Temporary Architecture
Guideline to determine a wind and snow load per the Eurocode on the example of a membrane structure and an inflatable structure.

Master-Thesis

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Engineering

submitted to

Anhalt University of Applied Sciences

Faculty of Architecture,
Facility Management and Geo Information

by

Bernhard, Dachs
08.02.1989, Augsburg

Matrikel number
4063634

Submission date:

First Tutor: Prof. Dr. Robert Off

Content

Abbreviations

Latin Letters

A	Site altitude above sea level
A	Surface area
c_A	Wind force coefficient
c_{dir}	Directional factor
C_e	Exposure coefficient
$c_e(z)$	Exposure factor
c_p	Wind force coefficient
$c_{pe,10}$	Pressure coefficient of the external pressure
$c_r(z)$	Roughness factor
c_{season}	Seasonal factor
C_t	Thermal coefficient
E	Effect of actions
E_d	Design value of actions
EN	European Standards
G	Ground area
$G_{k,j}$	Characteristic value of permanent action
g	Self-weight of structure
H	Horizontal forces
h	Per hour
H_d	Required mass horizontal
H_{total}	Total horizontal forces
kg	Per kilogram
kN	Kilo Newton
k_r	Terrain factor
L	Lateral area
m	Ballast per fixing point
m	Per meter
m^2	Square meter

m^3	Cubic meter
M_{req}	Required ballast
M_{total}	Total required ballast
n	Vertical force coefficient
q	Impact pressure
q_b	Reference mean (basic) velocity pressure
$q_p(z)$	Peak velocity pressure
$Q_{k,I}$	Characteristic value of the accompanying variable action
$Q_{k,1}$	Characteristic value of the leading variable action
R_d	Design value of the resistance
s	Snow load on the roof
s_k	Characteristic value of snow on the ground
sec	Per second
SLS	Serviceability Limit State
ULS	Ultimate Limit State
V	Vertical forces
v	Wind speed
v_b	Basic wind velocity
$v_{b,0}$	Fundamental value of the basic wind velocity
V_{total}	Total vertical forces
w	Wind load on external surfaces
w_e	Wind pressure on external surfaces
Z	Snow load region
z	Height above ground
z_0	Roughness length
$z_{0,II}$	Terrain category factor II
z_{max}	Maximum height above ground
z_{min}	Minimum height above ground

Greek Letters

α	Angle of roof pitch
γ	Safety coefficient
$\gamma_{G,j}$	Partial factor of permanent action
$\gamma_{p}P$	Partial factor of pre-stressing actions
$\gamma_{Q,i}$	Partial factor for permanent actions
$\gamma_{Q,1}$	Partial factor for permanent actions, accounting for model uncertainties
μ	Friction coefficient
μ_{i}	Snow load shape coefficient
ρ	Air density
φ	Airflow, Blockage
$\psi_{0,i}$	Factor for combination value of variable action

Figures

Tables

I. Introduction

Many buildings have more than one beginning and not necessarily a definite end. Embracing time in architecture means embracing change.[1]
A fundamental tenet of the modern movement in architecture was that structure, material, and technique determined form. New materials and structural systems, as they evolved, gave shape to the architecture of their time.[2]
Better Materials pose a fascinating paradox. Their strength and resilience ensure longer-lasting "permanent" buildings, but those same qualities make them endlessly recyclable into new, temporary structures. This new way of building responds with more flexibility to our changing mobility.[3]
The purpose of this document is the application of the European structural design standards to temporary architecture. The short lifecycle of temporary structures is questioning the necessity of standardized loadings. This paper is reviewing the European structural standardization and is challenging the difference between temporary and permanent design.
Temporary architecture occurs in varied sizes and locations. They display mostly a performative and engaging character. The disinterest in eternal life allows to develop new ways of engineering and designing. This paper will provide an overview how purposely short-lived structures can look like and where to find them.
Different types of temporary structures bring out different structural load behaviour. Structures with a definite end are subjected to different loads. Those challenges are addressed in a structural guideline out lining the period of use for temporary structures and how it's going to affect the structural design. It will provide guidance how to determine basic load cases for wind and snow.
This is followed by practical example calculations and an independent snow and wind load guideline.

---

[1] Cf. *Franck*, Architecture Timed: Designing with Time in Mind, Jan. 2016, No. 239, p. 9 - 12, p. 10.
[2] Cf. *Robbins*, Engineering a new Architecture 1996, p. 6.
[3] Cf. *Siegal*, More Mobile Portable Architecture for Today 2008, p. 7.

II. Temporary Architecture

There is something contradictory about building structures with the knowledge they will be raised a short time afterward. At least this is true when the structures are of a pronounced architectural character. Architecture in general is meant to be permanent, to serve a practical and aesthetic purpose over an indefinite period.[4] The permanent character generates a sense of monumentality and is deepening the understanding of architecture and its profession.[5]

The ephemeral effect in relation to temporary architecture describes any space that is mobile or intended only to be used for a short period of time. It is often responsive and adaptable to function and location. Without the pressure of lasting permanently, temporary architecture can act as testing ground for new technologies.[6]

It is defined as purposely short-lived structures, exhibitions and programmes that create experimental sites for interaction and engagement. It can be found as a tiny travelling theatre or a community lido on an abandoned railway site. Many are experimental, innovative, questioning the form of permanent architecture gone before. Temporary architecture isn't purely pop-ups and pavilions, disappearing as quickly as they appear. It can also be something far subtler, involving a wide range of participants working together with deeper social meaning.[7]

The following projects describe a variety of what temporary architecture can look like, showcasing ways of structural technologies in participation of membrane and foil elements, ranging from interactive artwork structures which live from public engagement to unique transformable origami structures.

---

[4] Cf. *Chabrowe*, On the Significance of Temporary Architecture, Jul.1974, Vol. 116/No. 856, p. 384 - 387, p. 385.

[5] Cf. *www.dezeen.com* (retrieved from <https://www.dezeen.com/2017/07/06/david-chipperfield-renovation-royal-academy-arts-architecture-gallery-london/> (viewed 10.11.2017)).

[6] Cf. *www.synthetica.ca* (retrieved from <https://synthetica.ca/live-from-berlin/2012/11/11/ay-dmor0qf0keauiz1bsmul4yplpft2> (viewed 03.09.2017)).

[7] Cf. *www.designcurial.com* (retrieved from <http://www.designcurial.com/news/this-is-temporary-transient-architecture-4802906/> (viewed 02.09.2017)).

1. Peace Pavilion

Architects / AZC - Atelier Zündel Cristea

Project Address / Museum Gardens, Bethnal Green, London, UK

Gross floor Area / 62 m^2

Existed / May - June 2013

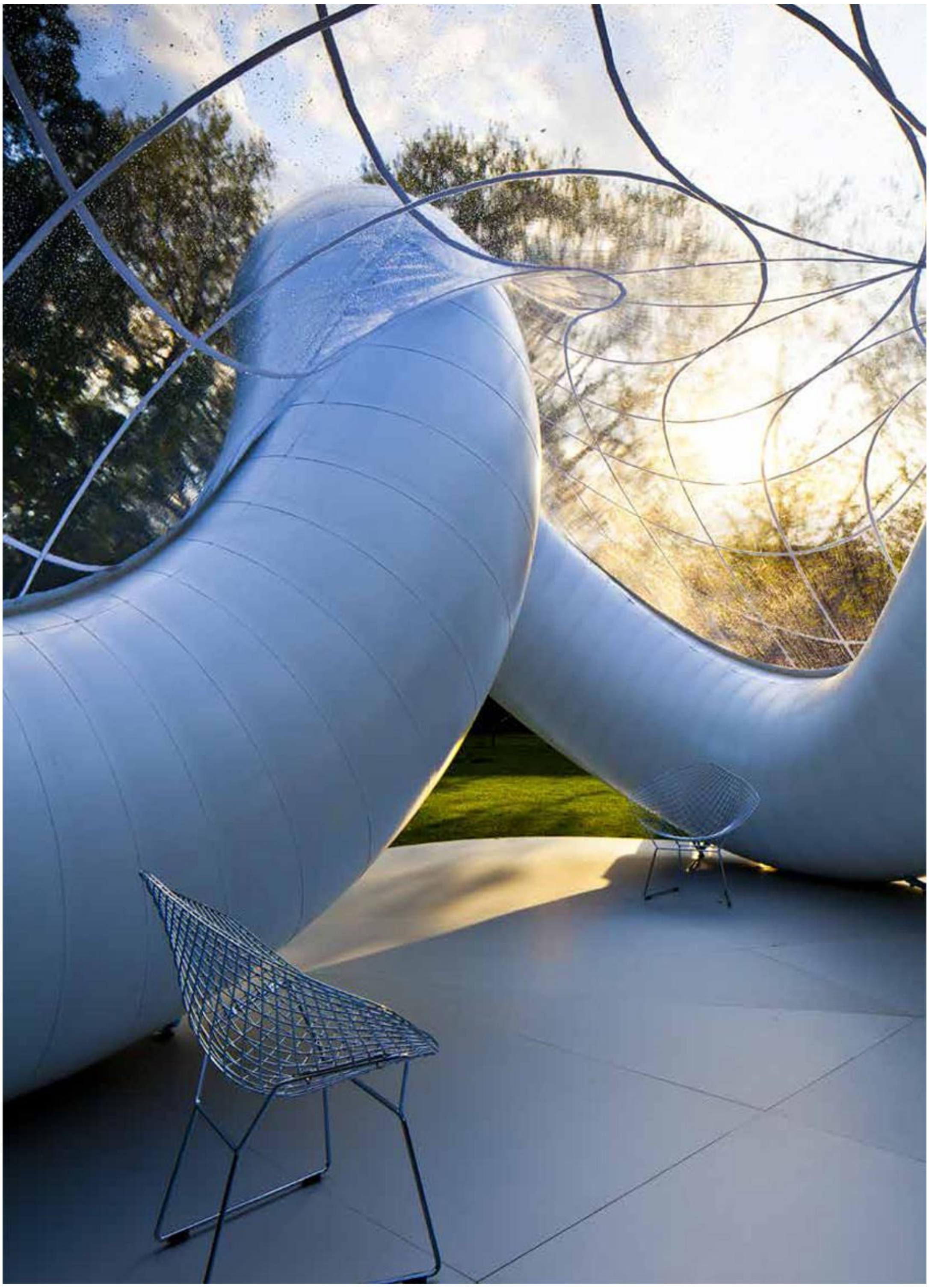

Figure 1 - Isometric view, Peace Pavilion by AZC, Photo: Sergio Grazia.

Figure 2 - Side view, Peace Pavilion by AZC, Photo: Sergio Grazia.

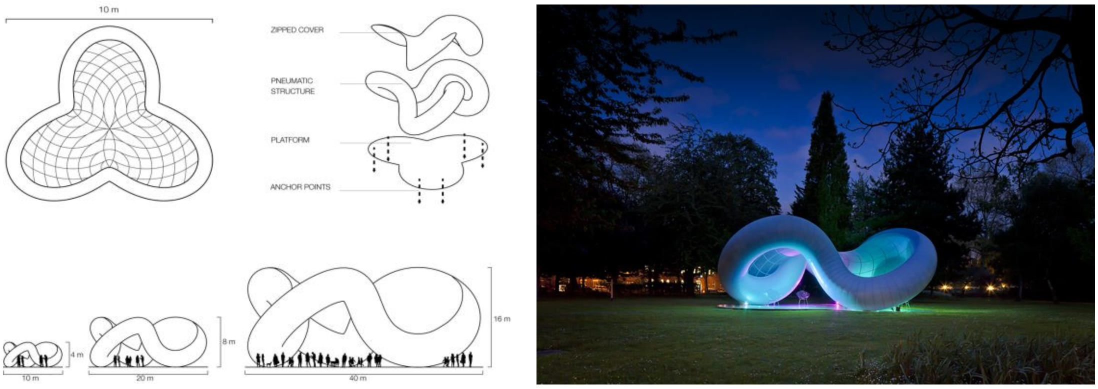

Figure 3 - Plan view, Peace Pavilion by AZC, Photo: Sergio Grazia.

The architects proposed a pavilion that is visually and aesthetically engaging as shown in *figure 1*. It's providing an ideal contemporary space and offers a sense of calmness, beauty and an exceptional value at the very heart of the museum gardens in London. The charm of the shape lays in its symmetry and fluidity as shown in *figure 2*. The pavilion was designed to appeal to a wide audience. The geometry of the pavilion blurred the notion of inside and outside as shown in *figure 3*. The simple act of moving through the exterior and interior spaces brought an understanding to the visitor. To achieve such an apparently complex shape, the architects united advanced tools of parametric design.[8]

[8] Cf. *www.zundelcristea.com* (retrieved from http://www.zundelcristea.com/en/design/peace-pavilion/(viewed 07/11/2017)).

2. JNBY

Architects / HHD_FUN Architects

Project Address / Shanghai, China

Gross floor Area / 150 m^2

Existed / October - November 2010

Figure 4 - Isometric view, JNBY by HHD_FUN Architects, Photo: n.d.

Figure 5 - Side view, JNBY by HHD_FUN Architects, Photo: n.d.

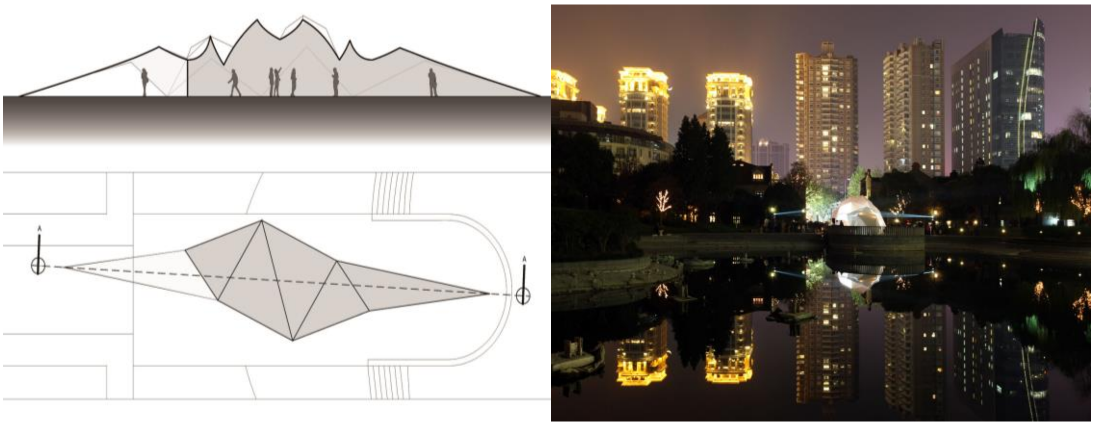

Figure 6 - Plan view, JNBY by HHD_FUN Architects, Photo: n.d.

HHDFUN architects, Beijing, presented a transformable temporary structure for the JNBY and Cotton USA fashion show as shown in *figure 4*.[9] It was held in Shanghai, which had an ability to take on numerous different forms. The unique structural design was created based on the formation of origami triangles, combined with the use of the latest parametric design tools and topological analysis as shown in *figure 5*. The whole structure consisted of six inter-locking components, sharing three varied designs as shown in *figure 6*. Each design was achieved from a process of deformation and manipulation of one triangular surface, resulting in a shape that corresponds to the overall layout. The archways have dimensions that correspond to other archways and so increasing the number of possible overall forms.[10]

---

[9] Cf. *www.hhdfun.com* (retrieved from http://www.hhdfun.com/201020-jnby-pavillion(viewed 07.11.2017)).
[10] Cf. *Baker*, Temporary architecture 2014, p. 184.

3. Luminaria

Architects / Architects of Air; Alan Parkinson

Project Address / n/a various locations

Gross floor Area / 1000 m^2

Existed / 1992 - present (duration 2 - 3 weeks)

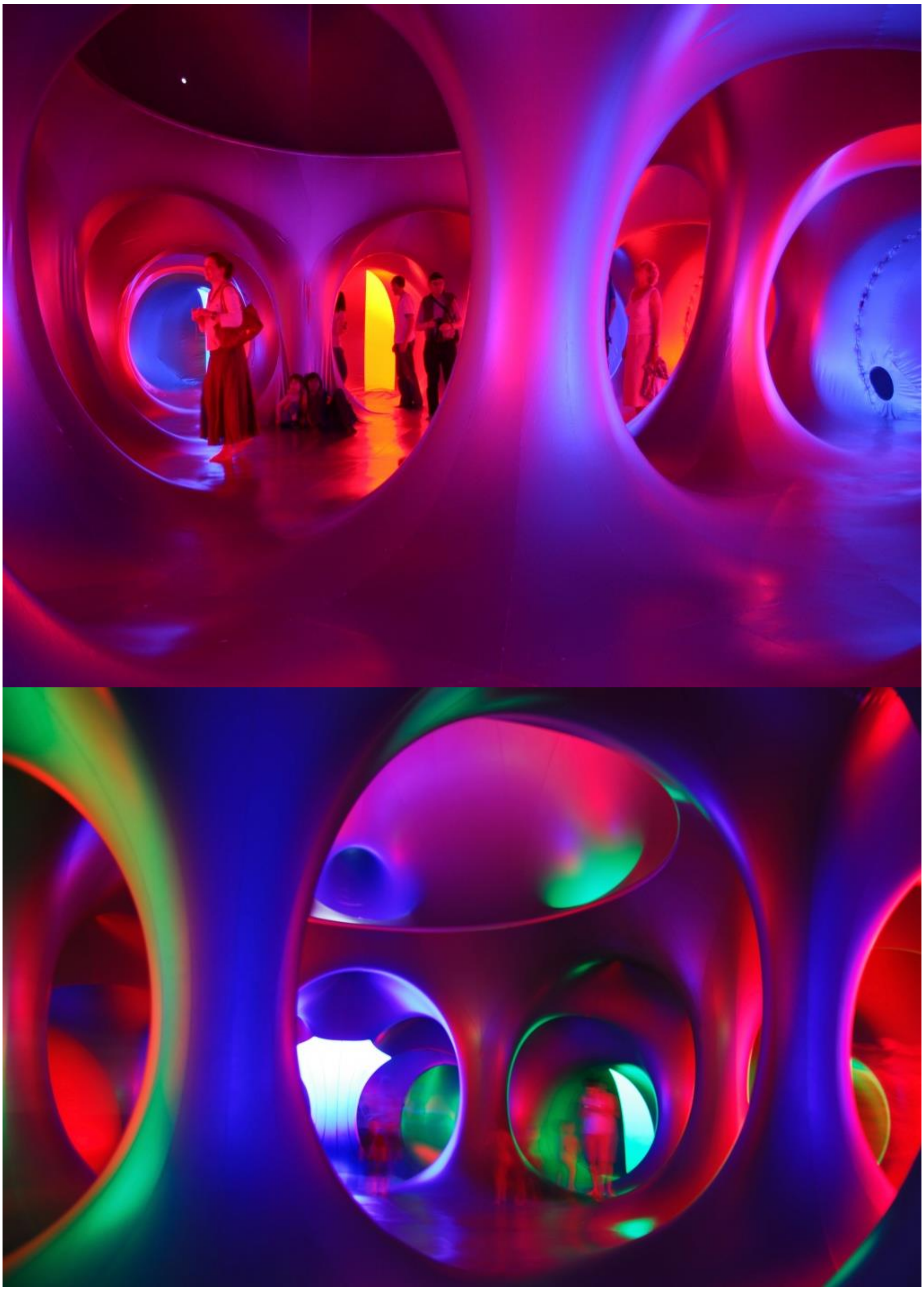

Figure 7 - Isometric view, Luminaria by Architects of Air, Photo: Architects of Air.

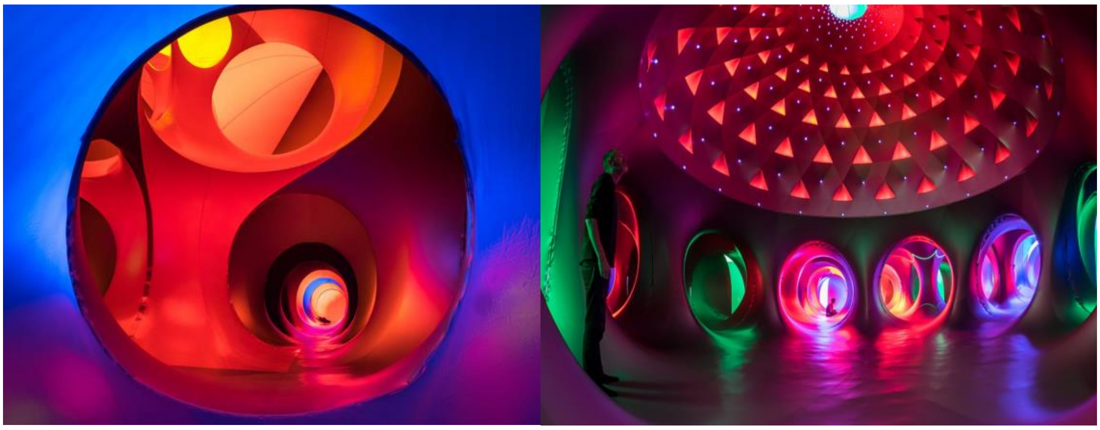

Figure 8 - Isometric view, Luminaria by Architects of Air, Photo: Architects of Air.

Figure 9 - External view, Luminaria by Architects of Air, Photo: Architects of Air.

The Luminarium form Architects of Air is a dazzling maze of winding paths and soaring domes as shown in *figure 7*. The Luminaria was designed by Alan Parkinson who started experimenting with pneumatic sculptures in the 1980s. The design was generated with only four colours of plastic. Each luminarium is based on roughly 20 elements as shown in *figure 9*. All elements are zipped together on site to occupy an area of 1000 square meters. There are different versions of the Luminarium but every single one is an original design. The principle difference between the different versions can be found in the rendering of the domes and in the layout of the tunnels as shown in *figure 8*.[11]

[11] Cf. *www. architects-of-air.com* (retrieved from http://www.architects-of-air.com/luminaria.html (viewed 22.10.2017)).

4. Serpentine Pavilion 2015 by SelgasCano

Architects / Jose Selgas and Lucia Cano

Project Address / Kensington Gardens

Gross floor Area / n/a

Existed / June - October 2015

Figure 10 - Isometric view, 15th Serpentine Pavilion, Photo: Iwan Baan.

Figure 11 - Isometric view, 15th Serpentine Pavilion, Photo: Iwan Baan.

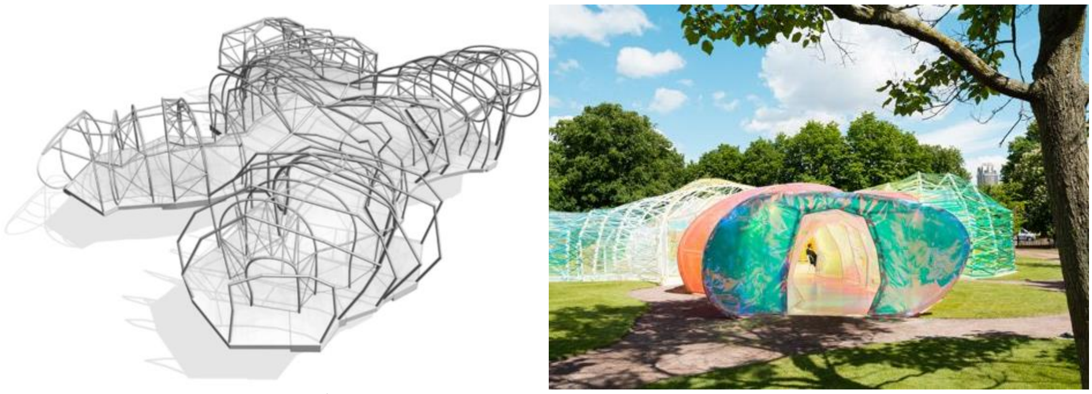

Figure 12 - Isometric view, 15th Serpentine Pavilion, Photo: Iwan Baan.

The 15th Serpentine Gallery Pavilion designed by Jose Selgas and Lucia Cano consists out of a double-layered plastic skin in a variety of colours, wrapped around a series of metal arches as shown in *figure 12*. The architects used ETFE to create the colourful wrapping as shown in *figure 11*. The pavilion allows visitors to enter through several openings. Each entrance allows for a specific journey, characterised by its colour, light, irregular shapes and volume. The shell is created out of a double-layered shell, made of opaque and translucent fluorine-based plastic in a variety of colours as shown in *figure 10*. The centre is designed as an open space, allowing for various events and performances.[12]

[12] Cf. *www.serpentinegalleries.org* (retrieved from http://www.serpentinegalleries.org/exhibitions-events/serpentine-pavilion-2015-designed-selgascano(viewed 30.10.2017)).

III. Construction versus Architecture

The adoption of modern techniques has altered the relationship between design and construction. The separation between building and designing, with design ending and construction beginning has evolved.[13] In an interview, Frank Lloyd Wright defined modern architecture: it was not architecture made in the modern period but rather "organic" architecture made with tensile strength.[14] Wright didn't see any conflicts between engineering and design. He saw that the converse is true; new aesthetics are the inescapable consequence of new engineering techniques.[15] The Eurocode and the European design standards are challenging the relationship between design and structural standardization.

The following chapters are evaluating on European regulations and practical execution focusing on temporary architecture. It's developing a structural guideline how to calculate basic wind and snow loads and how to classify temporary structures regarding structural calculations. This is closed out by a summery reflecting on the design working life and the adaptiveness of the European standards to temporary structures.

1. Structural guideline according to the Eurocode

The following guideline is to determine basic load cases and combinations according to the Eurocode[16] to define a wind and snow load for temporary structures. It can be described as short-lived structures with the ability to occur in varied sizes and locations.[17]

Diverse locations and sizes bare different loads which are essential to the structural calculation. It is in discretion of the designer and the structural engineer to define the

---

[13] Cf. *Franck*, loc. cit. (foot. 1), p. 17.

[14] Cf. *Wallace*, The Mike Wallace interview with Frank Lloyd Wright, 01/09/1957 and 28/09/1957, (retrieved from http://www.hrc.utexas.edu/multimedia/video/2008/wallace/wright_frank_lloyd_t.html (viewed 27.10.2017)).

[15] Cf. *Robbins*, loc. cit. (foot. 2), p. 1.

[16] The Eurocodes are ten European standards specifying how structural design should be conducted within the European Union. These were developed by the European Committee for Standardisation upon the request of the European Commission, Cf. *www.eurocodes.jrc.ec.europa.eu* (retrieved from http://eurocodes.jrc.ec.europa.eu/showpage. php?id=13 (viewed 09.10.2017)).

[17] Cf. *Baker*, loc. cit. (foot.8), p. 6.

importance of appearing loads and the resulting impact on the structure. The structure must be structurally safe and sound throughout its entire lifetime.

a) Scope

EN 1990:2002, Basic of structural design,[18] is intended to be used in conjunction with EN 1991-1-1:2002, Actions on structures, Part 1 - 1,[19] for the structural design of building and civil engineering works, including execution of temporary structures.[20] EN 13782:2015, Temporary structures, Tents - Safety,[21] specifies safety requirements for mobile, temporary installed tents with more than 50 m^2 ground area. For the purpose of this European Standard, the following definitions apply:[22]

- **Tent**
  A mobile or temporary installed structure enclosed or open
- **Tent with primary load-bearing structure**
  A tent with load bearing support structured and enclosing elements
- **Membrane tent**
  A tent with a load bearing pre-stressed textile structure with double curved shape, supported by mast and/or cable system
- **Traditional pole tent**
  A tent with centre poles, and extensive use is made of guying to stabilise the fabric covering

The structural analysis is depending on the structures context, lifespan and its location. Those factors are determining the variable loads and their importance. In all cases the principles of risk management such as the appropriateness of the proposed design code and a site-specific analysis e.g. location specific load occurrences, should be applied.[23]

---

[18] *EN 1990:2002*, Eurocode, Basic of structural design, in the version dated 29 November 2001.
[19] *EN 1991-1-1:2002*, Actions on structures, Part 1 - 1, in the version dated 30 November 2001.
[20] Cf. *EN 1990:2002*, Basic of structural design 2002, p. 9.
[21] *EN 13782:2015*, Temporary structures, Tents - Safety, in the version dated 30 April 2015.
[22] Cf. *EN 13782:2015*, Temporary structures, Tents, Safety, p. 6 - 7.
[23] Cf. *EN 1990:2002*, loc. cit. (foot. 20), p. 9.

b) Design working life

EN 1990:2002 specifies the design working life as follows:

Design working life category	**Indicative design working life (years)**	**Examples**
1	*10*	*Temporary Structures*
2	10 to 25	Replaceable structural parts,
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures

Table 1 - EN 1990:2002: 25, Design working life, Indicative design working life.

The examples presented in *II. Temporary Architecture* fall under category 1 as described in *table 1*. It categorizes a design working life of 10 years. This timeframe is applicable to temporary structures but not needed to its full extend. The average lifespan expectation of temporary structures is between 3 - 4 months as shown per the examples *1 - 4* in *II. Temporary Architecture*.

c) Durability

The structure is to be designed so its design working life does not impair the performance of the structure.[24] The structure must be sustainable and durable throughout its whole design working life cycle.

[24] Cf. *EN 1990:2002*, loc. cit. (foot. 20), p. 25.

2. Design situation

Temporary structures refer to the transient design situation (temporary conditions of the structure). This situation is relevant during a period much shorter than the design working life of the structure.[25] The transient design situation is described as:

$\boldsymbol{E_d} \leq \boldsymbol{R_d}$ (Equation 1).[26]

- Design value of a material product property:[27] $\boldsymbol{R_d}$
- Design value of effect of actions:[28] $\boldsymbol{E_d}$.

$\boldsymbol{E_d} = E\{\Sigma_{j\geq1}\gamma_{G,j}G_{k,j}\text{"} + \text{"}\gamma_p P\text{"} + \text{"}\gamma_{Q,1}Q_{k,1}\text{"} + \text{"}\Sigma_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}\}$
(Equation 2).[29]

The formula is in relation to the following coefficients:

- $\boldsymbol{E}$= Effect of
- $\boldsymbol{\Sigma_{j\geq1}\gamma_{G,j}G_{k,j}}$ = Permanent actions
- $\boldsymbol{\gamma_p P}$ = Prestress
- $\boldsymbol{\gamma_{Q,1}Q_{k,1}}$ = Leading variable action
- $\boldsymbol{\Sigma_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}}$ = accompanying variable actions.

a) Fundamental load combinations and partial safety factors

The Eurocode suggests that simplified load combinations should be used. A partial load factor of 1,35 on permanent loads and 1,5 on variable loads needs to be applied.[30] All cases need to be checked as per *table 2*.

[25] Cf. *EN 1990:2002*, loc. cit. (foot. 20), p. 12.
[26] Cf. *EN 1990:2002*, loc. cit. (foot. 20), Equation 6.10, p. 44, Equation 6.8.
[27] Cf. *EN 1990:2002*, loc. cit. (foot. 20), p. 18.
[28] Cf. *EN 1990:2002*, loc. cit. (foot. 20), p. 20.
[29] Cf. *EN 1990:2002*, loc. cit. (foot. 20), Equation 6.10, p. 44, Equation 6.10.
[30] Cf. *www.twforum.org.uk* (retrieved from https://www.twforum.org.uk/ publications/public-twf-documents/en-discussion-document/ (viewed 26.08.2017)).

1.35	partial safety factor for unfavourable permanent actions
1.0	partial safety factor for favourable permanent actions
1.5	partial safety factor for only one variable action
1.35	partial safety factor for more variable actions

Table 2 - EN 13782:2015, Fundamental combinations and partial safety factors.

Load combination examples according to EN 1990:2002 and EN 13782:2015 for Serviceability Limited State and Ultimate Limited State as per the below.[31]

b) SLS - Serviceability Limited State

SLS 1: $1.0\ g$

SLS 2: $1.0\ g + 1.0\ w$

SLS 3: $1.0\ g + 1.0\ s$

SLS 4: $1.0\ g + 1.0\ s + 1.0\ w$

c) ULS - Ulitimate Limited State

ULS 1: $1.35\ g$

ULS 2: $1.35\ g + 1.5\ w$

ULS 3: $1.35\ g + 1.5\ s$

ULS 4: $1.35\ g + 1.35\ s + 1.35\ w$

The above load combinations for SLS and ULS can be used for further calculations and analysis. It includes the partial safety factor.[32]

[31] Cf. *EN 1991-1-1:2002*, Actions on structures 2002, p. 48.
[32] Described in *III. Construction versus Architecture, 2. Design situation, a) Fundamental load combinations and partial safety factors.*

3. Load assumptions

The relevant and imposed loads must be defined for the specific design situation. EN 1991-1-1:2002 gives guidance for actions for the following subjects:

- Self-weight
- Imposed loads for buildings.

If areas are intended to be subjected to dissimilar categories of loading the most critical one must be considered.[33] The following section is describing self-weight, snow and wind loads for temporary structures. All load cases are independent from each other and can be calculated separately.

a) Self-weight

The self-weight must be defined according to EN 1991-1-1:2002: Actions on structures, Part 1-1: General actions - Densities, self-weight, imposed loads for buildings.[34] The self-weight is specific to each structure and cannot be generalized. It is unique to the shape and the design as showcased in *II. Temporary Architecture*. For light weight structures, i.e. pneumatic tubes or types of membrane structures, the self-weight can be neglected.

b) Snow load

Snow loading is to be applied if the there is a risk of snow to occur e.g. the structure is installed outdoors during winter months. Snow loads should be calculated according to EN 1991-1-3:2003, Actions on structures, Part 1-3: General actions - Snow loads.[35] EN 13782:2015 states that snow loads need not to be considered where:[36]

---

[33] Cf. *EN 1991-1-1:2002*, loc. cit. (foot. 31), p. 8.
[34] Cf. *EN 1991-1-1:2002*, loc. cit. (foot. 31), p. 12.
[35] *EN 1991-1-3:2003,* Actions on structures, Part 1-3: General actions - Snow loads, in the version dated 9 October 2002.
[36] Cf. *EN 13782:2015*, loc. cit. (foot. 22), p. 15

- there is no likelihood of snow or;
- operated at a time of the year, where the likelihood of snow can be discounted or;
- where by design or operating conditions snow setting on the tent is prevented or;
- where pre-planned operation action prevents snow settling on the tent.

aa) Climatic region

The geographical location of the structure needs to be known to define the following:[37]

- Climatic Regions i.e. Alpine Region, Central Region, Central West
- Altitude (**A**) of the structure above sea level.[38]

Each climatic region has a specific snow map showing snow loads at sea level. The exact location of your structure will define a Snow Load Zone (**Z**) within the climatic region.

bb) Characteristic snow load

The snow load is described as:

$\boldsymbol{s = \mu_i * C_e * C_t * s_k}$ (Equation 3).[39]

The formula is in relation to the following coefficients:

- Snow load shape coefficient:[40] $\boldsymbol{\mu_i}$
- Exposure coefficient:[41] $\mathbf{C_e}$
- Thermal coefficient:[42] $\mathbf{C_t}$

---

[37] Cf. *EN 1991-1-3:2003*, Actions on structures, Part 1 - 3: General actions - Snow loads, p. 38, Annex.
[38] Site specific altitude/elevation can be found online or in specific geographical literature.
[39] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 18, Equation 5.1.
[40] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 21, Table 5.2, Snow load shape coefficients.
[41] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 20, Table 5.1, Recommended values for different topographies.
[42] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 20, Figure 5.2 (8), Recommended values for different topographies.

- Snow load relationship for **Central East** is describes as:

  $\mathbf{s_k} = (0{,}264 * Z - 0{,}002)\left[1 + (\frac{A}{256})^2\right]$ (Equation 4).[43]

cc) Reduced snow load

If it can be assured that the snow height is not exceeding more than 8 cm at any time, a reduced snow load for tents of 0.2 kN/m^2 can be applied.[44]

c) Wind load

The basic wind speed is given for a return period of 50 years and temporary structures are erected for much shorter periods, therefore we need to take into account the likelihood that a maximum wind will not take place.[45] This is in discretion of the structural engineer due to the period of use and the possibility to adapt the wind loads subjected to temporary structures.

aa) Terrain category

Wind loads should be calculated according to EN 1991-1-4:2005, Actions on structures, Part 1-4: General actions - Wind actions.[46] The location of the structure will define the following:

- Terrain category:[47] **0 - IV**
- Exposure factor:[48] $\boldsymbol{c_e(z)}$.

bb) Wind velocity

The velocity pressure can be modified to take the period of use into account. The probability and seasonal factors can be used but should be done with caution as part of a risk based approach.[49]

---

[43] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 40., Table C.1. Altitude, Snow Load Relationships.
[44] Cf. *EN 13782:2015*, loc. cit. (foot. 22), p. 15.
[45] Cf. *www.twforum.org.uk*, loc. cit. (foot. 30).
[46] *EN 1991-1-4:2005*, Actions on structures, Part 1-4: General actions - Wind actions, in the version dated 4 June 2004.
[47] Cf. *EN 1991-1-4:2005*, Actions on structures, Part 1 - 4: General actions - Wind actions, p. 20, Table 4.1, Terrain roughness.
[48] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 23, Table 4.2, Peak velocity pressure.
[49] Cf. *www.twforum.org.uk,* loc. cit. (foot. 30).

The basic wind velocity is described:

$$v_b = c_{dir} * c_{season} * v_{b,0} \text{ (Equation 5).}$$ [50]

The formula is in relation to the following coefficients:

- 10-minute mean velocity at 10 m above ground:[51] $v_{b,0}$
- Directional Factor (Recommended value is 1.0):[52] c_{dir}
- Seasonal Factor (Recommended value is 1.0):[53] c_{season}.

For temporary structures, the seasonal factor c_{season} may be used. For transportable structures, which may be used at any time in the year, c_{season} should be taken equal to 1.0.[54]

cc) Terrain roughness

The roughness factor $c_r(z)$ accounts for the variability of the mean wind velocity at the site of the structure due to the height above ground level and the ground roughness of the terrain.[55] The terrain roughness is described as:

$$c_r(z) = k_r * \ln(\frac{z}{z_0}) \text{ for } z_{min} \leq z \leq z_{max} \text{ (Equation 6).}$$ [56]

The formula is in relation to the following coefficients:

- Height of the building above the ground in meter:[57] z
- Roughness length in meter:[58] z_0.

---

[50] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 18, Equation 4.1.

[51] Location specific basic wind speed can be found online or in specific geographical literature (European wind map recommended).

[52] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 18, 4.2 Basic values, Note 2.

[53] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 18, 4.2 Basic values, Note 3.

[54] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 19.

[55] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 19.

[56] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 19, Equation 4.4.

[57] Resulting from the structure geometry.

[58] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 23, Table 4.1, Terrain categories and terrain parameters

$\boldsymbol{k_r}$ is described as:

$$\boldsymbol{k_r = 0,19 * (\frac{z_0}{z_{0,II}})^{0,07}} \text{ (Equation 7).}$$[59]

The formula is in relation to the following coefficients:

- According to the Terrain category:[60] $\boldsymbol{z_{0,II}}$

  i.e. Terrain category II; $\boldsymbol{z_0}$ = 0,05; $\boldsymbol{z_{0,II}}$ = 0,05
- Minimum height:[61] $\boldsymbol{z_{min}}$
- Maximum height (Recommended value is 200 m):[62] $\boldsymbol{z_{max}}$.

dd) Peak velocity pressure

The peak velocity pressure is described:

$$\boldsymbol{q_p(z) = c_e(z) * q_b} \text{ (Equation 8).}$$[63]

The formula is in relation to the following coefficients:

- Exposure factor:[64] $\boldsymbol{c_e(z)}$

$\boldsymbol{q_b}$ is described as:

$$\boldsymbol{q_b = \frac{1}{2} * \rho * v_b^2 * \frac{1}{1000}} \text{ (Equation 9).}$$[65]

The formula is in relation to the following coefficients:

- Air density:[66] $\boldsymbol{\rho}$
- Wind velocity:[67] $\boldsymbol{v_b}$.

---

[59] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20.
[60] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20, Table 4.1, Terrain roughness.
[61] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20, Table 4.1, Terrain roughness.
[62] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20.
[63] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 22, Equation 4.5.
[64] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 23, Figure 4.2, Illustrations of the exposure factor.
[65] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 23, Equation 4.8.
[66] Air density is depending on altitude, temperature and pressure. Location specific air density can be found online or in specific geographical literature.
[67] Described in *III. Construction versus Architecture*, *1. Structural guideline according to the Eurocode, c) Wind load, aa) Wind velocity*.

ee) Characteristic wind load on surfaces

The wind pressure on external surfaces $\boldsymbol{w_e}$ is described as:

$$\boldsymbol{w_e} = \boldsymbol{q_p}(\boldsymbol{z}) * \boldsymbol{c_{pe,10}}$$ (Equation 10).[68]

The formula is in relation to the following coefficients:

- Peak velocity pressure: $\boldsymbol{q_p}(\boldsymbol{z})$

  Peak velocity pressure described in *cc) Peak velocity pressure*
- Pressure coefficient for the external pressure:[69] $\boldsymbol{c_{pe,10}}$.

The shape factors for various structures needs to be defined per EN 1991-1-4, Section 7, Pressure and force coefficients.[70] *Figure 13* is showing various shapes and forms for pressure and force coefficients.

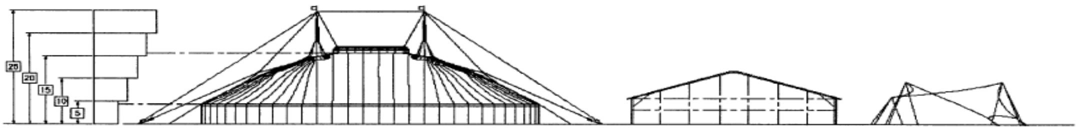

Figure 13 - EN 13782:2015, Figure 1, Application of wind loads.

4. Summery

The European Standards and most of the European structural design standards are intended to design permanent works. The indicated design working life of temporary structures is 10 years.[71] This lifespan is applicable to short lived structures but not needed to its full extend as shown in *II. Temporary Architecture*.

Temporary structures refer to a transient design situation.[72] This situation is suited for a period much shorter than the implied design working life situation of temporary structures. It defines fundamental load combinations and partial safety factors[73]. This is needed for further analysis.[74]

---

[68] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 24, Equation 5.1.

[69] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 31, Section 7, Pressure and force coefficients.

[70] Cf. *EN 13782:2015*, loc. cit. (foot. 22), p. 13.

[71] As described in *III. Construction versus Architecture, 1. Structural guideline according to the Eurocode, b) Design working life.*

[72] As described in *III. Construction versus Architecture, 2. Design situation.*

[73] As shown in *III. Construction versus Architecture, 2. Design situation, a) Fundamental load combinations and partial safety factors.*

[74] As mentioned in *III. Construction versus Architecture, 2. Design situation, a) Fundamental load combinations and partial safety factors.*

Snow and Wind loads for temporary structures should be calculated according to EN 1991-1-3:2003 and EN 1991-1-4:2005.[75]

EN 13782:2015 specifies requirements for mobile and temporary installed tents with more than 50 m^2. This structural design standard characterises seasonal factors for structures erected only throughout periods of the year. Those factors can be applied to temporary structures. However, for wind and snow load calculations it is still required to use EN 13782:2015 in conjunction with EN 1991-1-3:2003 and EN 1991-1-4:2005.[76]

Structural calculations for Temporary Architecture are guided by its location and erection period. It is for the structural engineer and the architectural designer to specify the most important load cases and how they are going to affect the structure. The structural engineer and designer need to consider the possibility of neglecting load cases according to their appearances.

---

[75] As described in *III. Construction versus Architecture, 3. Load assumptions, b) Snow load and c) Wind load.*

[76] Cf. EN 13782:2015, loc. cit. (foot. 22), p. 11 - 15.

IV. Example Calculations

The practical example calculations below are demonstrating best practice how to calculate wind and snow loads for temporary structures as mentioned in *I. Introduction*. The *Transportable Membrane Sail* is focusing on the structural guideline to determine a wind and snow load. The *Cylindrical Hangar Structure* is highlighting best practice how to calculate wind loads for pneumatic structures.

1. Transportable Membrane Sail

The following calculation is providing guidance how to use the guideline developed in *III. Construction versus architecture.*

The design is a transportable membrane sail located in Dessau. The structure will be fixed to the surrounding walls and elevated at one point through a mast. The membrane shape is comparable to a mono pitch canopy as shown in *figure 14 and 15*. Please see project details below:

- Location: Dessau (Germany)
- Height of structure: 8 m (highest point)
- Angle of roof pitch: 25^0 (highest value)
- Covered area: 65 m^2
- Existed: September – December

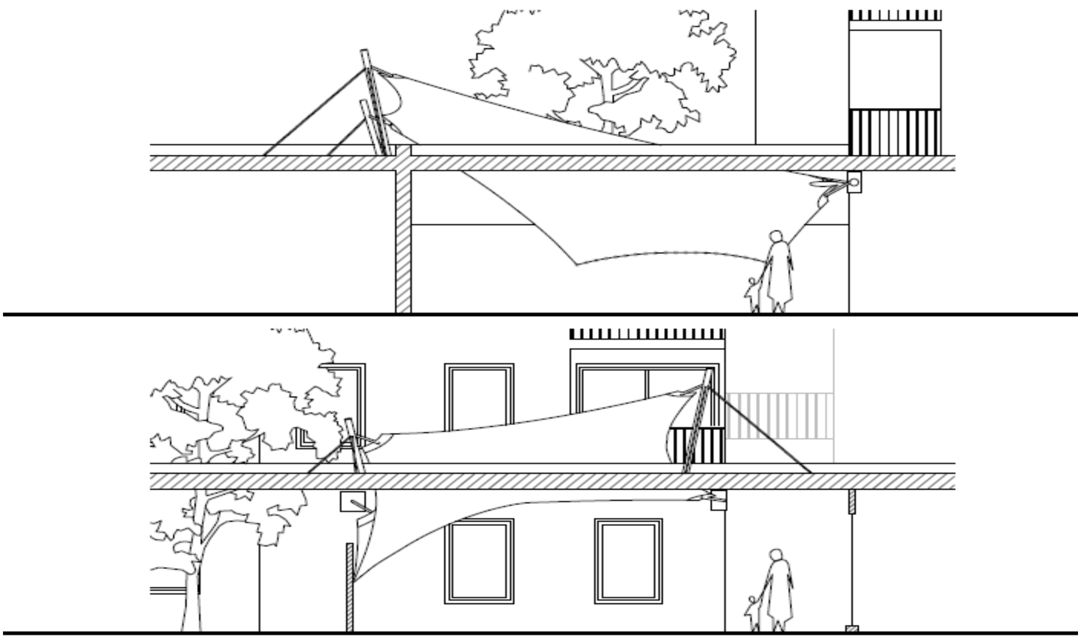

Figure 14 - Plan view, Transportable Membrane Sail.

The structure will be erected from September till December only. Therefore, the structure will be subjected to wind and snow loads.
The seasonal character of the design allows us to classify the project as a temporary structure.[77] The self-weight can be neglected due to the light weight nature of the design.[78] The mono pitch shape of the sail is providing enough angle so ponding is not to be expected.
This example is not providing any further load and material analysis.[79]

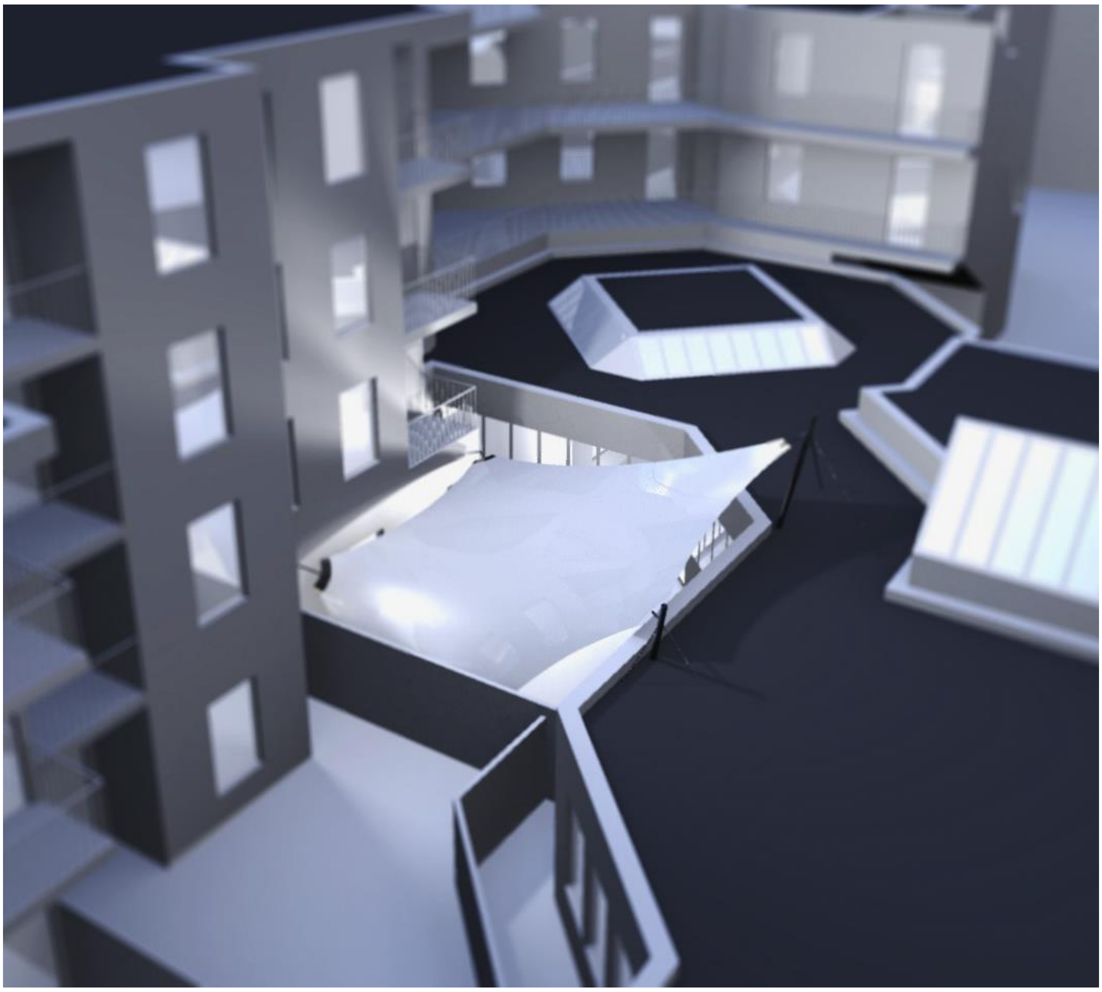
Figure 15 - Isometric view, Transportable Membrane Sail.

[77] As described in *III. Construction versus Architecture, 1. Structural guideline according to the Euro-code,* b) Design working life.
[78] As described in *III. Construction versus Architecture, 3. Load assumptions, a) Self-weight.*
[79] As described in *III. Construction versus Architecture, 2. Design situation, a) Fundamental load combinations and partial safety factors.*

a) Snow load

As per the project the description,[80] the structure will be subjected to snow loads.

aa) Climatic region

The geographical location is Dessau[81]. This will define the following coefficients:

- Climatic Regions:[82] **Central East**
- Altitude (A) of the structure above sea level:[83] **61 m**

The climatic region is specifying the snow map[84] showing loads at sea level for central east. The exact location is defining the following:

- Snow Load Zone:[85] **(Z)** = **3**.

bb) Characteristic snow load

The snow load is described as:

$\boldsymbol{s = \mu_i * C_e * C_t * s_k}$ (Equation 3).[86]

The structure geometry is defining the following coefficients:[87]

- Snow load shape coefficient:[88] $\boldsymbol{\mu_i}$ = **0.8 (-)**
- Exposure coefficient:[89] $\mathbf{C_e}$ = **1.0 (-)**
- Thermal coefficient:[90] $\mathbf{C_t}$ = **1.0 (-)**.

---

[80] As described in *IV. Example Calculations, 1. Transportable Membrane Sail.*
[81] As described in *III. Construction versus Architecture, 3. Load assumptions, b) Snow load, aa) Climatic region.*
[82] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 38.
[83] Site specific altitude/elevation can be found online or in specific geographical literature.
[84] The snow maps above sea level can be found in EN 1991-1-3: 2003, Annex C, European Ground Snow Load Maps.
[85] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 38.
[86] Taken from *III. Construction versus Architecture*, *3. Load assumptions, b) Snow load, bb) Characteristic snow load*.
[87] As described in *III. Construction versus Architecture*, *3. Load assumptions, b) Snow load, bb) Characteristic snow load.*
[88] Cf. *EN 1991-1-3*:2003, loc. cit. (foot. 37), p. 21.
[89] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 20.
[90] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 20.

Snow load relationship for **Central East** is describes as:[91]

- $\mathbf{s_k} = (0{,}264 * Z - 0{,}002)[1 + (\frac{A}{256})^2]$ = **0.835 (-)** (Equation 4).[92]

The characteristic snow load is to be calculated according to *Equation 2*. The defined coefficients above need to be taken into consideration. The characteristic snow load for the Transportable Membrane Sail is as follow:

$$\boldsymbol{s = \mu_i * C_e * C_t * s_k = 0.8 * 1 * 1 * 0.835 = 0.67} \ \textbf{\textit{kN/m}}^{\mathbf{2}}$$

b) Wind load

The structure is intended to be used during September till December.[93] The following calculation is considering the basic wind speed for a return period of 50 years.[94]

aa) Terrain category

The location of the structure is defining the terrain category, as described in *aa) terrain category*. The structure parameters, described in *1. Transportable Membrane Sail*, will define the following coefficients:

- Height of structure: **z** = **8 m**
- Angle of roof pitch: $\mathbf{25^0}$
- Terrain Category:[95] **II (-)**.

The structure height and the terrain category will define the following:

- Exposure factor:[96] $\boldsymbol{c_e(z)}$ = **2.8 (-)**.

---

[91] Cf. *EN 1991-1-3:2003*, loc. cit. (foot. 37), p. 40.
[92] Taken from *III. Construction versus Architecture*, *3. Load assumptions, b) Snow load, bb) Characteristic snow load*.
[93] As described in *IV. Example Calculations, 1. Transportable Membrane Sail.*
[94] As described in *III. Construction versus Architecture*, *3. Load assumptions,* c) Wind load.
[95] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20, Table 4.1, Terrain roughness.
[96] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 23, Table 4.2, Peak velocity pressure.

bb) Wind velocity

The basic wind velocity is described as:

$$v_b = c_{dir} * c_{season} * v_{b,0} \text{ (Equation 5).}$$ [97]

The location of the structure is defining the coefficients below:[98]

- 10-minute mean velocity:[99] $v_{b,0}$ = **26 m/sec**
- Directional Factor:[100] c_{dir} = **1.0 (-)**
- Seasonal Factor:[101] c_{season} = **1.0 (-)**.

For transportable structures c_{season} should be taken equal to 1.0.[102]
The basic wind velocity is to be calculated according to *Equation 3*. The coefficients defined above need to be considered. The basic wind velocity for the Transportable Membrane Sail is as follow:

$$v_b = c_{dir} * c_{season} * v_{b,0} = 1 * 1 * 26 = 26\ m/sec$$

cc) Terrain roughness

The terrain roughness is described as:

$$c_r(z) = k_r * \ln\left(\frac{z}{z_0}\right) \text{ for } z_{min} \leq z \leq z_{max} \text{ (Equation 6).}$$ [103]

The terrain roughness is guided by the structure geometry.[104] This will define the following:

- Height of structure: **z** = **8 m**

[97] Taken from *III. Construction versus Architecture*, *3. Load assumptions, c) Wind load, bb) Wind velocity*.
[98] As described *III. Construction versus Architecture*, *3. Load assumptions, c) Wind load, bb) Wind velocity.*
[99] Location specific basic wind speed can be found online or in specific geographical literature (European wind map recommended).
[100] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 18, 4.2 Basic values, Note 2.
[101] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 18, 4.2 Basic values, Note 3.
[102] As defined in *IV. Example Calculations, 1. Transportable Membrane Sail.*
[103] Taken from *III. Construction versus Architecture*, *3. Load assumptions, c) Wind load, cc) Terrain roughness.*
[104] As described in *III. Construction versus Architecture*, *3. Load assumptions, c) Wind load, cc) Terrain roughness.*

- Roughness length in meter:[105] z_0 = **0.05 m**.

k_r is described as

$$k_r = 0,19 * (\frac{z_0}{z_{0,II}})^{0,07} \text{ (Equation 7).}^{106}$$

The formula is in relation to the following coefficients:

- Terrain category II:[107] $z_{0,II}$ = **0.05 m**
- Minimum height:[108] z_{min} = **2 m**
- Maximum height:[109] z_{max} = **200 m**.

The terrain roughness is to be calculated according to *Equation 5* in conjunction with *Equation 6*.

$$k_r = 0,19 * (\frac{z_0}{z_{0,II}})^{0,07} = 0,19 * (\frac{0.05}{0.05})^{0,07} = 0.19 \text{ (-)}$$

$$c_r(z) = k_r * ln\left(\frac{z}{z_0}\right) = k_r * ln\left(\frac{8}{0.05}\right) = 0.964 \text{ (-)}$$

Proof is give as per the below:

$$z_{min} \leq z \leq z_{max}\text{: } 2 \leq 8 \leq 200 \text{ m}$$

dd) Peak velocity pressure

The peak velocity pressure is described as:

$$q_p(z) = c_e(z) * q_b \text{ (Equation 8).}^{110}$$

[105] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20, Table 4.1, Terrain categories and terrain parameters.
[106] Taken from *III. Construction versus Architecture*, *3. Load assumptions, c) Wind load, cc) Terrain roughness.*
[107] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20.
[108] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20.
[109] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 20.
[110] Taken from *III. Construction versus Architecture, 3. Load assumptions, c) Wind load, dd) Peak velocity pressure.*

The formula requires the following values:[111]

- Exposure factor:[112] $c_e(z)$ = **2.8 (-)**

The basic velocity pressure is described as:

$$\boldsymbol{q_b = \frac{1}{2} * \rho * v_b^2 * \frac{1}{1000}}$$ (Equation 9).[113]

Equation 9 is in relation to the following coefficients:

- Air density:[114] $\boldsymbol{\rho}$ = **1.25 kg/m³**
- Wind velocity:[115] $\boldsymbol{v_b}$ = **26 m/sec**

The peak velocity pressure is to be calculated according to *Equation 8* in conjunction with *Equation 9*.

$$q_b = \frac{1}{2} * \rho * v_b^2 * \frac{1}{1000} = \frac{1}{2} * 1.25 * 26^2 * \frac{1}{1000} = 0.4225 \; kN/m2$$
$$\boldsymbol{q_p(z) = c_e(z) * q_b = 2.8 * 0.4225 = 1.183 \; kN/m2}$$

ee) Characteristic wind load on surfaces

The characteristic wind load (wind pressure on external surfaces) is described as:

$$\boldsymbol{w_e = q_p(z) * c_{pe,10}}$$ (Equation 10).[116]

Equation 10 is in relationship to the following coefficients:

- Peak velocity pressure:[117] $\boldsymbol{q_p(z)}$ = **1.183 kN/m²**

---

[111] As described in *III. Construction versus Architecture, 3. Load assumptions, c) Wind load, dd) Peak velocity pressure.*
[112] Taken from *IV. Example Calculations*, *1. Transportable Membrane Sail, b) Wind load, aa) Terrain category.*
[113] Taken from *III. Construction versus Architecture*, *3. Load assumptions, c) Wind load, dd) Peak velocity pressure.*
[114] Air density is depending on altitude, temperature and pressure. Location specific air density can be found online or in specific geographical literature.
[115] Taken from *IV. Example Calculations, 1. Transportable Membrane Sail, b) Wind load, bb) Wind velocity.*
[116] Taken from *III. Construction versus Architecture, 3. Load assumptions, b) Snow load, ee) Characteristic wind load on surfaces.*
[117] Taken from *III. Construction versus Architecture, 1. Transportable Membrane Sail, b) Wind load, dd) Peak velocity pressure.*

- Pressure coefficient for the external pressure:[118] $\boldsymbol{c_{pe,10}}$.

The Pressure coefficient for the external pressure $\boldsymbol{c_{pe,10}}$ is depending on the shape of the roof. The structure shape is comparable to a mono pitch canopy roof.[119]
For mono pitch roofs the airflow $\boldsymbol{\varphi}$ must be defined.[120] This value is guided by its surrounding obstacles.[121]
The airflow $\boldsymbol{\varphi}$ for the Transportable Membrane Sail is to be taken equal to $\boldsymbol{\varphi = 1}$.
The maximum download $\boldsymbol{\varphi} = \textbf{max}$ should still be considered.
The characteristic wind load (wind pressure on external surfaces) is to be calculated according to *Equation 10*. The recommended pressure coefficients are divided into areas as per the calculation below.

$\varphi = \max$ (download)

Area A	$\boldsymbol{w_e = 1.183 * 2.0 = 2.36}$ ***kN/m²***
Area B	$\boldsymbol{w_e = 1.183 * 3.1 = 3.67}$ ***kN/m²***
Area C	$\boldsymbol{w_e = 1.183 * 2.3 = 2.72}$ ***kN/m²***

Table 3 - Characteristic wind loads φ = max for Transportable Membrane Sail.

$\varphi = 1$ (uplift)

Area A	$\boldsymbol{w_e = 1.183 * -1.5 = -1.77}$ ***kN/m²***
Area B	$\boldsymbol{w_e = 1.183 * -2.5 = -2.95}$ ***kN/m²***
Area C	$\boldsymbol{w_e = 1.183 * -2.8 = -3.31}$ ***kN/m²***

Table 4 - Characteristic wind loads φ = 1 for Transportable Membrane Sail.

c) Summery

The calculation for the Transportable Membrane Sail shows that the snow and wind load calculation according to EN 1991-1-3:2003 and EN 1991-1-4:2005 for temporary structures is possible but not entirely applicable. The Eurocode as itself does not provide enough seasonal factors or details to apply to temporary structures.

---

[118] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 31, Section 7, Pressure and force coefficients.
[119] As described in *IV. Example Calculations, 1. Transportable Membrane Sail.*
[120] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 55.
[121] As described in *IV. Example Calculations, 1. Transportable Membrane Sail.*

The structure can be classified as a temporary structure despite the shorter period of use.[122]

The calculated loads can be used for further analysis.[123] This is fundamental to determine construction materials and structural details.

The structure is erected only from September to December. The Eurocode is not providing enough depth to reflect on the period of use.

The recent climatic development in Germany is showing less snow during December and it is questionable if the calculated snow load[124] needs to be applied to its full extent. The calculated wind loads[125] are considering the basic wind speed for a return period of 50 years. It is arguable if wind loads to this extent are to be expected during this period.

The European standards are not providing enough guidance to consider the problems mentioned above. The application of the calculated loads might result in over dimensioned material properties which lead to higher production costs.

---

[122] According *to III. Construction versus Architecture, 1. Structural guideline according to the Eurocode, b) Design working life.*
[123] As described in *III. Construction versus Architecture, 2. Design situation.*
[124] As calculated in *III. Construction versus Architecture, 3. Load assumptions, b) Snow load, bb) Characteristic snow load.*
[125] As calculated in *III. Construction versus Architecture, 3. Load assumptions, c) Wind load, ee) Characteristic wind load.*

2. Cylindrical Hangar Structure

The Cylindrical Hangar Structure is an own representation based on the calculation of Action Space Air Structure - ArtEngineering GmbH.

The Cylindrical Hangar Structure is to be seen as a calculation away from the structural guideline.[126] It is recommending best practice how to calculate wind loads for pneumatic structures.

The design is an inflatable walk-in-structure in shape of a cylindrical hangar. The structure needs to be pressured whilst the pressure value is unknown as shown in *figure 16*.

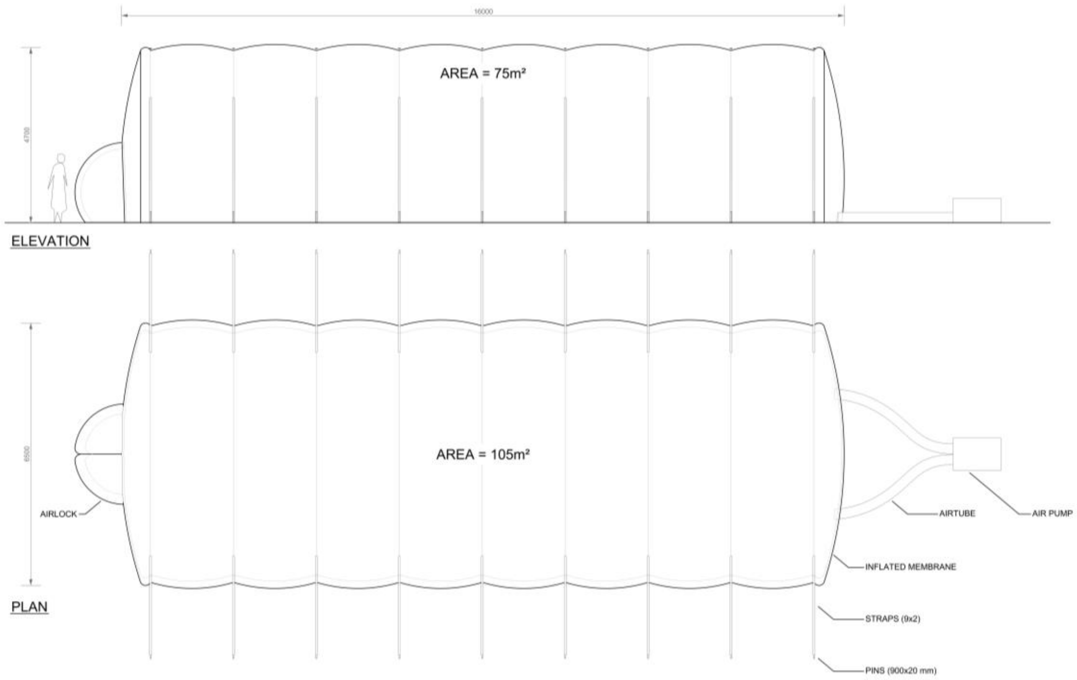

Figure 16 - Plan view, Cylindrical Hangar Structure.

The Structure will be erected through the summer months which allows us to neglect the snow load. The round shape of the structure will also not be sensitive to ponding. Therefore, only self-weight and wind loads will be applied to the structure. Since the inflatable material is only 0.35 mm thick, the self-weight can be neglected.

---

[126] Provided in *III. Construction versus Architecture, 1. Structural guideline according to the Eurocode.*

Due to wind loads only the structure needs to be prevented from the following:

- Lifting
- Overturning
- Sliding

To prevent the above, anchor pins or masses are distributed alongside the outer edges of the structure as shown in *figure 17 - 19*. Each must be fixed to the membrane surface by straps. The maximum wind speed for safe operation is limited to 40 km/h (11.1 m/sec). Expected wind speed of 25 km/h (6.9 m/sec) is considered. The calculation will be done for both wind speeds.

Figure 17 - Isometric view, Cylindrical Hangar Structure.

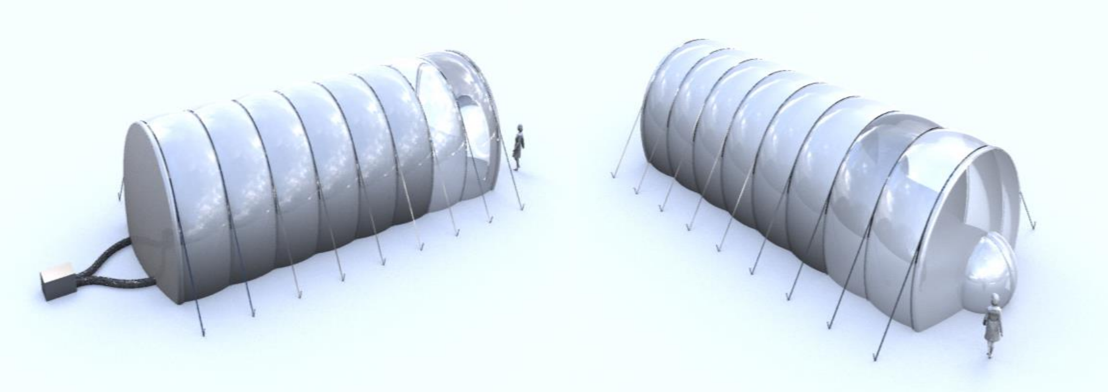

Figure 18 - Isometric view, Cylindrical Hangar Structure.

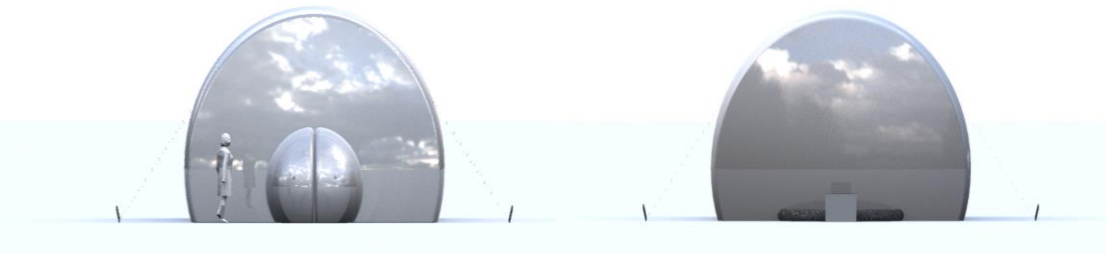

Figure 19 - Elevations, Cylindrical Hangar Structure.

a) Load assumptions

The wind speeds and impact pressure in kN/m^2 is calculated as per *Equation 11*:

$$\boldsymbol{q} = \frac{v^2}{1600} \text{ (Equation 11)}$$

Wind (km/h)	v (m/sec)	q (kN/m²)
40 km/h	11.1	**0.07**
25 km/h	6.9	**0.03**

Table 5 - Wind speeds and impact pressure for 40 km/h and 25 km/h.

aa) Wind force coefficients

The wind force coefficients are taken from known results. The values below are guidance values to estimate the resulting forces on the constructional element.

- **$c_{p,G}$** = 0.8 (maximum value)[127]

  Reference face **G** is the ground floor area. The chosen ground floor area is 105 m².
- **$c_{p,L}$** = 1.1 (recommended value)[128]

  Reference face **L** is the lateral area. The chosen lateral area is 75 m².

bb) Horizontal forces

The resulting horizontal forces on the inflated structure are calculated as per *Equation 12 and 13* (H_{total} per G and L):

$$\boldsymbol{H_{total}} = c_{p,G} * A_{total} * q \text{ (Equation 12)}$$

$$\boldsymbol{H_{total}} = c_{p,L} * A_{total} * q \text{ (Equation 13).}$$

Wind 40 km/h	c_p	A	q	H_{total}
G	0.8	105	0.07	**5.88**
L	1.1	75	0.07	**5.78**

Table 6 - Horizontal forces for 40 km/h.

---

[127] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 50.
[128] Cf. *EN 1991-1-4:2005*, loc. cit. (foot. 47), p. 120.

Wind 25 km/h	c_p	A	q	H_{total}
G	0.8	105	0.03	**2.52**
L	1.1	75	0.03	**2.48**

Table 7 - Horizontal forces for 25 km/h.

cc) Vertical forces (uplift)

The drag coefficient is applied to the structure to determine the vertical forces.

- **c_D** = 0.54 for half-cylinder (average value)

  reference area is G (ground floor) according to the direction of the force.

The vertical forces are calculated as per *Equation 14 and 15*:

$\boldsymbol{V_{total}} = V * n$ (Equation 14)

$\boldsymbol{V} = c_A * A * q * n$ (Equation 15).

Wind (km/h)	c_a (-)	A (m^2)	q (kN/m^2)	n (-)	V (kN)
40	0.54	105	0.07	1.2	**4.76**
25	0.54	105	0.03	1.2	**2.04**

Table 8 - Vertical forces for 40 km/h and 25 km/h.

b) Stability

The safety coefficient to prevent the structure from overturning are:

- Sliding and uplifting:[129] $\boldsymbol{\gamma = 1.2}$
- Friction coefficient:[130] $\boldsymbol{\mu = 0.4}$.

[129] Cf. *EN 13782:2015*, loc. cit. (foot. 22), p. 17.
[130] Cf. *www.engineeringtoolbox.com* (retrieved from https://www.engineeringtoolbox.com/friction-coefficients-d_778.html (viewed 15.10.2017)).

aa) Required mass (vertical)

Wind	V_{total}[131] (kN)	Required mass (kg)
40 km/h	4.76	**4760**
25 km/h	2.04	**2040**

Table 9 - Required vertical mass for 40 km/h and 20 km/h.

bb) Required mass (horizontal)

The horizontal sliding forces are calculated as per *Equation 16 and 17*:

Required mass in kg = $\frac{H_d}{\mu} * 100$ (Equation 16)

$\boldsymbol{H_d} = H_{total} * \gamma$ (Equation 17).

Wind (km/h)	H_{total}[132] (kN)	γ (-)	Hd (kN)
40 km/h	5.78	1.2	**6.94**
25 km/h	2.48	1.2	**2.98**

Table 10 - Hd for 40 km/h and 25 km/h.

Hd (kN)	μ (-)	Required mass (kg)
6.94	0.4	**1735**
2.98	0.4	**745**

Table 11 - Required mass for 40 km/h and 25 km/h.

cc) Required ballast (total)

The required mass is to be calculated as per *Equation 18*:

$\boldsymbol{M_{req}} = m_{req,vertical} + m_{req,horizontal}$ (Equation 18).

The total ballast is to be calculated as per *Equation 19*:

$\boldsymbol{M_{total}} = m * fixing\ points * 10\%\ contingency$ (Equation 19).

[131] V_{total} taken from *IV Example Calculations, 2. Cylindrical Hangar Structure*, a) *Load assumptions, cc) Vertical forces (uplift).*
[132] H_{total} taken from *IV Example Calculations, 2. Cylindrical Hangar Structure, a). Load assumptions, bb) Horizontal forces.*

The structure is secured with 18 fixing points as shown in *figure 17 and 18*. The ballast per fixing is **m** in kg. The ballast per wind speed varies. It can be assumed that for 40 km/h the ballast per fixing point is 450 kg and for 25 km/h the ballast per fixing point is 200 kg.

Wind (km/h)	**$M_{req, vertical}$ (kg)**	**$M_{req, horizontal}$ (kg)**	**M_{req} (kg)**
40 km/h	4760	1735	**6495**
25 km/h	2040	745	**2785**

Table 12 - Required mass for 40 km/h and 25 km/h.

m (kg)	**Fixing points (-)**	**10% Contingency (-)**	**M_{total} (kg)**
450	18	0.9	**7290**
200	18	0.9	**3240**

Table 13 - Total ballast for 40 km/h and 25 km/h.

Equation 20 compares the required mass to the total mass.

$$\mathbf{1.0} > \frac{M_{req}}{M_{total}} \text{ (Equation 20).}$$

Wind (km/h)	**Mreq (kg)**	**Mtotal (kg)**	**Proof < 1.0**
40 km/h	6495	7290	**0.89**
25 km/h	2785	3240	**0.86**

Table 14 - Proof of required ballast for 40 km/h and 25 km/h.

dd) Anchor pins

The structure is secured with 18 anchoring points. The calculation is according to EN 13782:2005.[133] The anchoring pins have the following details:

- Length: **l** = **80 cm**
- Diameter: **d** = **2.5 cm**
- Length in ground: **l'** = **80 cm**
- Quantity: **n** = **18**

[133] Cf. *EN 13782:2015*, loc. cit. (foot. 22), p. 22.

The pins will be loaded on an angle of 60^0. The resulting force is to be calculated as per *Equation 21*:

$$\boldsymbol{Z_d} = \frac{Z_h}{\sin 60^0} \text{ (Equation 21).}$$

Wind (km/h)	V_{total} (Z_v)	H_{total} (Z_h)	β	Z_d
40	4.76	5.78	60	6.67
25	2.04	2.48	60	2.86

Table 15 - Resulting anchor pin force for 40 km/h and 25 km/h.

$Z_{R,d}$ is to be calculated as per *Equation 22*.

$$\boldsymbol{Z_{R,d}} = 10 * d * l' * (n) = 10 * 2.5 * 80 * (18) = \mathbf{36\ kN}$$

(Equation 22).

Equation 23 is comparing the two resulting forces on the anchoring pin:

$$\mathbf{1.0} > \frac{Z_d}{Z_{R,d}} \text{ (Equation 23).}$$

Wind (km/h)	Z_d	$Z_{R,d}$	Proof < 1.0
40 km/h	6.67	36	**0.18**
25 km/h	2.86	36	**0.08**

Table 16 - Proof of anchor pins for 40 km/h and 25 km/h.

The minimum diameter for the anchoring pins to prevent any bending is to be calculated as per *Equation 24*:

$$\boldsymbol{d_{min}} = 0.025 * l' + 0.5 = 0.025 * 80 * 0.5 = \mathbf{2.5\ cm} \ \leq \mathbf{2.5\ cm}$$

(Equation 24).

The calculation is valid for semi-solid to compact soils and cohesive soils of at least medium to stiff consistency.

c) Summery

The structure has a 11% reserve for ballast. It is recommended to use all the masses for the pins due to uncertainty in calculations and soil consistency.

The guiding factor to calculate the ballast of is the friction coefficient. The structure must be designed to achieve a friction coefficient higher than 0.3.

Due to the large dimensions of the ground floor area in relation to its height, overturning is not to be expected. Lifting can also be ignored due to the weight of the structure.

Wind (km/h	**Anchor pins (fixing points)**	**Proof Ballast**	**Proof Anchor pins**
40 km/h	18	**89 %**	**18 %**
25 km/h	18	**86 %**	**8 %**

Table 17 - Summary of results.

V. Conclusion

Temporary architecture is driving alternative technologies and develops new ways of designing and engineering. It is experimental and always questioning the form of permanent architecture. The use of new shapes and materials demand innovation in architectural design as well as in engineering and in constructing.

Temporary structures cover a wide range of variety and can be seen and found in many various locations. They are mostly always for public use and involve the public as key protagonists in their formation and performance.

The European standard does not provide enough detail and depth to specify purposely short-lived structures. Most of the European structural design standards and all the Eurocodes are intended to design permanent works.

The difference between permanent architecture and temporary architecture makes the straight application of the European Standards difficult. Structural calculations for temporary structures are challenging. It is for the structural engineer to decide between the difference of short term and permanent use and to consider which load cases are most important.

Temporary structures change over time and are subjected to continues transformation. They can appear in unusual places and different climatic regions. The Eurocode and the structural design standards should be adapting to those criteria’s. It would be beneficial if the code would add a periodical review of loadings to avoid high factors of safety and overdesigned loadings.

The design working life for temporary structures is defined as 10 years. This timeframe is only partly applicable to temporary structures. A subcategory with a more applicable timeframe would gain more visibility and clarification for temporary structures.

Appendix

The following appendices are providing step by step instructions how to calculate wind and snow loads. It is derived from the guideline described in *III. Construction versus Architecture*.
It is listing all necessary formulas and coefficients to determine basic load cases for wind and snow. The recommended values are referring to the relevant European standard. The guideline is to be used in conjunction with EN 1991-1-3:2003 and EN 1991-1-4:2005.

Appendix A - Snow load guideline

1. Climatic region

The geographical location of the structure needs to be known to define the following:

- **Altitude of the structure: A**
  Altitude information can be found online or in specific geographical literature.
- **Climatic Region**
  Snow Load Maps are defined in EN 1991-1-3:2003, p. 38.
  - **Snow load zone: Z**
    The snow load zone is defined through the specific snow load map.

Altitude	**A**	**m**
Climatic Region		**(-)**
Snow load zone	**Z**	**(-)**

2. Characteristic snow load

The characteristic snow load is described as:

$$s = \mu_i * C_e * C_t * s_k$$

The structure geometry and the specific location are defining the following coefficients:

- **Angle of roof pitch**
  Depending on the structure geometry.
  - **Snow load shape coefficient: μ_i**
    Recommended values can be found in EN 1991-1-3:2003, p. 21.
- **Exposure coefficient: C_e**
  Recommended values can be found in EN 1991-1-3:2003, p. 20.
- **Thermal coefficient: C_t**
  Recommended values can be found in EN 1991-1-3:2003, p. 20.
- **Snow load relationship: s_k**
  Snow load relationships according to the climatic region can be found in EN 1991-1-3:2003, p. 40.

Snow load shape coefficient	μ_i	**(-)**
Exposure coefficient	C_e	**(-)**
Thermal coefficient	C_t	**(-)**
Snow load relationship	s_k	**(-)**

Characteristic snow load	$s = \mu_i * C_e * C_t * s_k$	**kN/m²**

If it can be assured that the snow height is not exceeding more than 8 cm at any time, a reduced snow load for tents of 0.2 kN/m^2 can be applied. This is applicable to tent structures defined in *EN 13782:2015, p. 6 - 7.*

Appendix B - Wind load guideline

1. Terrain category

The structure geometry and the specific location are defining the following coefficients:

- **Height of structure: z**
  Depending on the structure geometry.
- **Angle of roof pitch: α**
  Depending on the structure geometry.
- **Terrain category: 0 - IV**
  Recommended values can be found in EN 1991-1-4:2005, p. 20.

Height of structure	**z**	**m**
Angle of roof pitch	α	^{0}
Terrain category	**0 - IV**	**(-)**

The terrain category and the height of the structure are defining the following coefficient:

- **Exposure factor**
  The relevant table can be found in EN 1991-1-4:2005, p. 23.

Exposure factor	$c_e(z)$	**(-)**

2. Wind velocity

The wind velocity is described as:

$$v_b = c_{dir} * c_{season} * v_{b,0}$$

The specific location of the structure will define the following coefficients:

- **Mean wind velocity: $v_{b,0}$**

  Basic wind speed information can be found online or in specific geographical literature. It is recommended to use the European wind map.

- **Directional factor: c_{dir}**

  Recommended values can be found in EN 1991-1-4:2005, p. 18.

- **Seasonal factor: c_{season}**

  Recommended values can be found in EN 1991-1-4:2005, p. 18.

Mean wind velocity	$v_{b,0}$	**m/sec**
Directional factor	c_{dir}	**(-)**
Seasonal factor	c_{season}	**(-)**

Wind velocity	$v_b = c_{dir} * c_{season} * v_{b,0}$	**m/sec**

3. Terrain roughness

The terrain roughness is described as:

$$c_r(z) = k_r * \ln(\frac{z}{z_0}) \text{ for } z_{min} \leq z \leq z_{max}$$

The structure geometry and the specific location are defining the following coefficients:

- **Height of structure: z**

  Depending on the structure geometry.

- **Roughness length: z_0**

  Recommended values can be found in EN 1991-1-4:2005, p. 20.

- **Terrain category II:** $z_{0,II}$

  Recommended values can be found in EN 1991-1-4:2005, p. 20.

- **Minimum height:** z_{min}

  Recommended values can be found in EN 1991-1-4:2005, p. 20.

- **Maximum height:** z_{max}

  Recommended values can be found in EN 1991-1-4:2005, p. 20.

Height of structure	**z**	**m**
Roughness length	z_0	**m**
Roughness length II	$z_{0,II}$	**m**
Minimum height	z_{min}	**m**
Maximum height	z_{max}	**m**

The terrain factor $\boldsymbol{k_r}$ is described as:

$$\boldsymbol{k_r = 0,19 * (\frac{z_0}{z_{0,II}})^{0,07}}$$

Terrain factor	$\boldsymbol{k_r = 0,19 * (\frac{z_0}{z_{0,II}})^{0,07}}$	**(-)**

Terrain roughness $z_{min} \leq z \leq z_{max}$	$\boldsymbol{c_r(z) = k_r * \ln(\frac{z}{z_0})}$	**(-)**

4. Peak velocity pressure

The peak velocity pressure is described as:

$$q_p(z) = c_e(z) * q_b$$

The formula is in relation to the following coefficients:

- **Exposure factor: $c_e(z)$**

  To be taken from *Appendix B, Wind load guideline, 1. Terrain category.*

- **Wind velocity: v_b**

  To be taken from Appendix B, Wind load guideline, 2. Wind velocity.

- **Air density: ρ**

  Air density information can be found online or in specific geographical literature.

Exposure factor	$c_e(z)$	**(-)**
Wind velocity	v_b	**m/sec**
Air density	ρ	**kN/m³**

The basic velocity pressure q_b is in relation to the coefficients above and described as:

$$q_b = \frac{1}{2} * \rho * v_b^2$$

Basic velocity pressure	$q_b = \frac{1}{2} * \rho * v_b^2$	**kN/m²**

Peak velocity pressure	$q_p(z) = c_e(z) * q_b$	**kN/m²**

5. Characteristic wind load on surfaces

The characteristic wind load (pressure on external surface) is described as:

$$\boldsymbol{w_e = q_p(z) * c_{pe,10}}$$

The formula is in relation to the following coefficients:

- Peak velocity pressure: $\boldsymbol{q_p(z)}$

  To be taken from Appendix B, Wind load guideline, 3. Peak velocity pressure.
- Pressure coefficient for the external pressure: $\boldsymbol{c_{pe,10}}$

  Recommended values can be found in EN 1991-1-4:2005, p. 31.
  - Airflow (Blockage): $\boldsymbol{\varphi}$

    Recommended values can be found in EN 1991-1-4:2005, p. 55.

Peak velocity pressure	$\boldsymbol{q_p(z)}$	**kN/m²**

The recommended pressure coefficients are divided into areas as per the example table below:

Blockage $\boldsymbol{\varphi}$	$\boldsymbol{\varphi =}$	$\boldsymbol{\varphi =}$
Area A	**kN/m²**	**kN/m²**
Area B	**kN/m²**	**kN/m²**
Area C	**kN/m²**	**kN/m²**
Area D	**kN/m²**	**kN/m²**

References

Baker, Lisa, Temporary architecture, Braun Publishing AG 2014.

Chabrowe, Barbara, (1974) On the Significance of Temporary Architecture, P. 385, Vol. 116, No. 856, Jul. 1974 Burlington Magazine Publications Ltd.

Franck, Karen, (2016) Architecture Timed: Designing with Time in Mind, P. 10,17, No. 239, Jan 2016 John Wiley & Sons.

Friction coefficient, viewed 15 October 2017, retrieved from <https://www.engineeringtoolbox.com/friction-coefficients-d_778.html>.

Grazia, Sergio, Peace Pavillion by Atelier Zündel Cristea, digital photograph, viewed 13 August 2017, retrieved from <http://www.archdaily.com/387121/peace-pavilion-arch-triumph>.

JNBY pavillion by HHD_FUN, digital photgraph, viewed 13 August 2017, retrieved from <http://www.archdaily.com/111922/jnby-hhd_fun-architects/>.

Luminaria by Architects of Air, digital photograph, viewed 22 October 2017, retrieved from < <https://www.youtube.com/watch?v=_qVhqJj6_fs:>.

Luminaria by Architects of Air, digital photograph, viewed 22 October 2017, retrieved from <https://www.pinterest.de/pin/150870656241388118/:>.

Luminaria by Architects of Air, viewed 14 Octover 2017, retrieved from <http://www.architects-of-air.com/luminaria.html>.

Peace Pavillion by Atelier Zündel Cristea, viewed 7 November 2017, retrieved from <http://www.zundelcristea.com/en/design/peace-pavilion/>.

Robbins, Tony, Engineering a new Architecture, Yale University Press New Haven and London 1996.

Royal Academy, viewed 10 November 2017, retrieved from <https://www.dezeen.com/2017/07/06/david-chipperfield-renovation-royal-academy-arts-architecture-gallery-lon-don/>.

Serpentine Pavillion 2015 by SelgasCano, digital photograph, viewed 14 October 2017, retrieved from <https://www.dezeen.com/2015/06/22/serpentine-pavilion-2015-iwan-baan-london-selgascano/>.

Serpentine Pavillion 2015 by SelgasCano, viewed 14 October 2017, retrieved from <https://www.dezeen.com/2015/06/22/serpentine-pavilion-2015-iwan-baan-london-selgascano/>.

Serpentine Pavillion 2015 by SelgasCano, viewed 30 October 2017, retrieved from <http://www.serpentinegalleries.org/exhibitions-events/serpentine-pavilion-2015-designed-selgascano>.

Siegal, Jennifer, More Mobile Portable Architecture for Today, Princeton Architectural Press 2008.

The Eurocodes, viewed 10 November 2017, retrieved from <http://eurocodes.jrc.ec.europa.eu/showpage.php?id>.

The Mike Wallace interview with Frank Lloyd Wright, 1/9/1957 and 28/9/1957 in New York, viewed 27 October 2017, retrieved from <http://www.hrc.utexas.edu/multimedia/video/2008/wallace/wright_frank_lloyd_t.html>.

The use of European Standards for temporary works design, viewed 15 August 2017, retrieved from <https://www.twforum.org.uk/ publications/public-twf-documents/en-discussion-document/>.

Temporary Architecture & Architecture for the temporary, viewed 22 Octoboer 2017, retrieved from <https://synthetica.ca/live-from-Berlin/2012/11/11/aydmor0qf0keauiz1bsmul4yplpft2>.

This is Temporary: Transient Architecture, viewed 2 September 2017, retrieved from <http://www.designcurial.com/news/this-is-temporary-transient-architecture-4802906/>.