracts interest from all age groups and social classes, making the leisure centre a place for everyone. The program is diverse so there will be activities throughout the day, well into the night. Several flexible spaces provide room for variety so that every time you visit the experience will be different.

Program
“A comprehensive and inclusive programme attracts interest from all age groups and social classes, without discrimination.” Sports, arts, theatre, leisure, education.
The building also attracts people who are not per se attracted to its program, but are curious about the architecture.

High-end architecture

The architecture is focused on experience, bringing people there who are interested in its architecture and not its program, making the visitors more diverse. This creates a great atmosphere.

But maybe most of all the way she designed the building. Most the factory hall was already there and got converted and enhanced. It acts like a cabinet for fun activities. And that is something I wanted to accomplish as well.
Lessons from Lina
- Accessibility
- A lively street bringing into the complex public live
- A comprehensive and inclusive program
- High-end architecture
- Atmosphere
Design goals
- Design an attractor complimenting the program of the theatre district in which people can take advantage of their potentials
- Providing Houstonians with a common experience
- Letting the Houstonian experience the city and waterscape
- Promote street live and the outdoors
First the urban design had to be realised. When looking at the old situation it is apparent that the forest of columns along the Buffalo Bayou makes up an unwelcoming space, the river does not have enough space and at this point the park does not continue.

The first step I have taken is removing the old post office, the train tracks and several roads and bridges.

The second step was to move the river bank more to the north and establish new infrastructure.

In the third step new mixed use buildings are placed on the north site. Public buildings at the north bank of the Bayou will function as an extension of the Theatre District. On the north bank a new part of the city park will arise bordering the public buildings. The new leisure centre is placed on the south bank with a good view on the park and the Bayou.

The new buildings of the master plan are situated on a small mount, just higher than the 1 in 500 year flood line. This so flooding of the buildings will be prevented. On the south side, the side of Downtown Houston this is not possible, so another solution against flooding should be sought for the leisure centre.
The Program is inspired on the program of SESC Pompeia (Lina Bo Bardi). A comprehensive and inclusive programme attracts interest from all age groups and social classes, without discrimination. The program had to be adjusted to the context: Houston, Texas. This diagram shows the relative size of every part of the program and how public or private each part of the program is. The diagram also shows the possible temperature fluctuation, which is an important part of the climate concept and helped define the aesthetics of the building.
The leisure centre will arise on the north bank of the Buffalo Bayou. The north side of the design location is looking out over the new park, festal terrain on the other side of the bayou. A pedestrian bridge is linking the two sides of the river. On the south bank the river side has a more urban design. Here a landing and terraces are forming the river bank.

On the south bank the newly designed master plan promotes interaction with the water. The new waterfront gives access to the water. The design of the leisure centre connects the Historical District and the Theatre District through its architecture and program. Because of the covered market square and the program of the leisure centre (has a cultural program as well as daytime program) it will create a buzz, produce crowds during night and day, attracting people from the different districts, Mainstreet and Market Square Park. At the same time, this design can handle a flood of 4 meters which is a 1 in 500 year’s storm. The urban and architectural design lets the city grid merge with the dynamic form of the waters of the Buffalo Bayou.
The **urban grid** is the starting point of the architectural design. This grid has a dimension of 75 x 75 meters. As starting point one block of the grid is taken. This plane is made green and then raised off the ground creating a green roof with space underneath it. Underneath this roof more planes are created with the same size of the urban block. These planes are forming the floors of the building.
Infrastructue In the old situation the grid extended over the river bank, creating left over and undesirable space at the river bank. To connect with the urban fabric, the grid will still stand as before. But to respect the natural landscape, the Buffalo Bayou, the floors of the lower part are cut off. This causes the design to interact with the natural and urban landscape, embedding the design into its surroundings.
The openness of the building creates a greater connection with the surroundings. This connection is the most apparent on the ground floor, where this floor is creating a public space in form of a covert square. This openness is created to take advantage of the climate and the views of the urban landscape.

The public square on the ground floor will be used for local markets, but can function as a small festival venue or a place for performances. Because of the temporary program on the ground floor, it can flood.

Routing and positioning of the program
Like SESC Pompéia, the program of the building is organised around a street, bringing public live from the street and the square underneath the building into the building itself. The streets spirals, like Très-Grande-Bibliothèque (OMA), but with stairs instead of ramps. An atrium in the middle of the building provides light to the building and its public square underneath it. The program is pushed back into the building to prevent heating of the building.
The program helped to shape the design. First the program was grouped so the function with strong relations to each other were on the same floor. Then the different functions were organised vertically, in such a way that the functions that have a strong relationship are on top of each other, but also that while moving through the building vertically, the rout stays interesting from ground floor to roof. Three components of the program which will have a very public function, the market, exhibition hall and restaurant were spread over the building vertically. As extra attractor to motivate people to go all the way to the top, a public open air space was added to the roof.

After organising the program vertically the floors have been shaped according to the function it houses, creating a sense of place within the building. The starting point were equally sized floors with same height. But the most important approach of the building is through Market Square Park, giving a good view of the building. Therefore towards the most important approach the space opens up. Stairs guide the visitor to the living room/lobby with view over the Bayou. Because of the importance of the library, it gets an extra high ceiling with an connection to the store and café. Because of the creation of the vide in the library, a slope is made that acts as the stand for the theatre. In front of the theatre is the foyer and restaurant. The art studios are facing north and are taking advantage of the views over the Buffalo Bayou and its park. The sports floor needs extra height. On the second highest floor is the depot, machine room, well out of reach of floods. The swimming pool is sunken into this floor. On the top floor is a bar where people can enjoy the views.
The supporting structure is the permanent and unchangeable part of the design. The material used for this is concrete. On this supporting structure different kinds of constructions can be added. These constructions are forming the façade, the stairs, and special parts of the program. These structures are made of other, less permanent materials, namely glass and wood.

Closed boxes are placed within the building. The boxes are placed in such a way that they themselves create new spaces on the different floors. These boxes penetrate the façade, creating an interesting composition.

Material and openness of the building define the intimacy needed for the program. The closed boxes have a low temperature fluctuation, in the open spaces it is medium. Within the building there are even places with high temperature fluctuations.
The floor pans are organised according to this diagram. There is a central vertical core with elevators and stairs. Another smaller core will function as emergency stair case. Within the courtyard, always on the exterior the inner street is winding up, floor by floor. Every other floor the landing on the opposite side of the elevators can be reached through a bridge crossing the courtyard so that both sides can always be reached from the central core. Along the landing of the inner street the entrances of different functions can be situated. In this way the building can still function while the different functions are closed off.

What are the rules?
- Floor with hole in the middle and a route and two cores
- Columns added 7,8 x 15,6m
- Grid of 2,6 x 2,6 m reflecting the ceiling
- On the grid, around the columns the boxes

Then the boxes are added. The boxes house parts of the program that need a more stable climate, sound proofing, a more intimate space. These boxes penetrate the outer layer of the façade and shutters, displaying their importance and adding a more diverse look to the building. Rules of the boxes
- On the outside the façade that sometimes goes inside
- On the outside, always on the same line the shutters
- Materialisation: all permanent things are of concrete and hard materials. All the dynamic elements are made of wood to show its softness, creating the more intimate spaces
The levels -1 and -2 are parking levels. These parking levels can house up to 266 cars. Being lower than the flooding line, the parking space will flood during a hurricane. Therefore, when there is a hurricane warning, the parking garage has to be evacuated. Thus this parking space is for visitors of the leisure centre and the rest of Downtown Houston and not a permanent parking spot.
On the first floor is the market place, situated at the public square. There is access to the water and the leisure centre.
On the second floor is the library and education centre.
View on library from bridge

06 DESIGN
On the first floor is the market place, situated at the public square. There is access to the water and the leisure centre.
Two foyers separate foyers provide entrance space for the different public programs: the theatre and the exhibition hall.
View on the theatre

06 DESIGN
The sporting floor is open to the element, but has shutters for shading.
This floor has public and private functions. The machine room is situated here, far from the harm of flood water.
The top floor has a roof garden, swimming pool and sun deck.
07 CLIMATE DESIGN
Smaller border between inside and outside climate
Three different climates within the building: not conditioned, mildly conditioned, totally conditioned.
Green roof
Window overhang
Sliding shutters as shading
Natural ventilation where possible
Mechanical ventilation if needed
Floor heating and cooling
Building functions as a big cold rock
Boxes only total conditioned spaces
Boxes the only space with insulation
Solar cells on a veranda like structure on the roof
- Program Climate Consult uses data downloaded from the internet for the wanted locations
- Climate info, in grey the comfort zone
- Ground temperature is around 22°C throughout the year. Therefore the heat exchange pump does not need to use a lot of energy to cool the building.
- To prevent condensation the structure needs to be heated above the dew point. The dew point is does not conflict with the temperatures needed for the building.
Recommendations for the warm and humid climate of Houston from the computer program that are integrated within the design.
- For the climate system to function with a minimum of energy usage, shading of the windows is needed.
- Most of the cooling will be done through the floor cooling system.
Prefab concrete elements are forming the core of the construction. The cantilever is supported by extra beams. The floor panels came in sets and make the structure easy and fast to assemble.
Prefab elements

CONSTRUCTION
1. Computer floor from stone like material
   l. 650 x w. 650 x h. 40 mm
2. Wooden tile l. 650 x w. 650 x h. 40 mm
3. Poured concrete forming beam with the prefab concrete slab
   beam: l. 15.600 x w. 650 x h. 1.000 mm
4. Steel reinforcement for beam
5. Prefab concrete slab with floor heating
   l. 12.775 x w. 2.600 x h. 500 mm
6. Prefab beam
   l. 15.600 x w. 650 x h. 1.000 mm
7. Prefab concrete slab with floor heating
   l. 7.350 x w. 2.600 x h. 500 mm
DELTA INTERVENTIONS

Ceiling structure
* Larger surface for the heath exchange
* Gives strength and stiffness to floors
* Creation of space and place
* Functions as ornament
* Recognisable feature of the building

Floor structure

08 CONSTRUCTION
Facade concepts
09 FACADE

- glass railing
- walkable zone 1300 mm
- gap between tiles for drainage
- concealed drainage
- sliding shutters
- sliding doors
- continuous floor plain
- openness
- continuous ceiling
- façade can be moved to the inside
Facade fragment

09 FACADE
1. Concealed aluminum window frame
2. Glazed barrier
3. Computer floor from stone like material
   1. 650 x w. 650 x h. 40 mm
4. Steel frame for computer floor
5. Waterproof membrane
6. Computer floor from composite material
   1. 650 x w. 650 x h. 38 mm
7. Steel frame for computer floor
8. prefab concrete slab with floor heating
   1. 12.775 x w. 2.600 x h. 500 mm
9. Steel bracing element
1. Prefab concrete slab with floor heating
   l. 12.775 x w. 2.600 x h. 500 mm
2. Side beam of prefab concrete slab
   w. 250 mm
3. Silicone seal
4. - Wooden cover 25 mm
   - Aluminum frame window
   - Steel brace
   - Steel profile for fixing aluminum window frame
5. - Wooden cover 25 mm
6. - Top hung shutter roller
   - Top hung window roller
7. - Wooden shutters
8. - Wooden coffer
   - Aluminum window frame
9. Glass 12 mm
10. - Wooden brace
11. Computer floor from composite material
    l. 650 x w. 650 x h. 38 mm
12. Water proof membrane
13. Computer floor from stone like material
    l. 650 x w. 650 x h. 40 mm
Thermal comfort in warm urban spaces
Theory of Urbanism
Kito Samson
1371452

Abstract
Cities heat up easy and cannot lose their heat as easily as the rural areas. Cities become warm islands surrounded by cooler rural areas. This phenomena is called the “urban heat island” effect. The “urban heat island” effect is responsible for temperature differences up to 7°C. To promote street life and make it sustainable, the urban area must be a comfortable place to stay. The thermal comfort is, besides aesthetics, the dimensions and acoustics, important in determining how comfortable an urban space is.

This paper will focus on the thermal comfort in the warm urban space. Through a literature study this paper will discuss why a comfortable urban space is preferable and what the different methods are to increase the thermal comfort in the warm urban spaces: which elements promote a thermal comfortable urban space and what are the point to take into consideration. Firstly the paper will discuss which physical factors has effect on the temperature and comfort of an urban space, starting with the materials, then vegetation, orientation, humidity and air flow and shading. Secondly the physiological aspects will be discussed by the topics adaptation and metabolism. Lastly, the psychological aspects will be discussed together with spatial preferences.

Introduction
By the middle of 2009 the number of people living in urban area surpassed the number of people living in rural areas. Many of the world’s cities are located in warm areas. But also cities in colder areas are confronted with the heat that the city can produce or accumulate. Because of the lack of cooling vegetation surfaces, the build environment and their increased anthropogenic activity the city has a unique micro climate. The city is systematically warmer than the countryside. This creates the “urban heat island” (UHI) effect. Cities lack night-time relief from high temperatures (Smith, 2008).

Mechanical cooling reduces the internal temperature, but the waste heat that is emitted directly to the surrounding environment intensifies the UHI effect (Smith, 2008). The emitted radiant energy is being stored in the build surfaces. Furthermore, the building sector is currently responsible for over a third of global greenhouse gas emission. Traditionally in warm climates outdoor environment has been regarded as important as indoors in the life of the populace. This is expressed in the vernacular architecture. However, today many cities in the region experience rapid urban growth, but with a lack of involvement of the urban environment. (Agmed, 2003) Foreign architectural vocabulary, which are not fit for the warm climate are being imported in warm countries. The consequence is the use of air-conditioned building with hard boundaries between the inside and the outside, making the transition between the cooled inside space and the warm outside space big. This forms a boundary and is making the outside space unwanted.

Because of progressive degradation of the physical environment, the urban dwellers are inhibited to form any meaningful relationship with their urban outdoor setting. This makes their lifestyles increasingly introverted. (Agmed, 2003) So a reduction of the temperature in cities is not only wanted because of the UHI effect. The other reason for comfortable urban spaces is to strengthen the socio-cultural domain. (Agmed, 2003)

Comfortable outdoor spaces have a significant bearing on the comfort perception of the indoor ambience. Overheated outdoor environments have contributed to growing preference for a lower comfort temperature indoors. The comfort of the outdoors can be expanded into the indoors. This is particularly important for sustainable building, especially free running buildings. Comfortable urban space can be considered to have a more direct influence on the perception of comfort indoors. (Agmed, 2003)

The choice of materials has a great influence on the thermal gain, but also vegetation and spatial characteristics influences the thermal comfort. But, not only physical characteristics determine a positive thermal evaluation of a space, also physiological and psychological elements.

Physical influence on thermal comfort
The “urban heat island” effect is mainly influenced by urban design, namely the canyon radiative geometry, anthropogenic heat and the materials’ physical properties (Doulas, Santamouris, & Livada, 2004). A more positive balance can be achieved by reducing the thermal gain in the urban environment, and in particular by reduction of the absorbed solar radiation. While bringing the temperature down, a more thermally comfortable urban that will be used more and can strengthen the social-cultural domain.

Material
Buildings and streets can heat up from direct sunlight. But streets can also heat up because of the emitted infrared radiation from various buildings and street surfaces that impinges on the surroundings surfaces and is entrapped inside the street canyon (Doulas et al., 2004). The materials where these streets and buildings are made of have the potential of storing and emitting energy in the form of heat. The choice of building materials for buildings and streets can influence the temperature in an urban space. Certain kind of materials can influence warm urban spaces negatively. An example of this, out of a study by Asaeda, Co, and Wake (1996), at maximum, asphalt pavement emitted an additional 150 W per square meter in infrared radiation and 200 W per square meter in sensible transport compared to a bare soil surface.

Optical and thermal characteristics are important aspects of a building material to determine their thermal performance; the albedo to solar radiation and the emissivity to long wave radiation are the most significant factors (Doulas et al., 2004). The albedo of a material is an important factor in defining a material’s thermal characteristics. Differences in the mean daily surface temperatures of a material are mainly caused by the different albedo factors. The physical characteristics of the material that affects their albedo are the color, the surface texture and the construction material.

A study on different building material on pavements of Doulas et al. (2004) suggest that there is a range of materials, from “cold” to “warm”. It concluded that “Cold” materials can be characterized those having a smooth and light colored surface and construction materials made of marble, mosaic and stone. These materials are characterized by a high reflectivity factor to short wave radiation and high emissivity factor to the long wave radiation (Doulas et al., 2004). “Warm” materials can be defined those having a rough and dark colored surface and construction materials made of pebble, pave stone and asphalt (Doulas et al.,...
The use of the so-called “cold” materials can improve thermal comfort conditions during warm periods.

Vegetation

Vegetated areas or water bodies within a city can have a significant cooling effect on local temperatures. Urban green structures can cool hot air by evapotranspiration; shade parts of the ground and walls, which results in a reduction of radiant temperature and control of the thermal comfort felt by the users of a space. Vegetation can be used as a temporary and complimentary screening solution. (Picot, 2004) Vegetation not only reduces the solar radiation on buildings, thereby reducing the UHI effect, it can also be considered as a real tool for control of the thermal comfort felt by the users of a space. Vegetation reduces solar radiation absorbed by a person situated below a tree canopy. Trees absorb and reflect the biggest part of the solar radiation (global or diffuse). Vegetation is an active element, reflecting energy that can increase the terrestrial radiation absorbed by a person. (Picot, 2004) Vegetation can be used as a temporary and complimentary screening solution.

When using vegetation in as shading in a design, the designers have to take in account that vegetation needs time to reach their final shape. Not considering this aspect can have a higher energy consumption in buildings and higher temperatures in urban spaces as result (Picot, 2004).

Orientation

The amount of solar energy that buildings receive can be reduced by considering the orientation of streets and streamlining their design. East-west oriented streets suffer from a prolonged period of solar exposure by comparison with north-south oriented streets during the summer. This is a critical factor affecting thermal comfort, as direct solar radiation is capable of elevating the radiant temperature by as much as 25 K. (Smith, 2008)

Street orientation is also important for the urban ventilation. An angle of 45 to the prevailing wind direction is considered optimal (Smith, 2008). Advection across parks can accentuate the cooling effect of the wind.

Airflow and humidity

Airflow in urban spaces increases the number of people thermally satisfied at temperatures below 34°C. Airflow significantly increases the upper boundary of acceptable relative humidity. It was observed that notable adaptation to high humidity varying between 70 and 80% even without airflow was observed. With airflow above 2 m/s the level of humidity for comfort was found to extend up to 95%, (Agmed, 2003).

In warm-humid tropical conditions open spaces which allow breeze to pass through are comfortable, but semi-enclosed spaces that often restrict free air motion at times have been reported to be comfortable during hottest period of the day as well (Agmed, 2003).

However, there is a sharp decline in tolerance to high temperatures with progressively humid conditions. Tolerance to high humidity, ranging from 7 to 85% was notable even under calm conditions with close to skin temperature. It was observed that with increasing humidity, the difference between globe and air temperature reduced considerably, along with an overall decrease in comfort temperature. At a high humidity range of 80-95%, the sensitivity to convective as well as radiative thermal sensation concurs. The higher the humidity, the lower the comfort temperature (Agmed, 2003).

The body adapts itself to different situations. A person’s adaptation to higher temperatures are even better when aided. These adaptations can influence the boundaries of the levels of thermal comfort. People wear different kinds of clothes throughout different kind of seasons. They adapt to the outside temperature; when it is cool, they put on a heat, when it is too warm, they can take of their jacket. Cool beverages help to cool down the body temperature, making the bodies tolerance for high temperatures higher (Nikolopoulou & Steemers, 2003).

The effect of temporality (i.e. duration of the exposure to a particular ambiance) is most pronounced among subjects categorized as “indoor types”. Opposed to the “outdoor types” who stay more time outside. The indoor types feel during a short stay outside more warm discomfort. (Agmed, 2003) Temporal adjustments to warmer ambiences takes place following a considerable length of time.

Psychological influence on thermal comfort

Purely physiological approach is inadequate to characterize thermal comfort conditions outdoors. Although physical adaptation takes place, i.e. with seasonal variation of clothing and increased consumption of cool drinks noticed with increasing temperatures presence of sunlight, the results of studies imply that psychological adaptation seems to be more important. (Nikolopoulou, Baker, & Steemers, 2001)

The physical environment and the psychological adaptation are complimentary to each other. (Nikolopoulou & Steemers, 2003)

There are three psychological parameters that has influence on the judgment of an urban space, without being influence by other parameters.

The first parameter is the naturalness, which is part of the character of a place. Areas with naturalness are being evaluated positively in studies (Nikolopoulou, Baker, & Steemers, 2003). (Hesseling, 1987). The presence of some trees repeatedly neutralized the negative evaluation of empty space. The naturalness can be significantly increased, by ‘greening an area, adding vegetation or views of landscapes, particularly within the dense urban context, which would accentuate the distinct character of the different areas. (Nikolopoulou & Steemers, 2004)
The next parameter is past experience. Past experience is not so much site-related, as much as it is a variable people bring to the space. Some action can be taken to affect it, particularly the short-term experience. This would be more relevant to the design of the urban fabric or the urban block as opposed to a single site. Since, people’s thermal sensation is influenced by their immediate short-term experience, by providing more spatial variety in the city, a rich variety of different environments can be experienced, between indoors and outdoors, affecting their thermal sensation. (Nikolopoulou & Steemers, 2003)

The third parameter is perceived control. Perceived control can be affected by providing increased opportunities for physical adaptation to take place. Reactive adaptation, such as clothing and metabolic heat, depends on the individual and is not site related. Spatial variation, however, is a parameter that can be catered for. Providing a variety of sub-spaces within the same area is preferable. For example: access to the sun, shade, exposure to breezes as well protection from the wind. Also movable elements like parasols and awnings that give protection from the sun or rain provide spatial variation and are normally appreciated by users of the space. (Nikolopoulou & Steemers, 2003)

These are the main parameters that can be influenced from the design point of view. (Nikolopoulou & Steemers, 2003)

Other parameters are time of exposure environmental, stimulation and expectation. These parameters are influenced by the ones mentioned above: naturalness, past experience a perceived control. (Nikolopoulou & Steemers, 2003)

Time of exposure to the outside can be positively influenced by naturalness, past experience and perceived control. Environmental stimulation is when a person takes advantage of the environmental properties, i.e. sitting in the sun when he or she feels cold or taking in fresh air when coming from the indoors. It is desired to provide opportunities for these different kinds of environmental stimulation. (Nikolopoulou & Steemers, 2003)

People sit in the urban space of their own free choice. The degree to which they want to ‘charge up’ their body with heat and fresh air is important, especially when considered in combination with a person’s thermal history. Did they come from a cold office building and want to sit in the warmth of the sun.

Regarding expectations, this is also linked to the design of open spaces but only indirectly, by affecting the degree of perceived control. (Nikolopoulou & Steemers, 2003)

McIntyre (1980) findings shows that people voting for the neutral temperature in warm climates prefer to be cool and people in cold climates prefer to be warm.

Spatial preference

People have preferences for places to stay in their urban environment. Out of a study, done by Agmed (2003), the spatial preference of people throughout the day in a warm urban climate was the following:

In the early hours of the day, when temperature is below the daily mean, open spaces or spaces with partial shading are desirable (Agmed, 2003). Because of the openness of the space, it can easily dispase of its excess heat and thereby making it cooler. Also this space is open to the sun, so that users can take advantage of it rays.

During the midday, when temperatures are above mean, the preference go out to complete shading. i.e. transitional space on street level or higher level which are open to the street, Space like balconies, arcades, circulation corridor, entrance lobby etc., or Spaces such as those covered with overhead canopy and colonnades. All these spaces have an overhead cover and are being part of a building. No other barrier, like glass to the outdoor condition are preferred (Agmed, 2003).

In the late afternoon (17:00 h), when radiative gain is minimum, open fields or spaces with no enclosures are desirable. Such places allow radiative loss from a person’s body in all directions and any available airflow adds to convective loss. These spaces are outdoor open spaces that are not enclosed by any buildings or at a considerable distance from any building enclosures. Spaces, such as open field, large squares. These spaces include spaces next to a large water body; open spaces close to riverbanks, lakes and canals. (Agmed, 2003)

Conclusion

A comfortable urban space as many benefits. A lower temperature in urban spaces will lead to a reduction of energy usage for cooling and a reduction of the “urban heat island effect”. The lower outdoor temperature will have its impact on the experience of the interior climate of a building. A comfortable outdoors has influence on the comfort temperature indoors (it can be higher). Indoor comfort should not be perceived as isolated from the effects and influences of the outdoor conditions on a person. Moreover, a comfortable urban space will strengthen the social-cultural domain.

While designing a thermal comfortable urban space, three factors has to be taken into account. Those factors are the physical, physiological and psychological. These three factors are influencing each other strongly.

It is inadequate to design open spaces with regard to thermal comfort, solely on the basis of a physical model. Physical environment and psychological adaptation is important as well. A well designed space can provide protection from negative aspects and exposure to positive aspects of the climate, therefore increasing the use of outdoor space throughout the year. Different seasons require different approaches. A variety of spaces providing different environments would maximize both physical and psychological adaptation.


