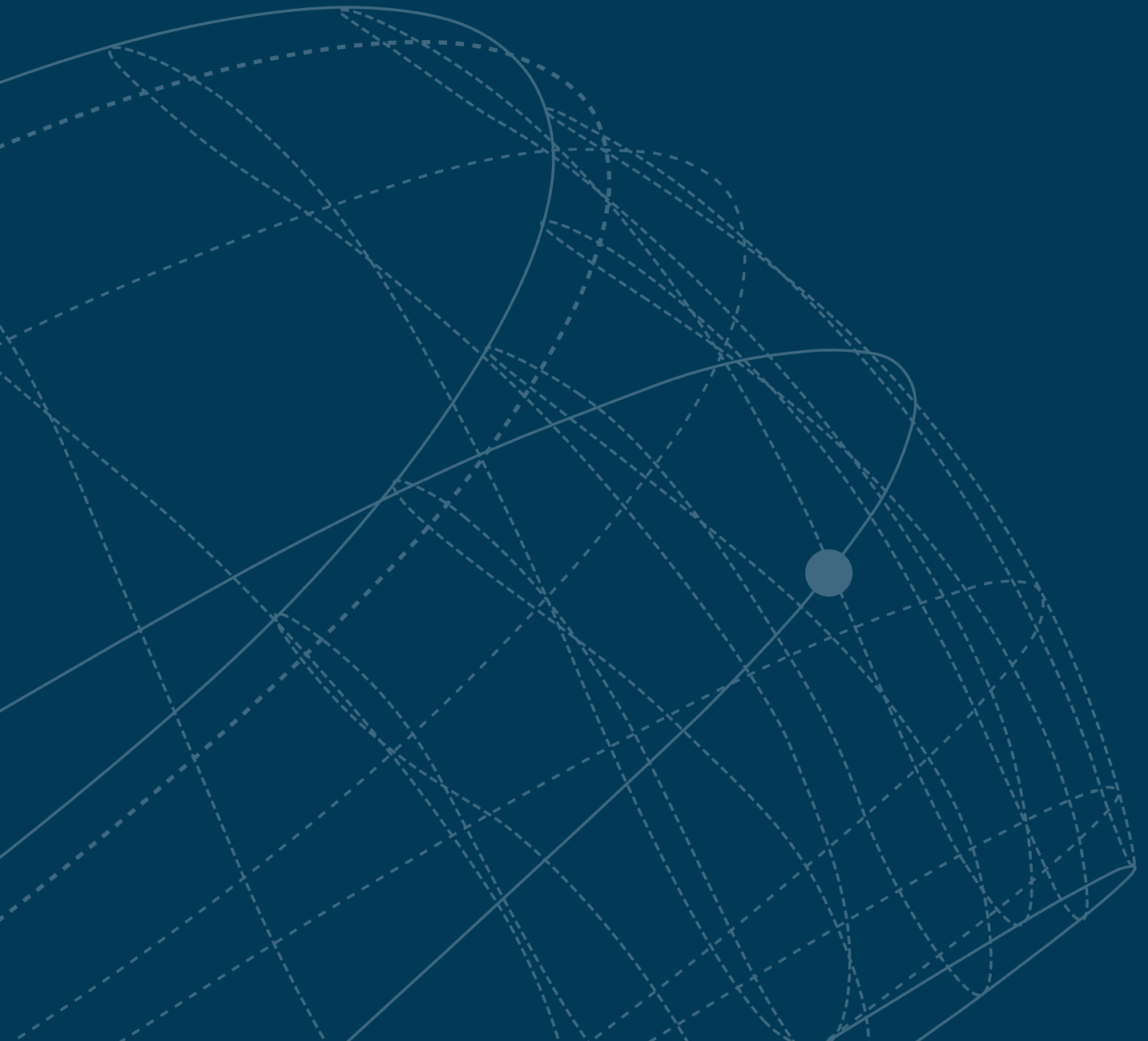


# DESIGNING FOR **CLIMATIC PHENOMENA**

by Bart Wolbert





## COLOFON

### TITLE

Designing for climatic phenomena, exploring the architectural potential of climate responsive design

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## ABSTRACT

Excessive amounts of fossil energy have disqualified climatic considerations as boundary factors for architecture. This has limited architects to operate in the visual realm, while the invisible senses that make up climatic design are generally disregarded. As a result contemporary buildings are usually unable to provide balanced living conditions without the support of external sources of energy.

When climatic phenomena are considered in building design, architecture can generate an informed response through its geometry. By allowing the local climatic context to influence archetypes and low-tech design solutions, buildings become able to benefit from their environmental energy potential through architectural means. Such climate responsive buildings reflect their surroundings through architecture, making them highly location specific.

This thesis examines the bioclimatic design philosophy in order to connect architectural thinking to climatic considerations. 9 buildings that are based on geometric principles found in sunlight, solar heat and wind show how architectural methods and techniques can be used to create climatically balanced living environments.

## KEYWORDS

bioclimatic design, climate responsive design, phenomenology, low-tech design, location specific architecture



# Preface

Actively experiencing the weather is a joy that I have come to appreciate greatly. Simply listening to the rhythmic dripping of the rain or watching clouds pass by through a window can give a reassuring feeling of time passing slowly.

I like to look at architecture as a way to influence this experience by reinforcing or limiting certain phenomena. The pavilion in the image at the left by artist James Turrell demonstrates this ability. It draws the visitor's attention towards a circular skylight where the sky seems to become tactile. The result is a truly meditative experience of the weather that is different at any given time.

This soft quality of architecture is often accidental and rarely the soul purpose of a building. However I am concerned that architecture is moving in a direction away from this experience, creating sealed boxes with perfectly balanced climatic

conditions.

My graduation project, for which this thesis is written, is a quest to find an alternative understanding of architecture where climate is seen as an integral quality instead of a technical consideration. This graduation-thesis will be presented together with the first findings of a coinciding design project at the faculty of Architecture and the Built Environment of the TU Delft at 20 June 2017.

I would like to thank my tutor Dr. Ir. Remco Looman for his support and advice that allowed me to write this work.

I hope you enjoy your reading.

**Bart Wolbert**

Delft, 6 June 2017

## **LEFT**

The Color Inside, James Turrell  
Skyspace (Holzherr, 2013)

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CHAPTER 1

# INTRODUCTION

## § 1.1

# Motive

The way in which architecture works together with its climatic surroundings is a reflection of the alliance between human and habitat. The health of this relationship can be considered as the essence of sustainability.

There is a certain misbalance between the built environment and the natural environment. This is largely due to the enormous amount of energy that has been and still is harvested from fossil fuels. Because energy has been available in excess for a long time, both our society and our architecture have become dependent on external sources of energy.

Mechanical climate control systems were developed to provide a stable comfort for buildings that are unable to do so by themselves. Heating, cooling and ventilation became detached from the architectural realm and became separate issues that were dealt with in stand-alone installations, often hidden in basements, ceilings and on rooftops. With enough machinery any building could be made habitable, no matter how bad and unadapted to its surroundings. Buildings have become able to operate without consideration of their natural climatic environment. This has disqualified climatic considerations as boundary-factors for design (Looman, 2017).

Architecture is essentially about creating space that is suitable for human habitation. But with the detachment of climatic considerations the discipline found itself restricted to the visual aspects of architectural perception. Architects have lost influence on issues of climate and comfort. This has become the responsibility of specialists in the field of climatic design, who are often only involved in the later stages of the design process (DeKay, 2014).

Because of this discrepancy it is difficult to reach integration between climate design and architecture. The problematic nature of this relationship became apparent as soon as energy consumption became an issue in the 1970's (Looman, 2017). Sustainability had to be integrated in architectural design, while the discipline had lost control of the climatic design that makes up its energetic performance. This is why sustainable buildings generally use ready made 'sustainable' solutions such as Photo Voltaic cells, solar hot water and heat pumps to solve climatic problems that are in fact caused by the architecture itself (Yanovshtchinsky, 2013).

The real challenge is to use the architecture of buildings to create comfortable, balanced living environments with as little technology as possible.

## § 1.2

# Problem analysis

Environmental sustainability has been a heavily debated topic in architectural discourse for the past few decades. Architects are often concerned that design becomes too technocratic when sustainability is a decisive factor. In other words, sustainability is seen as a distraction to architects when they try to design beautiful buildings. This shows the current limitations of the architectural realm.

The way in which we perceive and experience architecture is essential in order to understand this issue. Architecture has become increasingly focused on visual appearances, neglecting all the other senses (Pallasmaa, 1996). This ocular-centric approach is blind to the climatic considerations that are fundamental in the design of sustainable buildings. For the building climate is made up of mostly invisible phenomena, such as ventilation, humidity, temperature and acoustics.

Light became especially dominant in architecture in the first half of the 20th century, with the establishment of Modernism. One of its founders, Le Corbusier, famously explained architecture as “the masterly correct and magnificent play of masses brought together by light” (Le Corbusier, 1923, p. 31). This illustrates the visual approach to architecture which has signified architectural understanding to date. Architecture came to be about the creation and limitation of space. Because this concept did not include climatic considerations, a global architecture became within reach.

The dominant ideas of the modernist movement were critiqued in an exhibition about rural architecture at the MoMA, famously titled *Architecture Without Architects*. Its author, the American theorist Bernard Rudofsky expressed his concerns with the International Style of architecture that modernism aspired. He pointed out that vernacular architecture is often strongly embedded in its local culture and climate, qualities that modern architecture seemed to have lost (Rudofsky, 1965). This is because rural architecture had to deal with all aspects

of the design, including climatic considerations, simply because there were no alternative means available. The climatic context determined the design for a comfortable indoor climate, which resulted in site specific architecture.

But the locality that signified vernacular architecture is seldom seen in newly constructed buildings (Yanovshtchinsky, 2013). The 2014 Venice Architecture Biennale, curated by Rem Koolhaas, critically examines the age of modernism with respect to national identity. Koolhaas states that during this era the once specific architecture has become interchangeable and global. Contemporary architecture is deemed a “modernity with national features” as it recognizes the quality of local identity while failing to surpass modernist thinking (Koolhaas, 2014, p. 22).

One of the biennale’s installations shows a false ceiling underneath a solid dome ceiling, shown in the image at the right. This represents both the contrast between global and local identity, as well as the lost connection between architecture and climate design. One might argue that architecture has been reduced to the surface of the building, unable to influence its own climatic and energetic performance.

To create architecture that is in balance with its natural surroundings we must incorporate climatic considerations in architecture.



**ABOVE**  
Ceiling installation at the 14th  
Venice Architecture Biennale  
(OMA, 2014)

### § 1.3

## Objective

The objective of this research is to explore the architectural potential of designing in response to the local climate. Connections between climatic thinking and architectural thinking are investigated to allow climatic aspects to factor into design decisions. The underlying premise is that the integration of the now separate disciplines of architecture and climate design is fundamental to create balanced and sustainable living environments.

People are not naturally inclined to change. That is why sustainable alternatives can only be successful if they provides us with added value. This means that there is an important role to play for architects to discover non-environmental advantages in sustainable design solutions (Hal, 2014). Instead of making compromises, buildings

should perform noticeably better than before.

By showing that architecture effects both the local climate and the building climate, architects become aware of their influence. This is the starting point of the search for integral quality that comes from designing in connection to the natural cycles of climatic phenomena. Professor Ralf Knowles once stated that “something reassuring comes from matching our actions with the motions of nature”, he adds that “the something may remain forever unknown” (Knowles, 2003, p. 23). This shows the promise of using a climate responsive strategy for an enhanced architectural experience.

### § 1.4

## Research questions & thesis outline

Resulting from the objective and approach, the following central research question is formulated:

***How can buildings become in balance with their climatic environment through architectural design?***

In relation to this main question, the following sub-questions are researched in four corresponding chapters:

***1. How can climatic considerations be introduced to architectural thinking?***

In chapter two the topic of this thesis is conceptualized. A literary review presents different notions of what the realm of architecture entails in terms of dealing with the local climate. The result is a framework that shows the relationship between architecture and climatic phenomena.

***2. In what ways and with which techniques can architectural design be informed by the influence of sunlight, solar heat and wind?***

Chapters three, four and five show case studies based on the conceptual framework constructed in the previous chapter. Each chapter shows three buildings that are analyzed to show different strategies for dealing with the climatic environment. This research question is answered in three separate conclusions, corresponding to the three topics; sunlight, solar heat and wind.

# Methodology

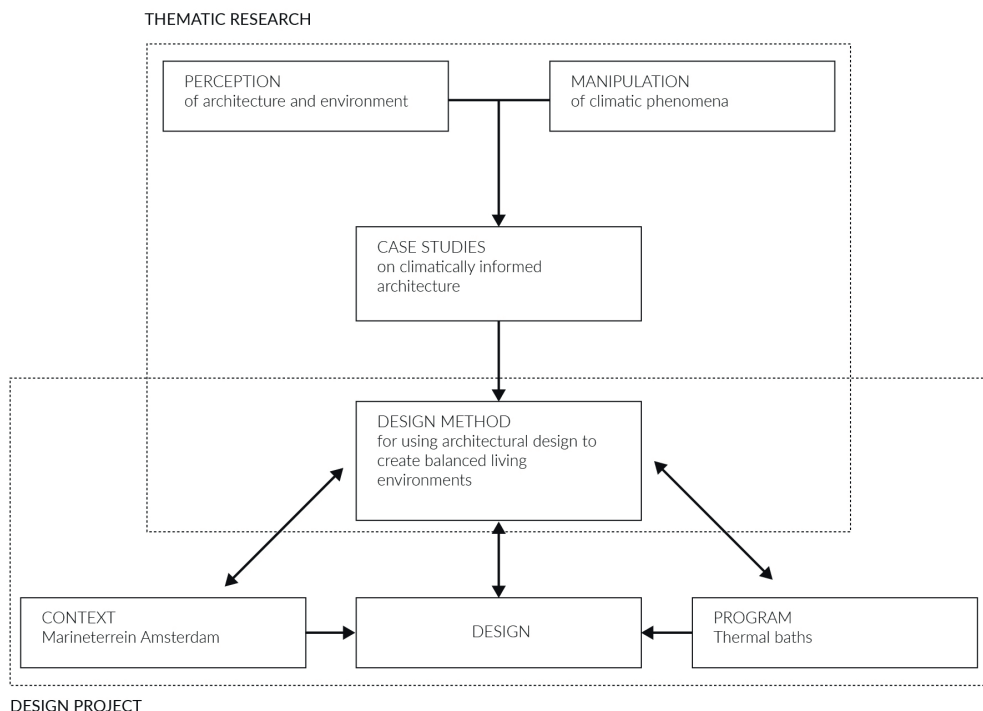
With regard to the philosophy of the 'Intecture' graduation studio for which this research is conducted, the focus is on the integration of technical solutions in architectural design. This implies an interdisciplinary approach where a gap between the 'technical' and the 'architectural' realm is bridged. The problem that is central to this research is located inside this gap. It is caused by a discrepancy between climatic knowledge and architectural application.

This research is qualitative and exploratory, as it looks for patterns, hypotheses and ideas that can create connections between architecture and climatic design. The primary method of research is the use of case studies on buildings that show different ways in which design can manage the influence of climatic phenomena. They are selected as clear examples of buildings whose design is based on specific aspects of their local climate, namely; airflow, sunlight and thermal

exposure.

Firstly the relationship between architecture and it's climatic environment is investigated in terms of perception. From the senses that are used to experience the environment, a connection is made to the climatic phenomena that influence our (built-)environment. After that a framework is constructed of ways in which the required physical properties of space can be translated into design input. This framework is filled with case studies on buildings that are designed to have an explicit relationship with a certain climatic phenomenon. These cases are interpreted in terms of techniques and methods that are used to orchestrate natural climatic influences.

As aforementioned this research is part of a graduation project that includes a design project, that is based on the findings of this thesis. The diagram below visualizes the relationship between the thematic research and the design project.



## § 1.6

# Constraints

This research is constrained to the climatic effects that building geometry has on its interior and surroundings. Because the shape of buildings is mainly designed by architects, this is where their primary influence on climatic issues can be found. The Hierarchy of Strategies pyramid as shown below explains the relationship between the different levels of design in accordance to the influence of architects and engineers. In this scheme, the bottom two levels can be addressed by a building's geometry. The first level is that of archetypes, where the orientation, shape, size and proportions are considered. Secondly the level of passive strategies deals with the configuration of the building in order to use natural forces to cool, heat and ventilate (DeKay, 2014).

The levels of efficient technology, integrated

performance and green power are outside the scope of this research as they are considered to be issues that lean towards engineering. By only addressing the two base levels of the pyramid the research has a clear focus on the potential influence that purely architectural decisions have on climatic issues.



# Relevance

To reduce societal dependence on fossil fuels we have to design our built environment to be in energetic balance. This study aims to integrate ways in which architectural design can be informed by climatic influences. Such a study could be relevant for anyone interested in the improvement of architecture through the adaptation of climatic principles.

Lots of literature can already be found about bioclimatic design and climate responsive design. It is the search for connections with architectural thinking that might lead to new insights. With the multi-sensory understanding of phenomenological architectural perception, bioclimatic and climate-responsive design can be studied from a different perspective. The aim is to create a bridge in knowledge between these two fields of research, with the ultimate goal being a more sustainable (built-)environment.

The idea of using climatic phenomena to shape architecture is inspired by pioneering architecture practices such as UN Studio, Foster + Partners & BIG. These firms are actively engaged in theoretical-research, while simultaneously testing out their findings in experimental architecture.

The connection to climatic expertise is made through manuals for architects by engineers. Firstly *Sun, Wind & Light* describes methods for architects to deal with climatic influences on their buildings (DeKay, 2014). Secondly *Climate-Responsive Design* shows an elaborate overview of the design principles and solutions that architects can use to establish sustainable energy-concepts (Looman, 2017).

**LEFT**

Hierarchy of Strategies  
(after DeKay, 2014)

CHAPTER 2

# BIOCLIMATIC THINKING

This chapter aims to find connections between architecture and climatic phenomena. The corresponding research question is:

***How can climatic considerations be introduced to architectural thinking?***

Within this study, the bioclimatic design philosophy is used to analyze the influence of climate on architectural perception and expression. This specific attitude towards architecture aims to create a built environment in harmony with the natural (climatic) environment. With this inclusive understanding of climate and architecture, buildings are able to respond to their climatic context through their design. This is referred to as climate responsive design (Looman, 2017).

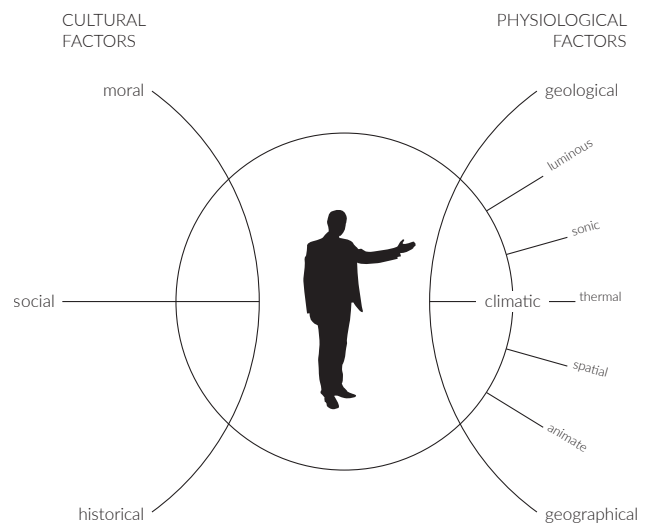
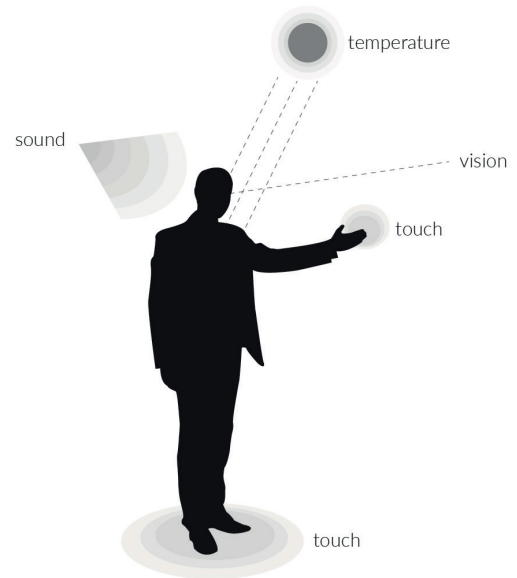
Although the primary motive for applying this method is to benefit from the environment's energetic potential, there is a possible gain for architectural expression to be explored. In this chapter connections between architectural thinking and climatic thinking are analyzed in terms of perception, authorship and sensibility. The result is a framework of climatic influence on architecture that forms the basis for case studies in the following chapters.

## § 2.1

# Architecture and perception

As mentioned in the problem analysis of the previous chapter, contemporary architectural thinking has been dominated by visual perception since the nascency of Modernism. Because of this singular focus other senses that are used to experience the environment are rarely considered as crucial design considerations. This section is based on the premise that our visual understanding of architecture is entangled with its current discrepancy with climatic considerations. An alternative to the modernist ocular-centric understanding of architecture can be found in architectural phenomenology. This episteme is based on the appearance of built space in which human experience is central. Architects involved in this movement share a desire to create a more sensual architecture. One of its best known representatives is Juhani Pallasmaa, who stated that the increasing visual focus in architecture has led to a flattening of our multi-sensory capacities of imagination, where architecture has been decayed into passive visual manipulation (Pallasmaa, 1996, p. 14). In his fundamental book; 'The eyes of the skin', Pallasmaa advocates considering all the senses that are used to experience environments in architectural design, illustrated in the image at the top of this page (Pallasmaa, 1996).

This body-centered philosophy was fundamental in the development of bioclimatic design. In 'Design With Climate', one of the books that established the topic, human experience is considered as the basis for architecture (Olgay, 1963). This understanding allows climate to become one of the main factors to influence architectural expression, as shown in the image at the bottom of this page.



**TOP-LEFT**  
Sensing the environment

**BOTTOM-LEFT**  
Factors influencing architectural expression  
(Adapted from Olgay, 1963)

**RIGHT**  
Design method for vernacular architecture

# Climate as author

Bioclimatic thinking allows climatic considerations to become decisive factors in the design process. This allows architecture to be informed by and respond to its climatic environment. Buildings can form an alliance with their surroundings, taking advantage of the natural energy sources that are present for passive or low-energy comfort provision, which is called climate responsive design (Looman, 2017).

When a building is designed as a response to its climatic environment, the relationship between architecture and climate is redefined. Buildings can be regarded as intermediary between human and habitat. Naturally occurring elements like sunlight and wind are filtered to control the experience of the inhabitants (Rocca, 2007).

This method is not a recent invention but a mere re-appropriation of traditional values found in vernacular architecture. Such architecture is often based on low-tech comfort provision by managing available flows of energy. It reflects its climatic environment, making it highly site specific (bottom image).

In this respect, climate can be seen as a co-author of architecture, influencing the design and use of buildings in a creative dialogue with architects and users (Hill, 2012). This dominant role of climate in architectural design is expressed by a brand of architects who use the potential of computation to integrate (climate) engineering with their discipline.

UN Studio's principle architect Ben van Berkel once stated that the potential of computation in architecture lies in "its flexibility to communicate design across multiple disciplines via associative data" (Berkel, 2016, p. 287). His office frequently uses climatic analysis software to come up with architectural geometry in a method they call "Form Follows Energy" (Zotov, 2017).

This incorporation of climatic conditions in architecture could be a solution for its current lack of cultural identity, according to architect Bjarke Ingels. He states that when buildings are appropriated to the local climate for which they are intended, architecture will once again be location-specific (Ingels, 2015a).

But with vernacular strategies alone, meeting our current standard for comfort is not always possible (Bilow, 2012). Climate responsive design shows that adapting to the local climate does not mean going back in time to recreate vernacular examples. By using digital techniques of analysis and parametric generation new archetypes can be created that form an alliance with their climatic surroundings.



## § 2.3

# Time and climatic phenomena

Time and climatic phenomena are strongly intertwined. When climate is considered in architecture, so are the effects of time. Suddenly architecture can be acknowledged as a dynamic form which changes its appearance and operation over time (Hill, 2012).

In this sense responsive design is not a synonym to transformable design. Its response can also be a passive reaction to a dynamic environment. The essential precondition for responsiveness is not activity, it is sensitivity (Beesley, 2006). Therefore climate-responsive design focusses on the sensitivity of architecture rather than on its own dynamics.

During the architectural design process the 'sensing' of climatic phenomena is primarily executed in a digital environment through computational analysis. This provides architects

with the means to design in correspondence with the geometry of the climate, effectively managing relations between time and space.

Because of this entanglement, the success of climate responsive design is dependent on our ability to predict the future. When the long term climate changes, so does the energy potential of the environment (Looman, 2017). A degree of flexibility is required to adapt to changes in climatic context. Because of the uncertain future of climatic development, it is wise to design for a foreseen period of time. This means that the period after use has to be considered before construction, including principles of reuse and sustainable demolition.

## § 2.4

# Framework

A framework is constructed for the selection of case studies that are executed in the following chapters. This framework includes a selection of climatic phenomena, and a division of architectural design in levels of scale.

### TOPICS AND SCALES

The possibilities for architecture to respond to its climatic surroundings are dependent on the availability of climate resources. This makes up the energy potential of the local environment which is used by climate responsive design to meet comfort demands.

A classification can be made with the topics; sun and sky, earth, wind and water (Looman, 2017). Because this research is limited to architectural means for climate design, only the influence of climate on archetypical and passive strategies is considered. The energy potential of earth and

water is generally harvested through mechanical systems, limiting its effect on architectural expression. This leaves the topics sun and sky, and wind. The prior is divided in sunlight and solar heat, disregarding atmospheric conditions because of their fickle nature. This results in the classification; sunlight, solar heat, and wind.

Three levels of scale correspond to the three topics of climatic influence: urban form, building shape and facade geometry. These levels represent the scales of architectural design that are influenced by climatic conditions. Firstly the level of 'urban form' represents the influence that the building's shape has on its surroundings. The level 'building shape' refers to the way the building's geometry can affect interior conditions. Finally the level 'façade geometry' deals with the impact that the building-skin has on the indoor climate.

## SELECTION CRITERIA

Three selection criteria were used to find the right projects to investigate, in accordance to the design project that will be executed based on the findings of this research. These criteria are: scale, function and local climate.

Firstly the scale. The selected cases should correspond to the global dimensions of the design project; a mid-rise public building. This is mainly important for the first two scale levels because they consider the overall shape of the building. The facade level is less concerned with the building's size because the design solutions are often repeated to cover a larger surface area, making them scalable. This level will show the most variation in this aspect.

Secondly, the case studies are selected to be in line with the proposed function of the aforementioned design project; a thermal bath complex

with public swimming facilities and a restaurant. To correspond to this occupation only non-residential buildings will be considered. Because this project is multifunctional, the occupation is not the most strict of criteria.

Finally the local climate of each case is compared to that of Amsterdam, where the design project is set. This context will greatly determine the building's attitude towards certain climatic phenomena. It is therefore important that the selected projects are set in a climate that is comparable to Amsterdam's Temperate Oceanic Climate.

The following table shows the 9 selected projects that will form the case studies in the following sections.

	SUNLIGHT	SOLAR HEAT	WIND
<b>URBAN FORM</b>	Solar Carve Tower <i>building shaped for public solar access</i>	SUTD Campus <i>building shaped to cast shade on its surroundings</i>	EEA & Tax Offices <i>building shaped to manage wind flows of its surroundings</i>
<b>BUILDING SHAPE</b>	Mirai House <i>building shaped to allow solar access to itself</i>	City Hall London <i>building shaped for self shading</i>	30 St. Mary Axe <i>building shaped to manage wind flows for interior use</i>
<b>FAÇADE GEOMETRY</b>	Endesa house <i>facade shaped to allow solar access to itself</i>	Shenzhen International Energy Mansion <i>facade shaped for self shading</i>	GSW Headquarters <i>facade shaped to manage wind flows for interior use</i>



## § 2.5

# Conclusion

In the previous sections the relationship between climatic considerations and architectural thinking is examined. Through the topics of environmental experience, architectural authorship and responsiveness connections are made between the two bodies of knowledge, resulting in the following conclusions.

A body-centered approach to architectural design is essential for creating balanced climatic environments. A multi sensory understanding of environmental perception makes it possible to include the invisible aspects of climate design like ventilation and acoustics as decisive factors for architectural design. In this sense a connection between bioclimatic design and architectural phenomenology becomes apparent. The ideology of phenomenological architects can be used to extend the impact of bioclimatic design to the architectural realm, by designing for a sensual experience that includes aspects of both architecture and climate design.

When a building is designed as a reaction to its climatic surroundings, climate can be regarded as an author of architecture that helps to generate archetypes that are highly site specific. This shows that designing with climatic phenomena can lead to a reinforcement of architecture's local identity.

When architecture is designed to perform in different climatic scenarios through time, architecture is considered as a dynamic form. It becomes responsive to climatic phenomena because it senses its environment. This does not necessarily mean that the building itself is able to move or transform, it means that its design was informed by a certain sensitivity.

A framework is constructed of climatic phenomena that can be sensed in (computational) analysis to induce an architectural response. The topics of this framework are; sunlight, solar heat and wind. The following three consecutive chapters will analyze these phenomena separately, on three levels of scale with one case-study each. The scales are; site, shape and skin.

CHAPTER 3

# SUNLIGHT

The sun is existential to all life and its importance to our environment can not be overstated. This chapter examines the ways in which architecture can be informed by sunlight in three case studies. In accordance to the framework presented in the previous chapter, the cases are selected as representative examples of; external illumination on building scale, internal illumination on building scale and finally internal illumination on facade scale.

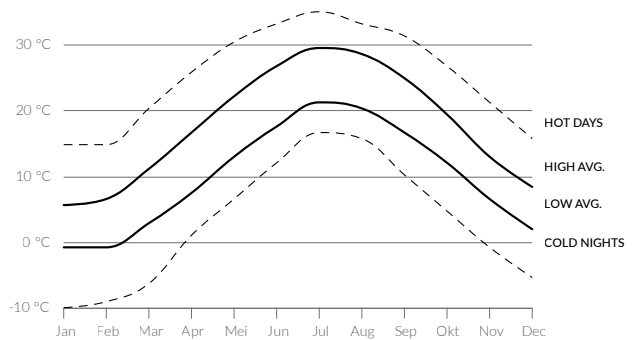
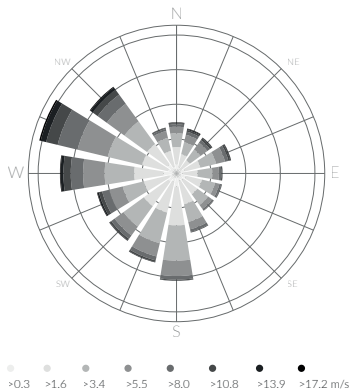
The first case examines an office tower in New York called the Solar Carve Tower. Like its name suggests, this building is shaped to allow solar access to its surroundings. Secondly the Mirai House in Leiden is analyzed as an example of a building that is shaped to allow optimal solar access to itself. Lastly the Endesa Pavilion in Barcelona shows how the same objective can be dealt with on the facade scale.

The findings from these three studies are combined to answer the question: ***In what ways and with which techniques can architectural design be informed by the influence of sunlight?***

CASE I

# Solar Carve Tower

*a building shaped for public solar access*



## GENERAL INFO

### PROGRAM

office building

### LOCATION

New York City, USA

### ARCHITECT

Studio Gang

### YEAR OF COMPLETION

under construction

### HEIGHT

60 m

### GROSS FLOOR AREA

13,300 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Humid Subtropical Climate

### PREVAILING WIND DIRECTION

West North-West

### AVERAGE WIND SPEED

4,0 m/s

### MEAN ANNUAL TEMPERATURE

12,8 °C

## BACKGROUND

This mid-rise office tower is set on a small plot at the very edge of Manhattan. With the Hudson River at the west and the High Line Park adjacent at the east the site is surrounded with valuable public area's. The quality of this space became the main inspiration for the design. Principle architect Jeanne Gang claims to be designing for social connectivity. Her work represents a critical view on high-rise buildings, for creating isolated environments that fail to connect to the street level public space while burdening them with environmental problems such as strong winds and shadows (Gang, 2015).

## MAIN CLIMATIC CONSIDERATION

To ensure the quality of the bordering High Line Park, the sun- and daylight access needed to be maintained. In addition the views from the elevated park on the Hudson River were to be preserved. A straightforward rectilinear envelope would block the view as well as the afternoon solar access from the west. Preserving these important civic area qualities was the main climatic consideration for the building-envelope design.

## CLIMATE RESPONSIVE STRATEGY

A form-finding strategy is used to maximize solar access to the surrounding public area, which the architect named "solar carving" (Gang, 2015, p. 121). This entails the manipulation of the angles of the building's envelope according to the sun-path. The intersection of these geometries creates a tapered form that represents the allowable space to built.

This geometry is further shaped by eye level directional angles from the park towards the waterside. Like the sun path this geometry is sliced off of the building envelope. Building within this three dimensional boundary should allow an additional 200 hours of daylight per year to the neighboring park according to the architect (Gang, 2015).

The building is closely fit within the generated envelope to demonstrate its response to the environment. The result is an explicit shape that visually leans away from the public area.

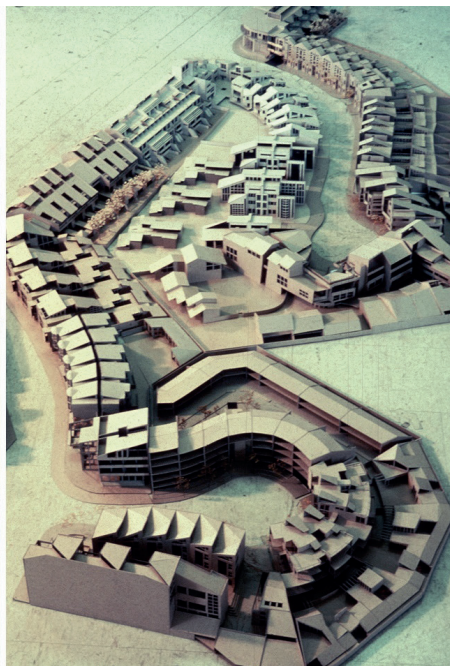
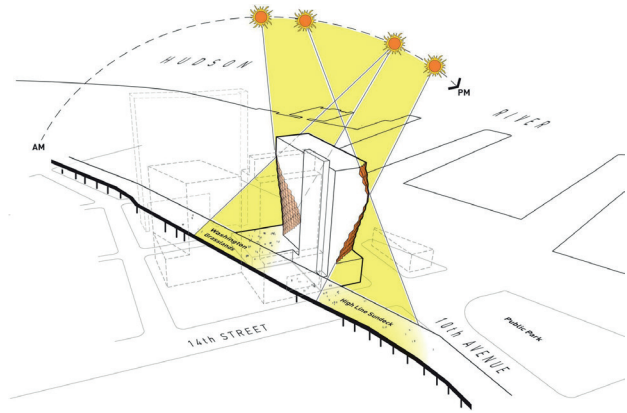
## LEFT

View from High Line Park  
(Gang, n.d.)

## TECHNIQUES & METHODS

The idea of using a solar envelope to control urban massing is based on the solar envelope by professor Ralf Knowles. This instrument of zoning is used to provide urban solar access by creating imaginary containers of space derived from the movement of the sun. Buildings within these three dimensional boundaries will not overshadow their neighbors within certain predetermined periods of solar access (Knowles, 2003). The project in the image below shows how the boundary conditions can be the basis for an urban scheme, where high-rise and low-rise buildings are naturally distributed to guarantee equity in solar access.

While the solar envelope was originally developed as a tool for sustainable urban zoning, Knowles recognizes the aesthetic potential for architecture and urbanism (Knowles, 2003). Architecture can reinforce the presence of natural cycles such as the rhythm of day and night. In the solar carve tower the connection with the movement of the sun is made explicit, in both its name and appearance.



**TOP**  
Solar carving of the envelope  
(Gang, n.d.)

**LEFT**  
Solar envelope massing  
(Knowles, n.d.)

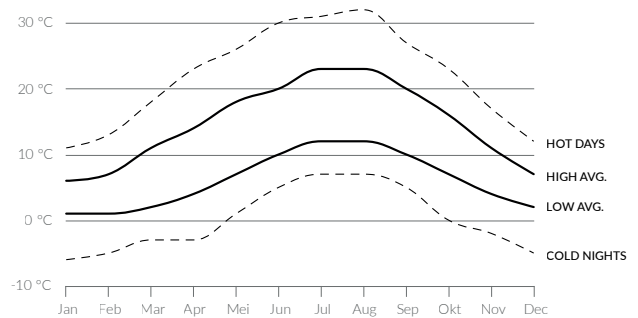
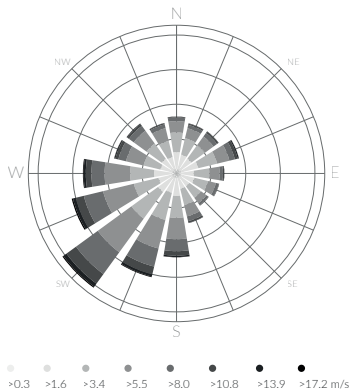
**RIGHT**  
Areal view  
(Gang, n.d.)



CASE II

# Mirai House

*a building shaped to allow solar access to itself*



## GENERAL INFO

### PROGRAM

office building

### LOCATION

Leiden, The Netherlands

### ARCHITECT

UN Studio

### YEAR OF COMPLETION

2012

### HEIGHT

30 m

### GROSS FLOOR AREA

16,700 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Temperate Oceanic Climate

### PREVAILING WIND DIRECTION

South-West

### AVERAGE WIND SPEED

7,5 m/s

### MEAN ANNUAL TEMPERATURE

9,5 °C

## BACKGROUND

The Mirai House is home to the Dutch branch office of a Japanese pharmaceutical company. It is set in the Bio Science tech park in Leiden, near to the university medical center. Two thirds of the functional program is made up of office space, the rest consists of laboratories. An important factor for the design was its safety. To not make the building look like a fort the architecture is used to prevent related issues, resulting in a self enclosing typology (Architectenweb, 2013).

## MAIN CLIMATIC CONSIDERATION

Allowing sufficient daylight to enter the building was the main priority for the massing of the building. Most of the facades are made of glass, to create a light and transparant atmosphere with views on its surroundings. During Holland's relatively hot summers the amount and temperature of sunlight is high, which requires regulating its access. This should prevent glare and excessive solar heat gain.

## CLIMATE RESPONSIVE STRATEGY

Both the building's shape and its facade and ceiling geometry are used to allow sufficient daylight to enter. The building is V-shaped, with its opening pointed towards the south, creating two wings that are west-east oriented. The south facing ends of the wings are closed to block the noon sunlight that is most intense. Most of the offices are north oriented while the courtyard embraces the sun from the south. A lower entrance area closes off the v-shape, creating a delta shaped floorplan on street level that encloses the courtyard. This part of the building has an overhanging roof to prevent direct solar access from the south (UN Studio, 2016).

## LEFT

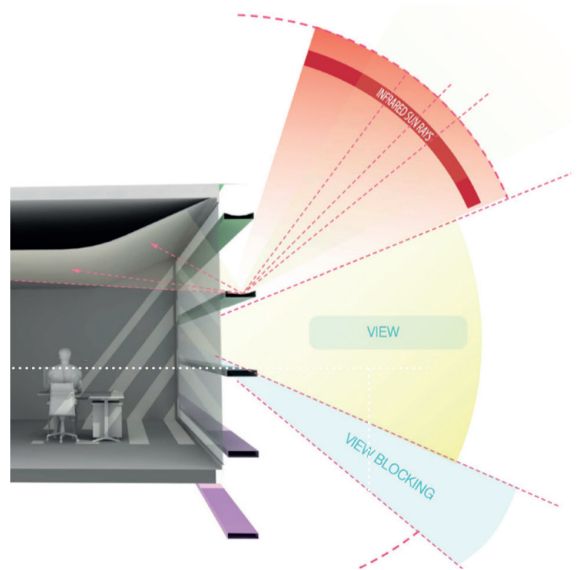
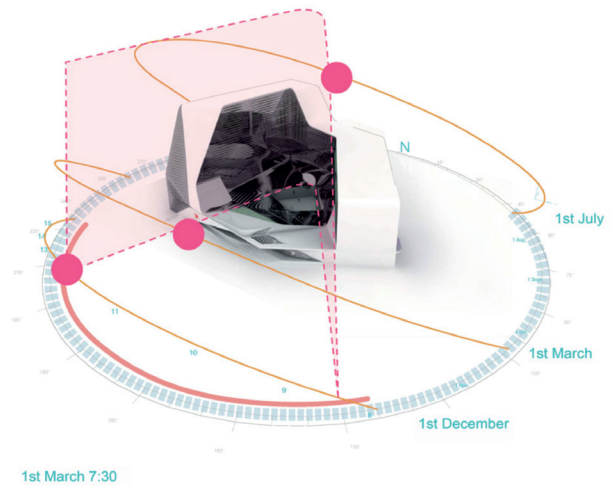
View at etrance (Richters, 2013)

## TECHNIQUES & METHODS

A method that the architect calls 'solar dynamics' is used to refine the shape of the envelope. Three critical dates are selected to represent different climatic scenarios during a year. On these dates the temperature and the amount of sunlight are combined to determine the correct strategy. The low winter sun is desirable and will be embraced by the v-shaped courtyard, from which it penetrates deep into the building (UN Studio, 2016).

During the morning when the sun rises, the west wing benefits from the lower east wing because it allows the sun to pass earlier in the day. In the afternoon when the sun sets, the west wing would block the sunlight access of the lower east wing. This undesired effect is minimized by 'slicing off' a diagonal piece of mass on its end, parallel to the direction of the winter sun.

In summer the warm sunlight will be mostly kept out of the building by the use of horizontal lamellae that double as light shelves on each facade. This results in a high quality of daylight throughout the seasons. The shape of the ceiling is used to reflect daylight deep into the building, visible in the image at the right of this page.



**TOP**  
Annual solar access  
(UN Studio, 2016)

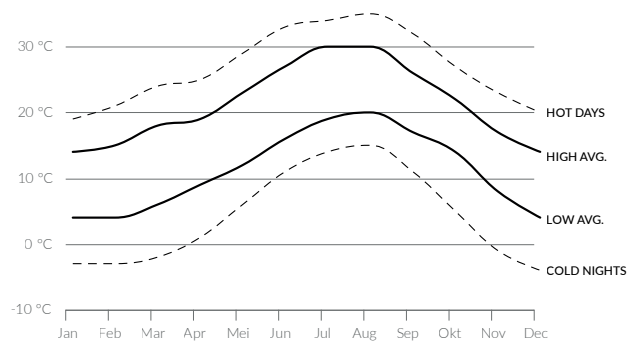
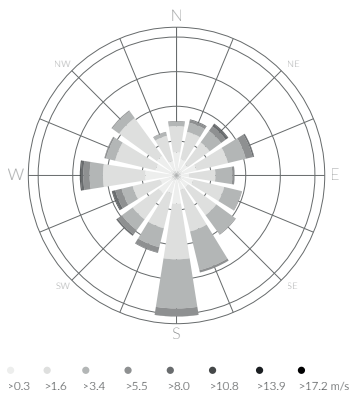
**BOTTOM**  
Light direction at facade level (UN  
Studio, 2016)



CASE III

# Endesa Pavilion

*a facade shaped to allow solar access to itself*



**GENERAL INFO****PROGRAM**

pavilion / research facility

**LOCATION**

Barcelona, Spain

**ARCHITECT**

IAAC

**YEAR OF COMPLETION**

2011

**HEIGHT**

6 m

**GROSS FLOOR AREA**153 m<sup>2</sup>**CLIMATIC DATA****CLIMATE CLASSIFICATION**Hot-summer Mediterranean  
Climate**PREVAILING WIND DIRECTION**

South

**AVERAGE WIND SPEED**

3,6 m/s

**MEAN ANNUAL TEMPERATURE**

21 °C

**BACKGROUND**

This small wooden pavilion was built at the Marina Dock in Barcelona for the 2011 Smart City Expo World Congress. It served as a research facility for projects on intelligent power management for a year, after which it was taken apart. With its 150 m<sup>2</sup> of floor area, this building's scale stands out in comparison to the other cases. But this pavilion functions as a prototype of a facade system applicable to different scales, shown on the next page (Markopoulou, 2015).

**MAIN CLIMATIC CONSIDERATION**

While this pavilion is a prototype that should function in various locations, its adaptable geometric concept is based on Barcelona's conditions. With its Hot-summer Mediterranean Climate the main concern was to keep the building cool. Direct sunlight is undesirable and should be eliminated for most of the year. In this climate, the challenge is to guarantee daylight access nonetheless. A coinciding opportunity comes from the high amount of available solar energy that can be harvested as electricity.

**CLIMATE RESPONSIVE STRATEGY**

The facade system makes up most of the building's functionality. Each modular element controls solar heat gain, daylight admission, artificial light, insulation, and its own energy production. With its saw tooth geometry, the facade casts shade on itself where needed to reduce undesired solar heat gain and glare. Indirect daylight reflects off the jagged surface through the sunken windows. In some more horizontal parts a window is added that allows reflected daylight from lower panels and the surrounding deck to enter, clearly visible in the image

**LEFT**View from High Line Park  
(Gang, n.d.)

on the bottom of the opposite page. PV panels on the top surfaces are used to generate electricity for the all electric climate support systems. These panels actually generate a surplus of energy of about 40%, which means that the building only uses the power of the sun to work (Markopoulou, 2015).

### TECHNIQUES & METHODS

The geometry and configuration of the facade system is generated from a parametric model that adapts to the location of the project and the orientation of the facades. The latitude determines the sun-path, which is used to analyze the admitted solar radiation. The angles and the length of the pointed wooden louvres are optimized to keep the direct sunlight. These dimensions determine the amount of vertical facade in between that can be used to place windows.

Because the design is parametric, replacing the sun-path to fit an alternative location will generate a new geometry to match. This allows the design to be used in any location with the same climatic considerations (Markopoulou, 2015).



#### TOP

Model for a multi-level application  
(IAAC, 2013)

#### TOP-RIGHT

Detailed view of the facade  
system (Goula, 2011)

#### BOTTOM-RIGHT

Interior view of daylight  
admittance (Goula, 2011)





## § 3.4

# Conclusion

The three cases show various ways and techniques in which architectural design can be informed by its relationship to sunlight. The sun-path provides a clear geometry for architecture to respond to.

Throughout the scales of architectural design the geometric principles stay the same. The first case shows how solar analysis can be used to create a building that allow sunlight access to its surrounding civic spaces. This is achieved by constructing a solar envelope that the building may not exceed. In this case the access to sunlight was the building's primary consideration.

The same principles are used in the second case, where the building's mass is limited by the solar access on itself in stead of its surroundings. In this case however, more factors way in to the process of developing the shape, like issues of program and security. The design process is therefore less linear than that of the previous example, multiple iterations are necessary to achieve a result that satisfies all evaluation criteria.

In the last example a parametric facade concept provides a generic solution that can be specified to its location. A basic strategy for sunlight and solar heat management is customized by adaptation to the site specific sun-path and orientation.

This results in a facade that looks and performs differently because of its specific relationship to the sun.

This shows a gradient of responses to the sun; from the creation of a sun-based boundary, to an iterative process where the sun is one of the design criteria, to a facade-system where the sun is a parameter. This degree of responsiveness to sunlight is based on the scale of design.

CHAPTER 4

# SOLAR HEAT

Apart from its light, the sun provides the earth with solar heat. Whether a building embraces or takes shelter from this heat is primarily dependent on its climatic environment. In this chapter three case studies are examined to study the ways in which architecture can be informed by solar heat access. These cases represent an architectural response to solar heat on three scales of design; site, shape and skin.

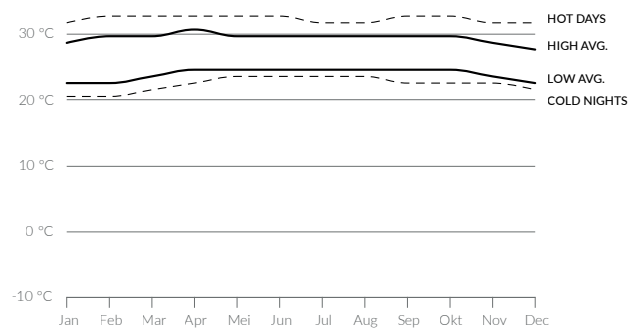
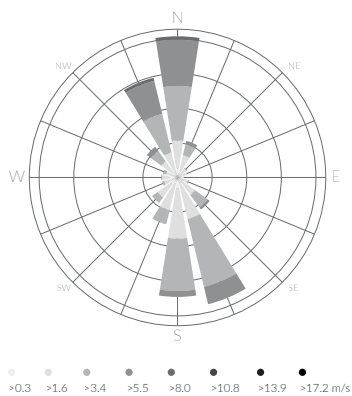
Firstly the SUTD Campus in Singapore exemplifies a building that is shaped to cast shade on its surroundings. The second case is the City Hall in London, a building that is shaped for self shading. Thirdly the Shenzhen International Energy Mansion shows how a building's facade can be shaped to the same effect.

The results of these studies combine to formulate an answer to the question: ***In what ways and with which techniques can architectural design be informed by the influence solar heat?***

# CASE IV

## SUTD campus

*a building shaped to cast shade on its surroundings*



## GENERAL INFO

### PROGRAM

university campus

### LOCATION

Singapore

### ARCHITECT

UN Studio

### YEAR OF COMPLETION

2015

### HEIGHT

32 m

### GROSS FLOOR AREA

213,000 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Tropical Rainforest Climate

### PREVAILING WIND DIRECTION

North

### AVERAGE WIND SPEED

2,65 m/s

### MEAN ANNUAL TEMPERATURE

27 °C

## BACKGROUND

The campus of the Singapore University of Technology and Design (SUTD) consists of five interconnected structures that create a comfortable in-between environment for circulation and relaxation. Interaction was a key aspect for the spatial organization. Four faculties are spread across the different parts of the building in a non-linear way that allows students and faculty members of different disciplines to meet. This characteristic is reflected in the transparency and lightness of the interior spaces. At the intersection point in the centre of the campus a flexible multi-purpose space is realized for exhibitions and other events (Fearson, 2015).

## MAIN CLIMATIC CONSIDERATION

The architect's primary objective for this academic campus was to create healthy spaces conducive to learning (UN Studio, 2016). An important requirement to achieve such a space is sufficient daylight. But allowing the sun to enter a building can easily result in a huge cooling load due to Singapore's location of about 1° off the equator. The city-state has a Tropical Rainforest Climate with temperatures that rarely drop below 25°C. Therefore the main climatic consideration was to create sunlit spaces without the undesired solar heat gain.

## CLIMATE RESPONSIVE STRATEGY

A courtyard system with 11 large atria makes the complex inward oriented, opening up possibilities for self shading. The different building blocks provide shade to each other, to themselves and to the open public spaces that are intertwined throughout the complex. Ranging from shaded courtyards and lounges to half open circulation spaces

### LEFT

View from entrance  
(Hufton+Crow, 2015)

that connect these areas on all floor levels (Berkel, 2016).

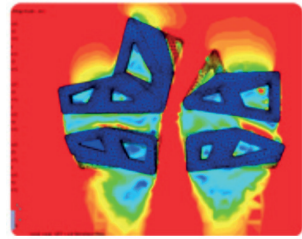
The building's circulation space is mostly outside which means that the interior volume that needs to be climatized is relatively small. Because the corridors are positioned on balconies behind the half open facade, the heat gain is reduced. This is due to the setback of the glass and external shading at the edge of the balconies. In areas without these balconies horizontal louvres operate to the same effect.

### TECHNIQUES & METHODS

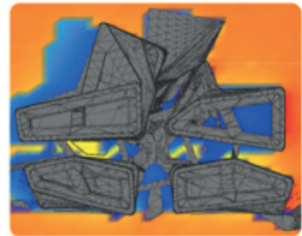
The building is oriented to minimize the hot east/west solar exposure while allowing access to northeast and southeast prevailing winds for the purpose of natural ventilation (UN Studio, 2016). Therefore both the separate building blocks and the enclosed atria are elongated and west-east oriented. Perforations at different floor levels allow the wind to flow through the building, cooling down the half open hallways. This effect is reinforced by plants and trees that cool the air due to natural evaporation while providing additional shading.

The shape of the building mass was optimized using various dynamic modeling analyses of climatic conditions such as natural ventilation, outdoor daylighting, solar radiation and outdoor shading, shown at the right side of this page. This influenced the parameters that generated the design, such as the orientation and shape of the structures and the distance in between. By controlling these parameters the buildings massing provides the interior and the outdoor gathering spaces with shade and a light breeze (UN Studio, 2016).

Natural Ventilation



Outdoor Daylighting



Solar Radiation



Outdoor Shading



**TOP**

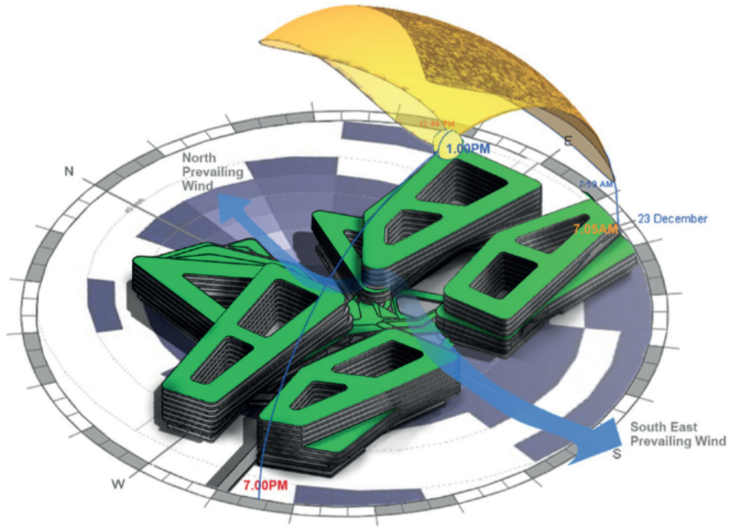
Virtual climatic analysis  
(UN Studio, 2016)

**TOP-RIGHT**

Wind and sun access  
(UN Studio, 2016)

**BOTTOM-RIGHT**

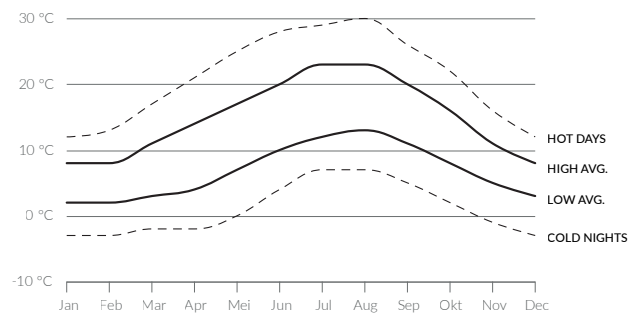
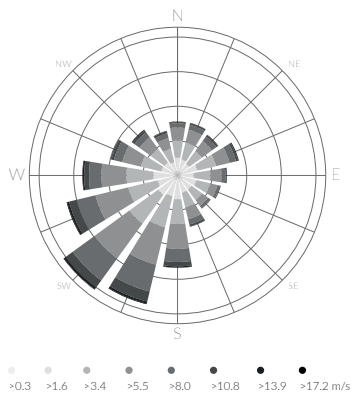
View on courtyard  
(Hufton+Crow, 2015)



# CASE V

## City Hall London

*a building shaped for self shading*



## GENERAL INFO

### PROGRAM

office, congress and public functions

### LOCATION

London, United Kingdom

### ARCHITECT

Foster + Partners

### YEAR OF COMPLETION

2002

### HEIGHT

45 m

### GROSS FLOOR AREA

19,800 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Temperate Oceanic Climate

### PREVAILING WIND DIRECTION

South-West

### AVERAGE WIND SPEED

3,6 m/s

### MEAN ANNUAL TEMPERATURE

11 °C

## BACKGROUND

The City Hall in London was constructed in 2002 as a part of the Foster-designed 'More London' masterplan on the south bank of the river Thames. It is home to the Mayors Office and the Greater London Authority (GLA). Next to 500 workspaces for the administration, the City Hall includes the city's parliament chamber and several public functions. A 500 meter long spiraling visitors' ramp in a large atrium at the north side of the building is used to connect all floors. It starts at the exhibition space at ground level and passes the debating chamber and the mayor's office to end in London's Living Room at the top of the building. Office spaces are wrapped around this oval atrium at the south side. At basement level a sunken outdoor amphitheater connects the adjacent conference rooms and exhibition space to the public area (Foster, 2002).

## MAIN CLIMATIC CONSIDERATION

The building is designed to set an example for sustainable architecture and aims to be a "symbol for the future" (Foster, 2002, p. 1091). A goal was set for the maximal energy consumption for mechanical installations of 25% compared to similar structures. This meant that the the reduction of heating and cooling requirements became a crucial part of the design. Next to the energetic demands the design brief stated that the building should promote transparency and democracy. Combining these two objectives made the creation of a transparent building with limited solar heat gain the main climatic consideration.

## LEFT

Exterior view from boulevard (Sánchez, 2009)

## CLIMATE RESPONSIVE STRATEGY

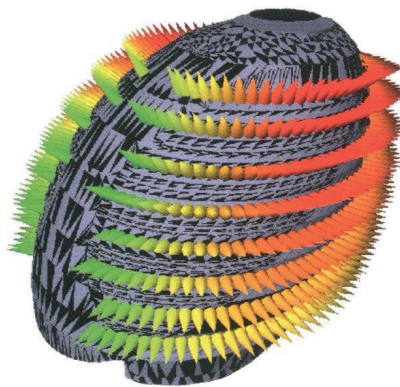
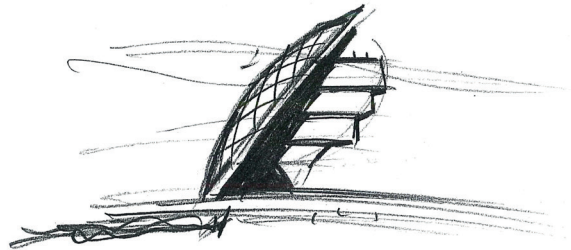
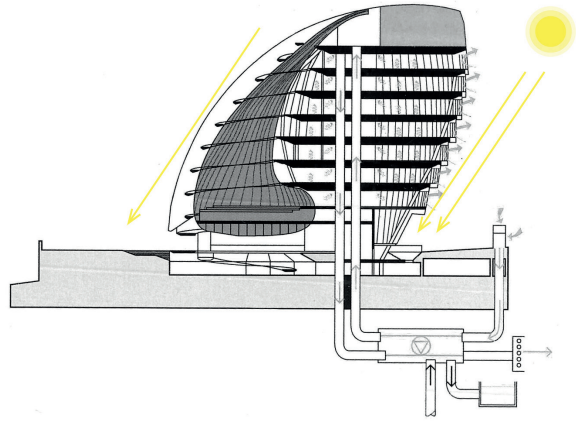
The building's unusual shape comes from a desire to create a radically energy friendly yet soft and modest building (Foster, 2002). The geometry is generated to be as compact as possible to reduce the envelope area exposed to heat loss as well as solar heat gain (Baird, 2010). As a result the building is ovoid shaped and oriented towards the point in the sky where the sun admits the most heat on a yearly basis. The principle behind this geometric strategy is called self shading.

The environmental control systems that are employed to assist the passive climate strategy exploit the naturally available resources of wind, sun and water. For instance the excess heat that is still admitted to the building is transmitted to the neighboring river Thames (Foster, 2002).

## TECHNIQUES & METHODS

Digital solar analysis tools were used to generate the shape of the building in accordance to the solar path. The self-shading is managed on two levels of scale; the overall shape of the building which is ovoid and pointed towards the sun, and the jagged facade geometry at the south side of the building. The latter provides the building with an extra tool to block solar heat gain at its hottest facade. Each floor slab cantilevers slightly relative to the lower ones, which allows them to cast shade on the lower windows. An early design sketch at the right side of this page clearly shows the distinction between these two geometric climate principles.

A thermal map of the surface based on the solar heat gain throughout the year is expressed in the building's cladding. The ration of cladding to glazing increases in areas with a high amount of admitted solar radiation (Foster, 2002). This principle is reflected in the internal organization, with the large conservatory located behind a clear glass facade at the North side of the building. To further increase the amount of insulation, highly insulated panels were used alongside high performance glazing (Baird, 2010).





**TOP-LEFT**

Climatic section  
(Foster & Partners, n.d.)

**CENTER-LEFT**

Early concept sketch  
(Foster & Partners, n.d.)

**BOTTOM-LEFT**

Insolation and heat load analysis  
(Foster & Partners, n.d.)

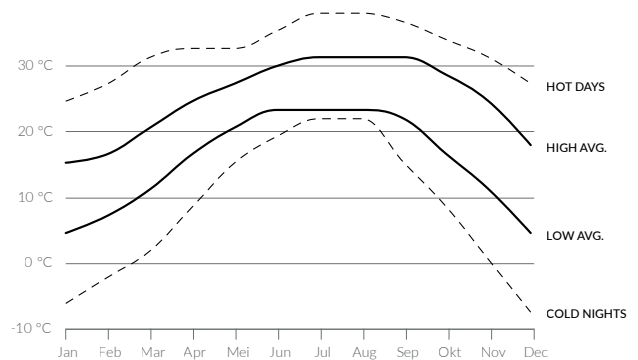
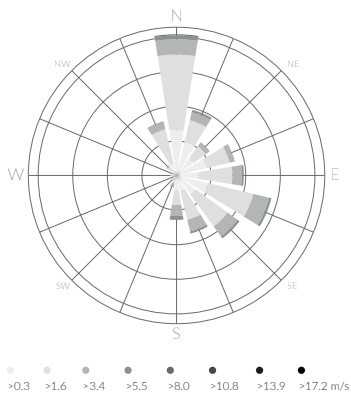
**RIGHT**

Birds eye view  
(City Hall London, n.d.)

CASE VI

# Shenzhen International Energy Mansion

*a facade shaped for self shading*



## GENERAL INFO

### PROGRAM

office building

### LOCATION

Shenzhen, China

### ARCHITECT

BIG

### YEAR OF COMPLETION

under construction

### HEIGHT

200 m

### GROSS FLOOR AREA

96,000 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Monsoon-influenced Humid  
Subtropical Climate

### PREVAILING WIND DIRECTION

North

### AVERAGE WIND SPEED

8,2 m/s

### MEAN ANNUAL TEMPERATURE

24 °C

## BACKGROUND

Shenzhen is one of the five largest cities in China. The former fishing village is characterized by its rapid development since 1980 into the megalopolis it is today. Immense productivity is what the city is known for, as well as the accompanied energy use and pollution. This case-study is on the regional headquarters of the Shenzhen Energy Company that is currently undergoing construction. Energy use became the central topic in the design, that is a self proclaimed “model for the 21st century skyscraper” by its architect (BIG, n.d.).

## MAIN CLIMATIC CONSIDERATION

Shenzhen has a Monsoon-influenced Humid Subtropical Climate, which means that cooling generally makes up most of the building’s energy demand. In the case of this skyscraper the cooling load was decreased by presumably 30% relative to comparable structures (Ingels, 2015b). To accomplish this task minimal sunlight can enter the building. But because the building is mostly occupied with office space sufficient daylight is required. The main climatic consideration for the building envelope was to reduce the thermal heat gain while allowing daylight to enter.

## CLIMATE RESPONSIVE STRATEGY

The building’s massing of two connected towers was restricted by the urban masterplan. This precondition meant that the primary freedom for geometric innovation was to be found on the level of the facade, which is considered as a surface for heat exchange. The strategy to adapt the proposed rectilinear glass box to its subtropical climate is based on the relative positioning of open and closed parts (BIG, 2015).

## LEFT

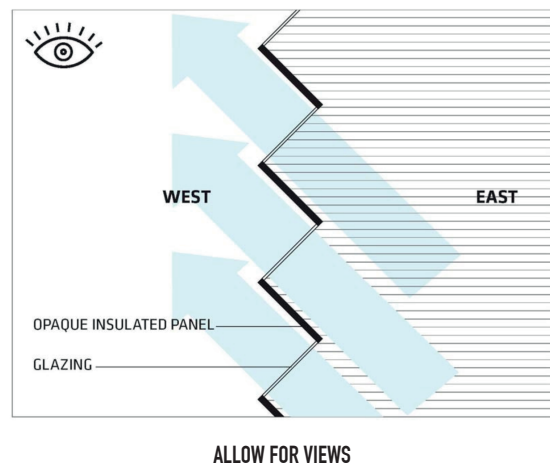
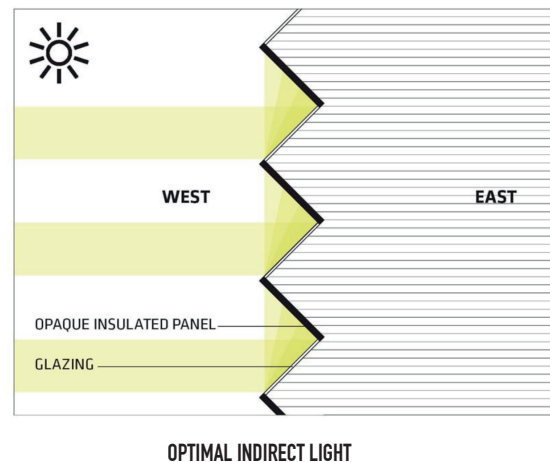
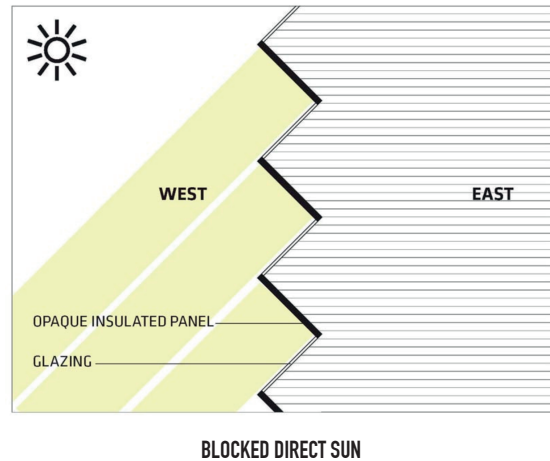
Exterior visualization from the north (BIG, n.d.)

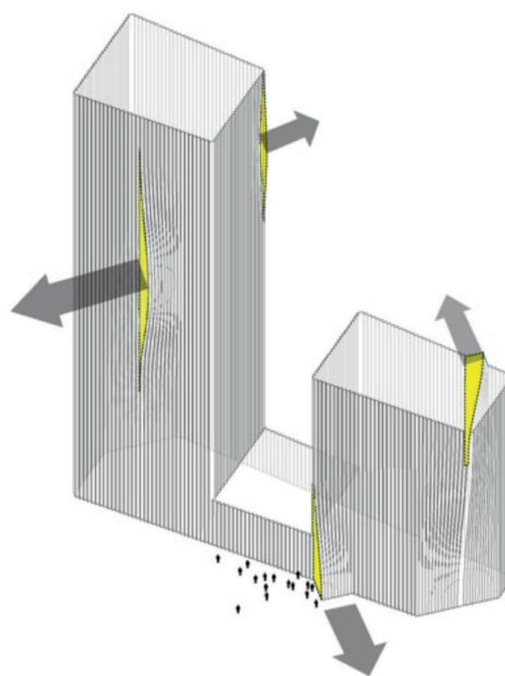
To make sure the solar heat gain keeps within bounds the facade is closed off at the surfaces where the potential heat gain is at its highest and kept open in the remaining area.

### TECHNIQUES & METHODS

The facade geometry is shaped according to the sun path. A zig-zag pattern is employed to create several small surfaces on every elevation with alternating orientations. These planes are treated differently according to their orientation towards the sun. North facing surfaces are constructed with clear glass while the south oriented surfaces are made up of opaque insulated panels. In this way the orientation and infill of the zig-zag facade pattern blocks direct sunlight and opens up to indirect light. This reduces solar heat gain and glare while creating spaces that are day lit with views towards the north. The architect describes the facade as “kind of like a dress; a fabric that ripples and is closed towards the south and open towards the north” (Ingels, 2015b, p. 113). In the image at the right side of this page, the climatic performance of the facade is explained in three steps: blocking direct sunlight, optimizing indirect light and allowing for views.

Within this concept specific alterations are made, as shown in the image on the opposite page. Wider openings allow more views and light where needed without additional solar heat gain because the orientation principle remains unchanged. This principle is used to create communal spaces for the offices like lounges and entrance area's.





**LEFT**  
Climatic performance of the  
facade (BIG, n.d.)

**RIGHT**  
Alterations in facade geometry  
(BIG, n.d.)



## § 4.4

# Conclusion

The cases that are analyzed in the previous sections show different ways and techniques in which architecture can be informed by the influence of solar heat. In all three of the cases the main climatic consideration was a combination of daylight admission and solar heat gain reduction. The climate responsive strategies all started by blocking out sunlight through adaptations in geometry, followed by optimizing the daylight admission.

In the first case study a university campus in Singapore makes use of its own mass to block direct sunlight from the surrounding and included public space. Solar heat gain formed a key consideration for the design, which together with routing and spatial organization generated the building's shape. The form finding process is intuitive in basis, with a short feedback loop from climatic analysis for testing and optimizing the proposed solutions.

The orientation and morphology were also essential in the design of the second case, the City Hall in London. But because of the difference in climate, its morphology is quite the opposite. Where the prior example is highly porous, this building's ovoid shape aims to enclose a maximal volume with a minimal surface area. In this case

the solar radiation was clearly dominant in the design of the building's rigorous shape. This is due to the strict geometric boundary on which it is based.

The last case shows an office building in Shenzhen, with a facade concept that is based on the reduction of direct sunlight through orientation. In this case the design principle is based on the orientation of the facade towards the sun. Its responsiveness is limited to the generic solution of a jagged facade element which is arrayed across the building's surface and adapted to its function on specific locations.

It is clear that on different levels of design, the level of responsiveness varies greatly. Architecture's influence on the solar heat of its site is highly entangled with spatial organization and routing and can not be assessed separately. The shape of a building can be primarily formed by solar heat admission when this is the main consideration. If the geometric freedom for solving solar heat related issues is limited to the level of building skin, its response will be defined by the orientation of the facade-surface.

CHAPTER 5

# WIND

The way in which buildings influence airflow is often neglected by designers, making its effects accidental and undesired. When a more pro-active approach is used to the subject, options arise to prevent related complications and even to create added quality. Three case-studies show different ways in which architecture can be informed by the wind on the levels of; site, shape and skin.

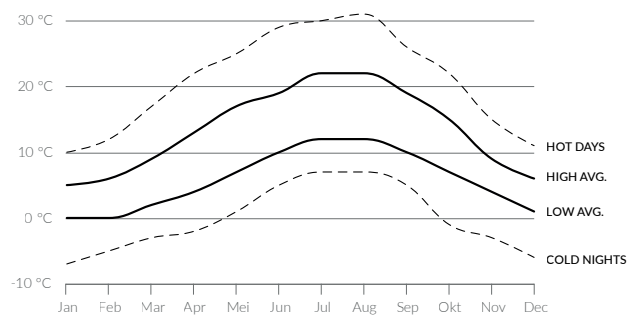
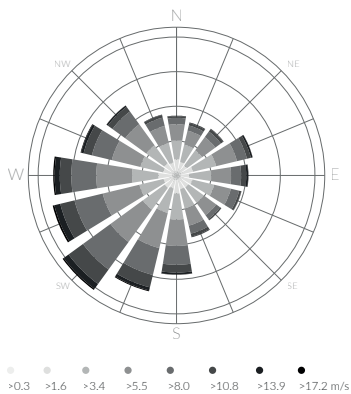
The first case shows an office building in Groningen that is designed to minimize undesired wind load on its environment. Secondly the 30 St. Mary Axe building in London is analyzed as an example of how a buildings shape can contribute to the living quality of the interior. The facade of a third case, the GSW Headquarters in Berlin shows how a building's skin can control airflow between inside and outside.

The combined results of these studies will lead to the answer to the question; ***In what ways and with which techniques can architectural design be informed by the influence of the wind?***

CASE VII

# EEA & Tax Offices

*a building shaped to manage wind flows of its surroundings*



## GENERAL INFO

### PROGRAM

office building

### LOCATION

Groningen, The Netherlands

### ARCHITECT

UN Studio

### YEAR OF COMPLETION

2011

### HEIGHT

92 m

### GROSS FLOOR AREA

47,000 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Temperate Oceanic Climate

### PREVAILING WIND DIRECTION

South-West

### AVERAGE WIND SPEED

4 m/s

### MEAN ANNUAL TEMPERATURE

14,8 °C

## BACKGROUND

This 25 story office complex houses two Dutch government institutions; the student loan administration and the national tax office. The buildings shape expresses its occupation by morphing two blocks together in a way that expresses unity. With its 2500 workstations, the building is of significant scale to the relatively small town of Groningen. Right next to the building a small ancient woodland shelters rare and protected species. Because of an integrated approach to sustainability that addresses a multitude of considerations including local ecology the building has been labeled one of the most sustainable large office buildings in Europe (Etherington, 2011).

## MAIN CLIMATIC CONSIDERATION

With its 92 meter in height the complex towers above the city of Groningen, which required special attention to ensure a healthy relationship to the surroundings. The main climatic consideration for the building's shape was to limit the disruption to the local microclimate and birdlife caused by alterations in wind flow. In addition the building was aimed to keep wind flows steady at tree level in the neighboring forest area to maintain its ecology (UN Studio, 2016).

## CLIMATE RESPONSIVE STRATEGY

The building's aerodynamic strategy is twofold. Firstly the overall shape of the building allows the wind to pass without ease because of its orientation and rounded shape. On a smaller scale the geometry of the facade is used to control the windflow in a vertical direction. Through the use of fin-shaped elements that double as sun-shading

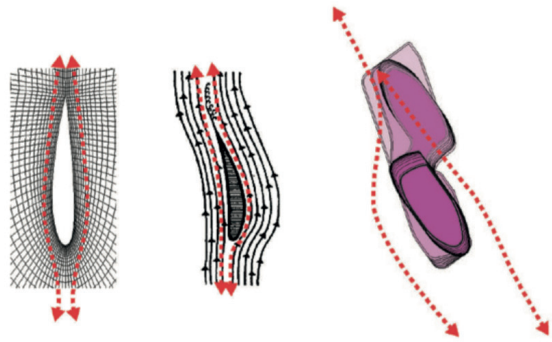
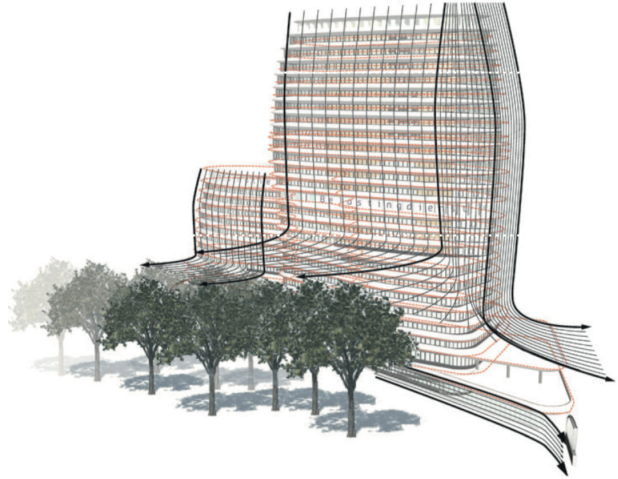
### LEFT

Exterior view from at entrance  
(DUO, 2016)

and light reflectors, the wind is directed to pass the building horizontally. Vertical downdrafts are averted which leads to a steady airflow on the public area at street level and on the woodlands at tree level, shown in the image at the top-right of this page (UN Studio, 2016).

### TECHNIQUES & METHODS

The tower is designed to have an aerofoil shaped section, shown in the image on the bottom right of this page. This principle that is commonly seen in wings, blades and sails is used to create an aerodynamic force. Manipulation in pressure distribution around streamlined bodies can be used to control lift, drag and flow separation (Sivakumar, 2012). Because this building's section is slightly asymmetrical, the wind path is altered to better fit its surroundings. This controlling principle is used to reduce the wind speed at the forest-side of the building.



#### TOP

Aerodynamic concept.  
(UN Studio, n.d.)

#### BOTTOM

Aerofoil shape. (UN Studio, n.d.)

#### RIGHT

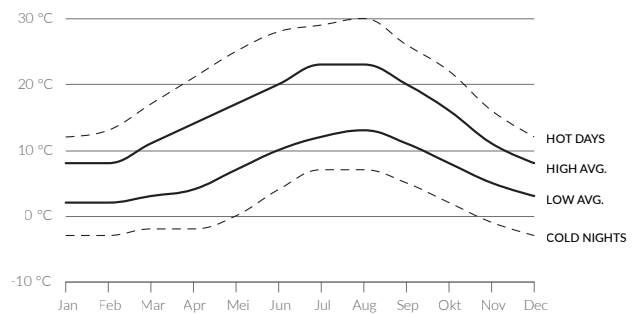
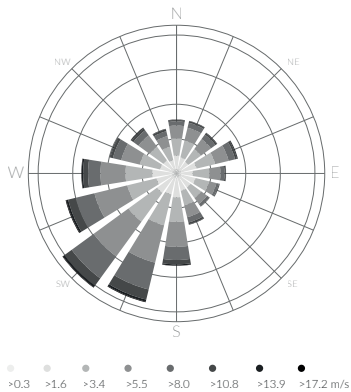
Birds eye view.  
(Aerophoto Eelde, 2011)



CASE IIX

# 30 St. Mary Axe Building

*a building shaped for internal airflow*



## GENERAL INFO

### PROGRAM

office building

### LOCATION

London, United Kingdom

### ARCHITECT

Foster & Partners

### YEAR OF COMPLETION

2004

### HEIGHT

180 m

### GROSS FLOOR AREA

76,400 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Temperate Oceanic Climate

### PREVAILING WIND DIRECTION

South-West

### AVERAGE WIND SPEED

3.6 m/s

### MEAN ANNUAL TEMPERATURE

11 °C

### LEFT

Distant view  
(Foster+Partners, n.d.)

## BACKGROUND

Originally built as the Swiss RE Headquarters, 30 St. Mary Axe provided 40 stories of office space for the Swiss RE insurance company, as well as a shopping arcade at street level. After the original occupant moved out, it was converted into a multi-tenant office building. Because of its distinctive shape and appearance, the 180 meter tall tower became one of London's most recognizable urban landmarks and was nicknamed the 'Gherkin'.

The building's strict round geometry might look alienated from its surroundings, but the way in which it is adapted to the local climate proves the contrary. Because of its radical climatic strategy, the building was claimed to be London's first ecological tall building by its architect (Foster and Partners, 2001). Amongst building professionals the Gherkin became a prime example for sustainable tall office buildings (Massey, 2017).

## MAIN CLIMATIC CONSIDERATION

The Gherkin offers 360° views of central London through a full glass facade. Similar tall glass buildings in the City experience an enormous cooling load during the city's warm and humid summers. In the case of the 30 St. Mary Axe building however, the solar heat gain is compensated through the optimal use of natural ventilation. To insure a high quality natural ventilation the pressure distribution around a building is crucial (Sivakumar, 2012). The airflow management strategy was a decisive factor for both the climatic strategie and the building's architecture.

## CLIMATE RESPONSIVE STRATEGY

The climatic concept is based on the 'Climatroffice' by Buckminster Fuller, the onetime mentor of Norman Foster. In this unbuilt design, Bucky explored a new relationship between nature and workspace, where offices are placed in a garden setting that is encapsulated by a transparent triangulated skin, shown at the top of the next page. The resemblance is especially visible in Fosters early design that is displayed below the prior. The shapes of both the Gherkin and the Climatroffice aim to enclose a maximal volume with a minimal exterior surface area, resulting in a more efficient thermal skin (Foster and Partners, 2001). The prior has about 25% less surface area than a rectilinear building (Wood, 2012).

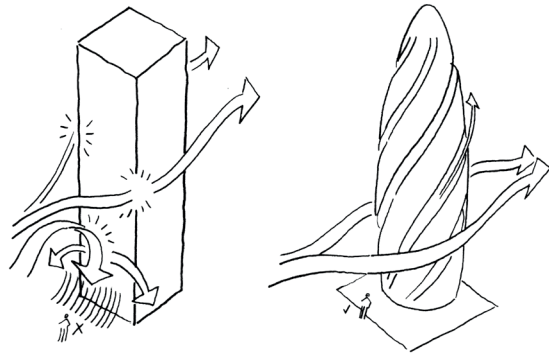
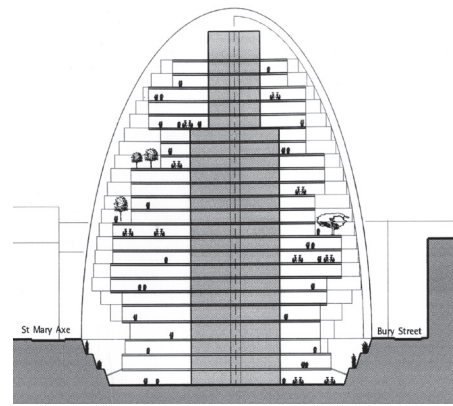
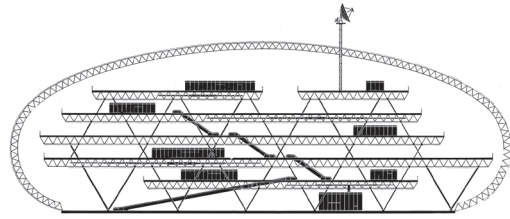
The main shape of the building is refined to work together with the wind, for the benefit both interior and exterior spaces. Two strategies for wind control were combined to create the iconic shape, both visible in the sketch at the bottom of this page.

Firstly, the building's rounded shape allows the wind to pass with little difficulty. This reduces undesired wind loads around the building, making the surrounding public space more habitable. Also the wind load on the building itself is reduced which leads to a lighter structure.

The second strategy refines the main shape of the building to manage wind flows for the benefit of natural ventilation throughout the building. A second skin facade is employed as an air buffer to control heat gain throughout the year. Six spiraling incisions in the internal volume channel the wind and guide it towards its apex. This creates an equal number atria between the two facades that are segmented every six floors to prevent strong vertical updrafts. The spiraling form of the atria creates stepped internal balconies or 'sky gardens' that are planted to improve the oxygen levels. From the atria, the windflow is used for natural cross-ventilation in the adjacent office areas (Foster and Partners, 2001).

## TECHNIQUES & METHODS

Wind currents create high and low pressure zones as they accelerate around the aerodynamic tower. The pressure differential is used for cross-ventilation, as it allows air to enter from the atria at the windward side while it disposes air at the leeward side. The air velocity in the atria is further increased by the stack effect which occurs in these six-story high spaces (Wood, 2012). This means that when the trapped air is heated it becomes lighter than the air above, which stimulates a continuous airflow towards the roof of the building. Because this natural ventilation principle is activated by the sun it automatically responds to the building's cooling load. During summer when the demand for cooling is at its peak the stack effect induced ventilation also



**TOP**

Climatoffice by Buckminster Fuller. (Aggregate, 2017)

**CENTRE**

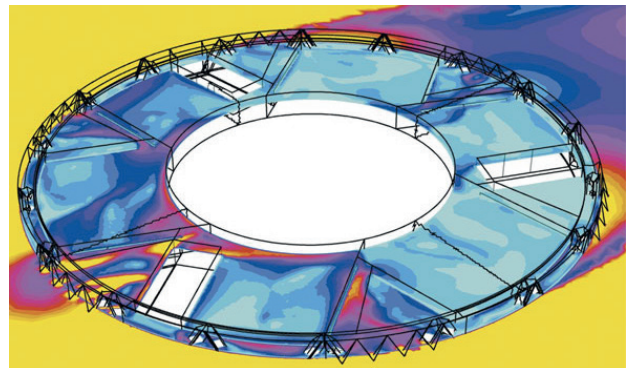
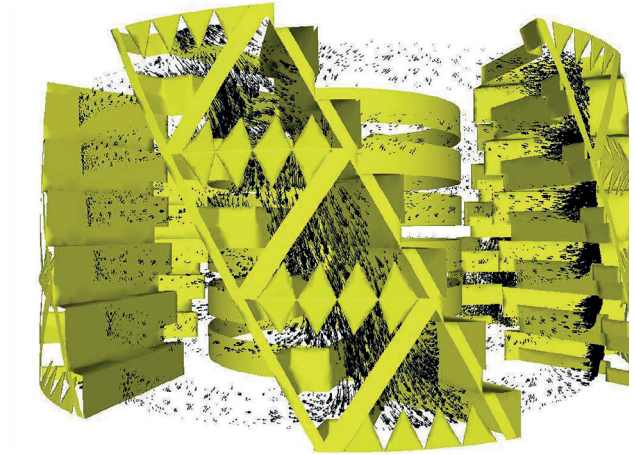
Schematic design of the 30 St. Mary Axe building. (Aggregate, 2017)

**BOTTOM**

Wind control strategy sketch (Foster, 2010)

reaches its apex.

The air inlet and exhaust is managed through electronically operable glass panels, situated on the outer facade of each atrium. These triangular windows are controlled through a building management system (BMS), which monitors both external weather conditions and the building's internal climate to determine the right configuration of facade openings (Wood, 2012).



**TOP**

Simulation of air velocity through the atria. (Aggregate, 2017)

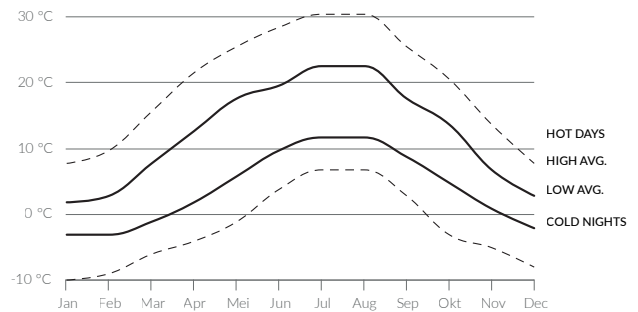
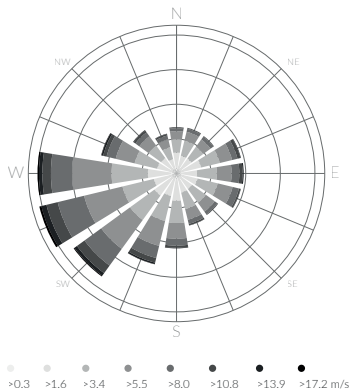
**BOTTOM**

Simulation of air velocity through an office floor. (Foster, 2010)

CASE IX

# GSW Headquarters

*a facade shaped to manage wind flows for interior use*



## GENERAL INFO

### PROGRAM

office building

### LOCATION

Berlin, Germany

### ARCHITECT

Sauerbruch Hutton Architects

### YEAR OF COMPLETION

1999

### HEIGHT

82 m

### GROSS FLOOR AREA

48,000 m<sup>2</sup>

## CLIMATIC DATA

### CLIMATE CLASSIFICATION

Temperate Oceanic Climate

### PREVAILING WIND DIRECTION

West

### AVERAGE WIND SPEED

2.7 m/s

### MEAN ANNUAL TEMPERATURE

9 °C

## BACKGROUND

The GSW headquarters in Berlin, a private real estate company, consists of one refurbished 1950s tower-block, three new low rise buildings and one new high rise slab. This case study is limited to the last of this ensemble, the building that is most significant to the project. Because this tower was one of the first mayor buildings to arise in reunified Berlin, the architects addressed the issue of re-joining the city halves in their design by combining their distinct characters (Sauerbruch Hutton, 2000).

The linear slab is gently curved to accentuate the edges and provides 20 stories of offices. Various layouts can be found across the office floors, ranging from an open office to a floor with 20 closed offices on the long ends of the building with a corridor in the middle. A service and circulation core at the south east end of the building houses the elevators, staircases, toilets and building services.

## MAIN CLIMATIC CONSIDERATION

Generous window-sizes at all four sides of the building allow the narrow workspaces to be daylit during office hours for most of the year (Sauerbruch Hutton, 2000). The enormous glass surface brings in a lot of solar heat, which could be problematic during Berlin's hot summer days. Natural ventilation is used to compensate this undesired effect. Airflow management became the main climatic consideration for the facade design, which determines the building's characteristic appearance.

## CLIMATE RESPONSIVE STRATEGY

To compensate the heat-load that the transparent facade brings, the building is supplied with double facades along the west and east elevation. These climatic zones are put in place to create a pressure difference between the two sides of the building that allows natural cross ventilation to run through the offices. Fresh air is admitted through single story double facade elements in the east facade, then across the office floor after which it is exhausted into the continual double-skin facade at the west side of the building, as displayed on the next page (Wood, 2012). On top of the building a wing-shaped wind roof is used to stimulate the upward airflow within this facade.

### LEFT

View at roof  
(Dalbéra, 2008)

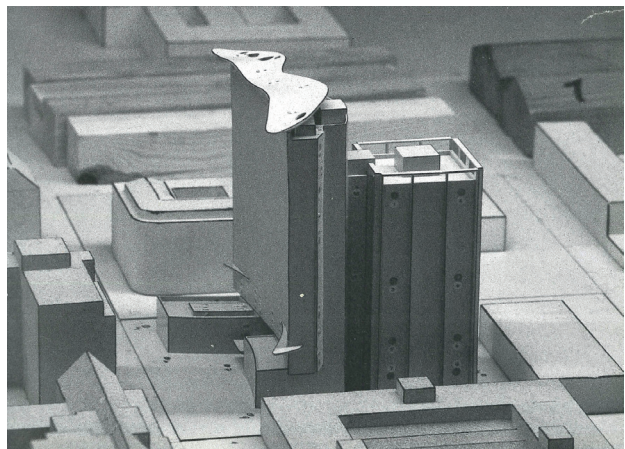
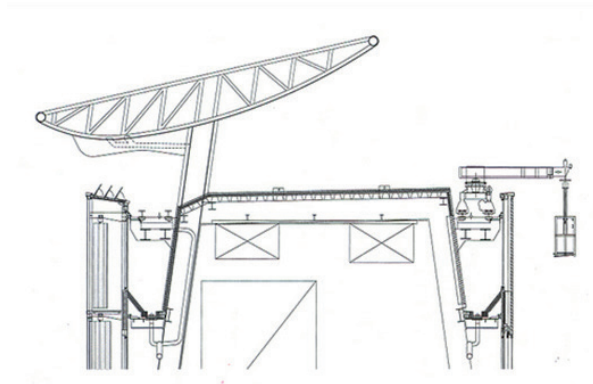
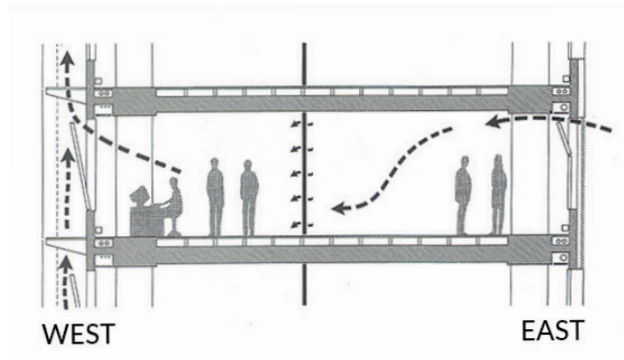
Flexible blinds between the two facade-layers allow individual control of the admitted sunlight (Sauerbruch Hutton, 2000). These blinds are kept cool by the natural ventilation that occurs in this area of the building, reducing the solar heat gain of the neighboring office area.

## TECHNIQUES & METHODS

The continual double skin facade on the west side of the building is the central element in the natural ventilation strategy. Because of its height of around 70 meters the air inside this cavity moves upwards due to the stack effect, which is explained in the previous case study on the 30 St. Mary Axe building.

A wing roof that sits on top of the west facade makes use of the Venturi effect to reinforce the afore described stack effect. This principle states that a flow of liquid or gas that flows through a narrowing passage will increase in velocity while it decreases in pressure. The bulge underneath the roof presses down the passing air to create a local low-pressure-area right above the cavity of the double facade, stimulating the airflow through the double-skin facade. This effect occurs whenever the wind is more or less perpendicular to the wing, which is north south oriented. When the wind direction is parallel to the building a series of fins underneath the roof cause the wind to eddy, which prevents the risk of down currents due to positive pressures (Wood, 2012).

The thermal and ventilation performance was analyzed with computational fluid dynamics (CFD). This software was used to dimension ventilation openings and shading. The proposed solutions were put to the test in the shape of scale models that were analyzed on two occasions in a wind tunnel. The wind roof was not a part of the initial design but came into existence as a direct result of the CFD and the wind-tunnel tests (Sauerbruch Hutton, 2000).



**TOP-LEFT**

Cross ventilation through office section (Sauerbruch Hutton, n.d.)

**CENTRE-LEFT**

Wing roof section (Sauerbruch Hutton, 2000)

**BOTTOM-LEFT**

Model for wind tunnel testing (Sauerbruch Hutton, 2000)

**RIGHT**

Facade clousup (Mietenblog, 2013)





## § 5.4

# Conclusion

Wind-loads are far more difficult to predict than the other two topics of this research; sunlight and solar heat. Its geometry is not linear but consists of a flow that constantly varies in velocity, pressure and direction. There are two commonly used options for analyzing windflow in the built environment; digital analysis using computational fluid dynamics (CFD), and the traditional method of using a wind tunnel. These analyses have no static outcome like solar analysis, but generate results for longer intervals. The studied cases demonstrate different ways of responding to these analysis.

The first case; the EEA & Tax Offices building in Groningen is shaped to manage external wind-loads for the protection of its surroundings. Its design responds to this environment by using aerodynamic principles to adjust the building's shape, which are tested and optimized in an iterative process.

In the second case the 30 St. Mary Axe Building in London uses its geometry to stimulate airflow in designated channels that spiral alongside the building. Like the prior example, an understanding of aerodynamics forms the basis of the geometric concept. Its strict geometry is then tested and

optimized using CFD.

The last of the case studies examines the GSW Headquarters in Berlin on its ability to control airflow with an aerodynamic facade. The facade is considered as a separate design that uses the prevailing winds to solve the building's ventilation. The vertical part of the facade is a passive adaptation of existing climatic principles while the horizontal roof facade is highly responsive to the on-site windflow. Its shape results from an extensive process of testing and optimizing.

These cases show that the effects of wind on architectural geometry are less direct than those of sunlight and solar heat. This is because of the inconsistent nature of the wind, as well as the fluctuating results from airflow analysis.

CHAPTER 6

# CONCLUSION

This work aims to show the architectural potential of allowing climatic phenomena to influence building design. The focus of research is at the philosophy and methods that are employed to create climate responsive architecture. In the introduction the following main research question was stated:

***How can buildings become in balance with their climatic environment through architectural design?***

This question is answered in the following sections by combining the results of the theoretical framework from the second chapter with the 9 case studies from the third, fourth and fifth chapter.

**CLIMATE FOR ARCHITECTURE**

Current architectural thinking is primarily occupied with visual aspects of design. This is limiting the integration of climatic thinking into the discipline, denying aspects of comfort and energy to impact initial design decisions. These considerations are often viewed as technocratic because they lack a connection to the sensual dimension of architecture. Ultimately this discrepancy causes issues of sustainability to become detached from

the architectural realm, denying its essential purpose of creating environments suitable for human habitation.

Bioclimatic design aims to create architecture that is balanced with its surroundings. This philosophy is based on a body-centered approach to architecture that corresponds to architectural phenomenology. In this episteme the human experience of architecture forms the basis for its design to reach a higher level of sensuality. By regarding architectural experience as a multi-sensory event, design will be able to exceed the visual realm. The acoustic and tactile senses are part of the experience of buildings, making them valid considerations for architecture. In this way the influence of climatic phenomena on architectural expression is recognized.

When a building is designed in a creative dialogue with its climatic surroundings, it will become a reflection of its environment. As a result, climate can be considered as an author of architecture. Buildings that sense their climatic environment to formulate a response are called climate responsive design. Besides its initial purpose of benefiting from the energy potential of the local environment, designing in response to the climate has an architectural potential that

is currently being discovered. One of the main reasons for architects to respond to climatic conditions in their architecture is the richness of geometric possibilities that it brings. Like vernacular examples have demonstrated before, responding to the local climate can enhance the cultural identity of architecture. This creates an architectural motivation to include climatic considerations in building design.

### **DIGITAL TOOLS FOR ANALOGUE MEANS**

Where vernacular architecture's response to its local climate was based on an evolutionary process of trial and error, modern climate responsive architecture makes use of computational methods of modeling, analysis and generation. With the advancement of these digital tools, designers have become able to test their ideas rapidly during the design process on issues of comfort and energy. This has created unprecedented possibilities for architecture to be informed by its local climate. By carefully analyzing the geometry of climatic phenomena an informed response can be designed to manage their influence. The case studies show a diverse range of solutions, based on case-specific climate responsive strategies.

The cases on sunlight and solar heat gain are based on the geometry of the sun, which is linear and reoccurring. This makes it relatively easy to predict and analyze their influence on the built environment. Sunlight and even solar heat analysis tools can be found in various digital modeling programs, establishing a direct link between analysis and design. It is even possible to use solar geometry as input for parametric design applications, which generate shape according to the sun path. Despite their corresponding geometric basis, the two subjects have a different influence on the architecture of the studied cases. The cases on solar heat gain are based on the concept of self-shading, which leads to jagged or stepped out geometry. For the cases on sunlight a different strategy was used. Building masses are sliced to allow daylight admittance to the spaces where it is required. This leads to more smooth,

rectilinear volumes. The third case on sunlight is an exception, because issues of both solar heat and sunlight are combined. This leads to a jagged surface that blocks direct sunlight while reflecting daylight towards the interior.

Wind is a different story entirely. Where solar geometry is strictly linear, wind moves in flows. Its speed, direction and density vary over time and based on the morphology of the built environment. Because of this capricious nature, wind simulations are more complex and less coherent than simulations of the sun. A direct link between design and analysis is therefore hard to establish. The cases on the influence of the wind are all based on aerodynamic strategies that are tested after modeling, and optimized in an iterative design process. This results in rounded, aerodynamic buildings and facade elements.

### **ARCHITECTURE FOR CLIMATE**

The cases show different climate responsive strategies, leading to various archetypical and low-tech design solutions. Throughout the scales and topics, a distinction is made in three ways of architectural responses to climate: climate as boundary, climate as criterium & climate as parameter, shown in the image on the opposite page. Each of these strategies are based on a specific relationship to a climatic phenomenon, leading to differing architectural solutions.

The first category uses climatic phenomena to create spatial boundaries as an initial step in the design process. These envelopes are based on the way they influence certain aspects of the local climate. A clear example is the Solar Carve Tower (case I), which is built within an envelope that is based on the sun access to the surrounding public area.

Secondly the influence of a climatic phenomenon can be seen as one of the criteria for the design. In the case of the Shenzhen International Energy Mansion (case IV) this criterium was that the faces of the building's skin that are oriented towards the sun should be closed. This rule was applied throughout the building, resulting in a distinct

facade geometry.

Finally climatic influence can be used as a parameter for design, both in so called parametric design as in manually modeled and optimized buildings. Climate as a parameter means that a basic climatic concept is applied according to local climatic conditions. The EEA and Tax offices (case VII) for example is based on the strategy of using a 'wing shaped', aerofoil section to control air movement on its surroundings. This basic concept is applied to shape the building in a way that the wind is directed away from a neighboring forest area. In an iterative process, the wind acted as an analogue parameter that generated the building's shape.

### BALANCED LIVING ENVIRONMENTS

Bioclimatic thinking is essential in the creation of balanced (built) environments. A body-centered understanding of architectural expression

enables design to address all the senses used to experience architecture, including the invisible phenomena that are usually addressed in climate design. This philosophy allows architecture to respond to climatic phenomena. Geometric principles derived from these phenomena can inform the architectural design process, allowing buildings to benefit from the energy potential of their environment.

When architectural means are used to address issues of comfort and energy balance, architecture's existential purpose of creating environment that are suitable for human habitation is met. By responding to sunlight, solar heat and wind with architectural geometry the architecture itself is used to create balanced living environments.



#### IMAGE

Ways of allowing climatic phenomena to influence architecture

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# Imagery

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## Introduction

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