MASTER

Modelling the model
an architectural Model Museum

Jansen, L.J.T.

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Leander Jansen

an Architectural
Model Museum

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Author
L.J.T. Leander Jansen

Student Number
0630853

Graduation Studio
ReCollection

Graduation Committee
prof.ir. J.D. (Juliette) Bekkering
ir. J.P.A. (Jan) Schevers
dr. S.M. (Sergio) de Sousa Lopes Figueiredo
ir. M.H.P.M. (Maarten) Willems
dr.ir. M. (Masi) Mohammadi

Master Architecture Building and Planning
University of Technology Eindhoven
The Netherlands

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Modelling the Model

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Abstract

The atmosphere and interpretation of the collection is important for conveying a message. Light in museum spaces has a major influence on the experience of the collection. Although there are numerous design solutions for daylight, an optimalization for the Architectural Model collection is the premise.

Modelling the Model is a research on a daylight optimalization for the central gallery space of the Architectural Model Museum design in Museumpark Rotterdam. The Architectural Models collection of Het Nieuwe Instituut (HNI) is an integral whole with the building design, it requires a subsequent lighting design.

In the first three sub-questions the effect of daylight and artificial light is explained and analysed. Specific in museum spaces, on museum collections and of museums in practice.
Characteristics of Light in Museum spaces describes the properties of the intensity, distribution, colour and direction of light with characteristics and application in museum spaces. Explained is the illuminance, typology and control of daylight and artificial light.
Characteristics of Light on Collections describes the properties of the intensity, distribution, colour and direction of light with the characteristics on the model collection. shown with the responsiveness, illumination and presenting of the collection.
Museum Light Design in Practice are casestudies analysing six museum light designs of renown architects; Sir John Soane's Museum, Vitra Design Museum, Kimbell Art Museum, Kimbell Piano Pavilion, de Young Museum and Kunsthaus Bregenz.

The experiment is a setup of casestudy models in different conditions to analyse the optimal light design for the central gallery space. The constraints for the design of the space and positioning of the collection are based on the boundary conditions of the Architectural design, literature research theory, casestudies and terms of HNI.

The results from the setup of Kimbell Piano Pavilion and Kunsthaus Bregenz are most similar to the constraints. The designs are combined in a hybrid form with an optimal illumination of the space and models of the central gallery. The design has an automated louvre system and three layers of translucent glass for a uniform distribution of diffuse light. There is a layering with diffuse artificial light for an even illumination and spotlights on the collection.

Preface

Light is an important aspect in the atmosphere and perception of a space.
The design process of the Architectural Model Museum has led to a belief that there was even more possible in the development of the light design for the exhibition spaces.
The design required technical product perfection and refinement in detail. With technical ingenuity and engineering solutions it is possible to achieve a design with a higher quality, an improved practicality and manufacturability.
In this research I will try to give an answer to the characteristics and light design solution of a gallery space with a model collection.
Many thanks go out for my tutors Juliette Bekkering, Maarten Willems, Masi Mohammadi, Jan Schevers and Sergio de Sousa Lopes Figueiredo, for their advice, knowledge and criticism which took this research and design to the next level.

Contents

Introduction

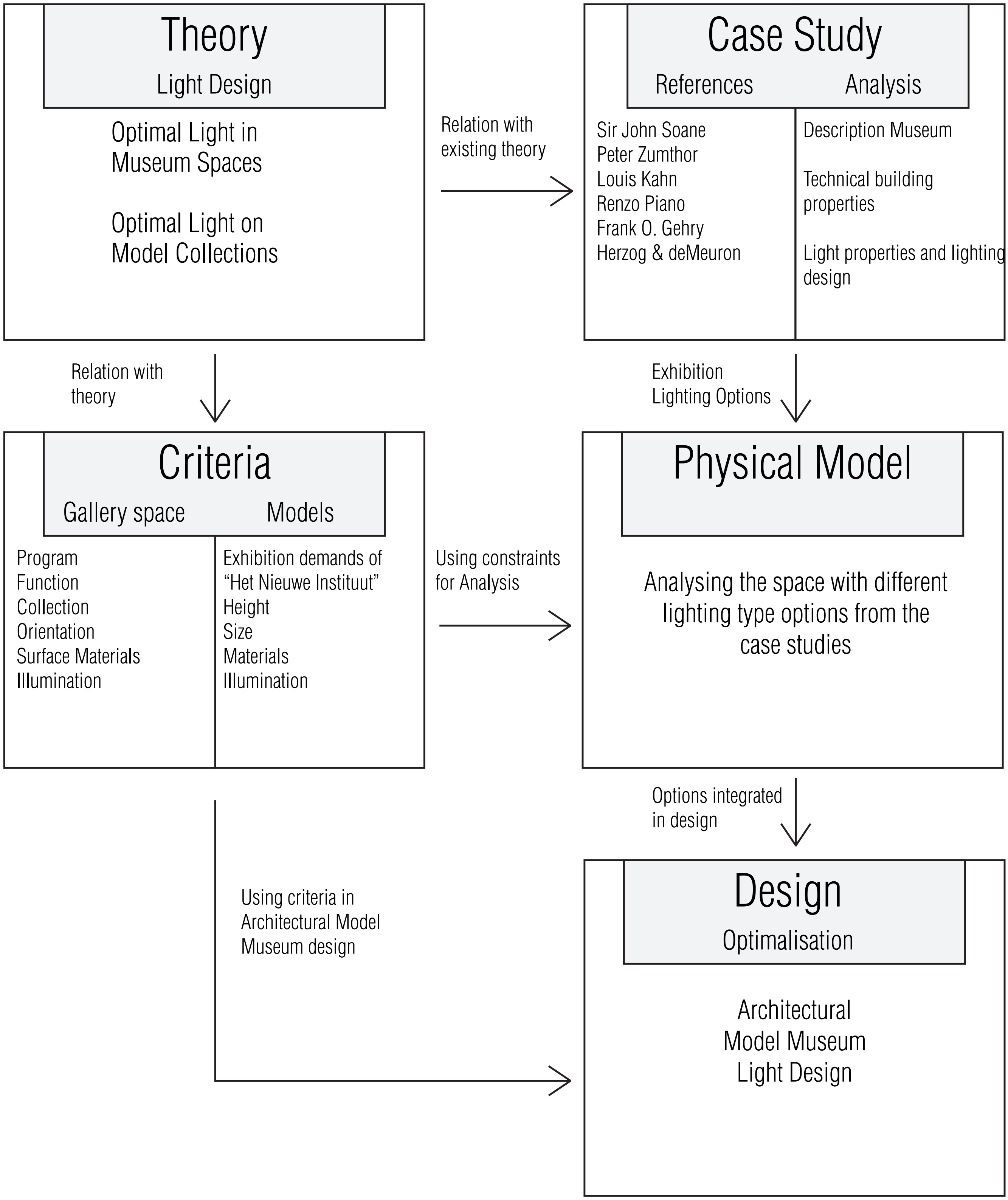
Architectural Model Museum

This project originates from the graduation studio ReCollection, in the chair Architectural Design and Engineering at the Technical University Eindhoven in the year 2014-2015. The studio is focusing on collections and the way of collecting these collections. How to deal with a space designed for a specific collection. The graduation project consists of two parts. There is a group research and there is an individual research with a design project. The result of the group research is a book *ReCollection Sir John Soane* (2014) (1) analysing the Sir John Soane's Museum in London. The individual research is the collection of three books *Modelling the Model, an Architectural Model Museum* (2015) (2).
The first part of the individual research is a design for an Architectural Model Museum in the Museumpark of Rotterdam. This is presented in the book *"Modelling the Model, an Architectural Model Museum, A Architecture"*. The collection of the Architectural Model Museum is combined in the book *"Modelling the Model, an Architectural Model Museum, C Collection"*. The research in this book, *"Modelling the Model, an Architectural Model Museum, B Building Technology"* is a design optimalization for the skylight in the museum gallery.

0.1 Sir John Soane's Museum, London, 2014

Light Design

The master track Building Technology at the Technical University Eindhoven is multidisciplinary, a combination of form, function and process. All aspects that are needed for the design and realisation of a building or building part. The design solution for a skylight requires a building physical knowledge about light in a museum space and on a model collection. An introduction to the properties of light design is investigated in *Attachment A*. This is basic knowledge which is necessary to understand the research of light in the museum. With the information of the technical aspects which are important for the design of a skylight, a founded choice can be made for a design solution.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Research Methodology

This study will do research on the optimalization of the light design for a gallery space and model collection and as a result a roof opening design for a gallery space in the Architectural Model Museum design in the Museumpark of Rotterdam.

The research is divided in two parts:

A literature study on the theory of light design and the optimalization of light design on space and collection.

The theories from literature research will be combined with the case studies. In the case studies, the museum light designs of renown architectural offices will be analysed.

The results of the case studies, the literature research together with my own criteria derived from theory, will form an analysis for the light design. This research is a combination in the research fields of theory and design.

Main research question
How can light be optimally used for the illumination of the museum space and models of the Architectural Model Museum gallery?

Sub questions
- How can light be optimally used for the illumination of museum spaces?
(sentiment, orientation, comfort
- How can light be optimally used for the illumination of architectural models

- How do renowned architecture offices design light on three dimensional objects in museums?

- How can theory and practice be implemented in the Architectural Model Museum?

The experiment which is derived from the theory will analyse the variants from the casestudies. The variants will be placed on the gallery space of the Architectural Model Museum design.

My own criteria, the predefined constraints from theory and results of the experiment will be combined and result in an integral optimized roof opening design for the Architectural Model Museum gallery space.

The design will be verified and compared to the casestudies of the first experiment with a second experiment.

figure 0.2 Elaboration of the research

Characteristics of Light in Museum Spaces

Characteristics of Light in Museum Spaces

Introduction

A museum space is devoted to the art it exhibits. The space should be presented and organized with justice to the objects, the form and light design of the space can enhance this experience. Light design can control the intensity, distribution, colour and direction of light. With all these characteristics there are endless possibilities of designing the light to the needs of the exhibition. The main focus should be a functional lighting according to the conservation requirements of the objects and the visual perception of museum visitors. The atmosphere and conservation of the exhibition is shaped with correct interpreting and understanding of light.

1.1 The overall daylight diffusing ceiling of the Deutsches Architecture Museum, Frankfurt, approaches a hemispherical sky. from: *Light for Art's Sake*

Illuminance

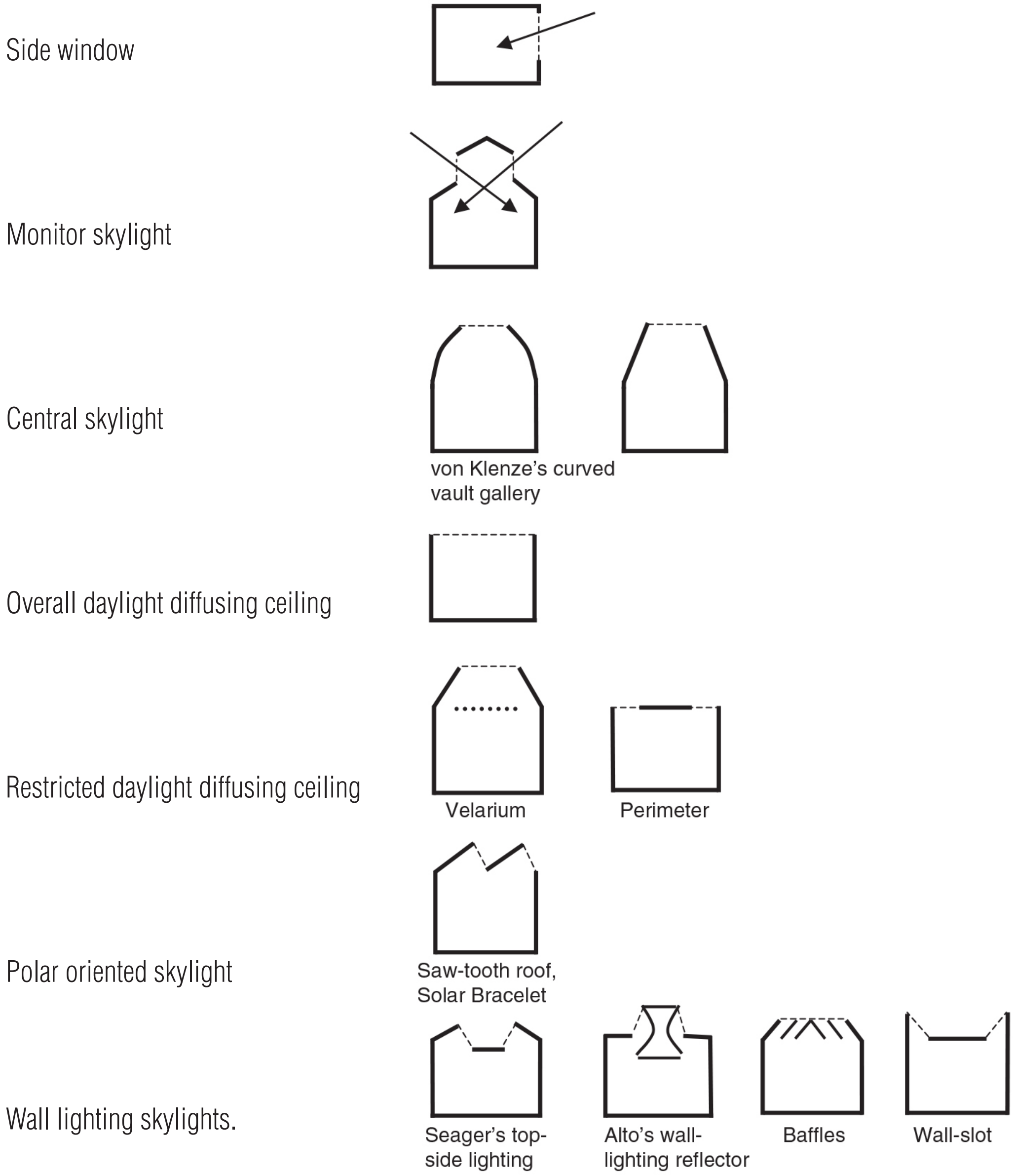
The form of the space and the effect on the objects can be enhanced with light effects. Lighting can bind the collection and artworks with different characteristics. This can be achieved with natural light, artificial light or a combination of both.

Natural light
The article of "*Colour and Light in the Museum Environment*" states about natural daylight in the interior space, "the illumination created by sunlight is very difficult to characterize in only one way since the sun's position in the sky and its interaction with the earth's atmosphere produce a wide range of light qualities."(3) On a clear sunny day, the incident on top of a skylight can be over 100.000 lux. These values are too bright for a museum interior space, high illuminance levels cause discomfort and values have to be lowered. The high illuminance can result in daylight glare and can be avoided by reducing the shadows and high differences of luminance of objects and surfaces. Daylight has a negative effect on the preservation of the collection. The ultraviolet spectrum has a high energy and can damage the collection, more about this in the next chapter "*Characteristics of light on model collections*". Space without enough ambience illuminance will appear gloomy and that adversely affects perceiving the collection.

Artificial light
Contrary to the design with daylight, the artificial light is more stable and reliable. *The Architecture of Light* (2008) states about the illumination levels of varying visual tasks in space, "This uniform lighting can provide a very unilateral light experience, therefor it is important to have variation with contrast, accents, and light levels."(4) A characteristic of artificial lighting is the high level of self-controllability, the direction, distribution, intensity and colour can be adjusted.

Combining light
According to "*Good Lighting for Museums, Galleries and Exhibitions*","Our knowledge of lighting engineering coupled with modern control and regulation technology makes it possible for daylight to be precisely directed and dosed."(5) This resulted in a major role for daylight in museum design. The criteria for illumination in museum space are preservation, human perception and design intention.
First it is important for the preservation of collection to affect the amount of light in a specific period and to follow the guidelines. More about this in the next chapter "*Characteristics of light on model collections*".
Second there is much information about

light today but the human perception and interaction with psychological effects of spatial perception is still very complex and there is not a single solution for good museum light design. “In addition to the safety aspect, room lighting also has the task of making visitors’ stay in the museum comfortable, for example for relaxation phases after concentrated observation or stimulation through changing of one’s spatial situation.” *Museum Buildings, a design manual* (2004) explains; “The necessary luminous intensity for lighting objects depends on the minimum luminous intensity for perceptibility and the limiting of maximum lighting according to conservational factors.”(6) A minimal luminous intensity also affects the human colour vision, the quality of perception and visual tasks changes. Gradations in lighting between space and objects are important to avoid fatigue and improve the overall impression. The eye can resolve contrast differences up to 1:100 and it selects the brightest surface in the field of vision. The objects of the exhibition should have a higher illuminance than the surrounding space. The Illuminating Engineering Society of North America (IESNA) advises in *Museum and Art Gallery Lighting: A Recommended Practice* (1996) (7) a 5:1 distribution ratio. The illuminated object should be perceived as evenly lighted and therefore according to *Museum Buildings, a design manual* (2004);“the proportion of maximum luminous intensity to minimum should be no more than 3:1, so that all the exhibits’ own contrasts are properly recognizable.” It is best for the viewing conditions if the surface behind the object has a similar luminance. If the eye constantly has to readapt because of the large difference of brightness, it leads to fatigue. The third criteria is the design intention. The light distribution and object perception can be determined by the surface of the space. The average illuminance in exhibition rooms ranges from 150 to 250 lux. “Viewers coming from brighter environments, such as daylight conditions, need to undergo a gradual process of progressive adaptation before entering the viewing space” states *Light for Art’s Sake* (2007) (8). Lighting in museums is a mixing of diffuse and directional light, this effects the harshness of the shadows and the three-dimensional perception of the exhibition objects. The different types of light form a distinction between the space and the objects. This can be influenced with overlaying techniques. “*Good Lighting for Museums, Galleries and Exhibitions*” states: “The diffuse lighting is almost all generated by the room lighting, which determines the distribution of brightness and sets lighting accents in the horizontal plane.”(9) The directional lighting is used for accents and focus on the exhibition, it is not bright enough to light the space. When artificial light and daylight are mixed, the particular colours of the spectral composition and the angles of incidence should be blended. The image of the exhibition is distorted when the spatial distribution of the light is not coordinated. An alternative is the segregation of the daylight and artificial light zones. Distracting casted shadows on the visitors and the exhibition should be prevented. The advantage of these characteristics is the spatial orientation and perception of objects. The position of the daylight openings should therefore be high in the space.



1.2 Summary of daylighting typologies. from: *Light for Art's Sake*

Daylight typologies

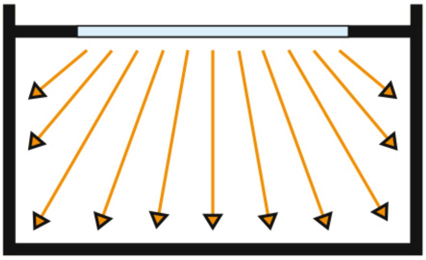
The use of natural light has a number of advantages.
- The spectral composition for colour rendering is better than artificial light, therefore the objects are presented closer to reality.
- Daylight is changing and makes a vivid space. The characteristic changes of intensity and colour enhance the experience of the visitor with a connection to the outside.
- Effective daylighting can provide psychological benefits with visual interest.

These characteristics have led to the application of daylighting in museum spaces.

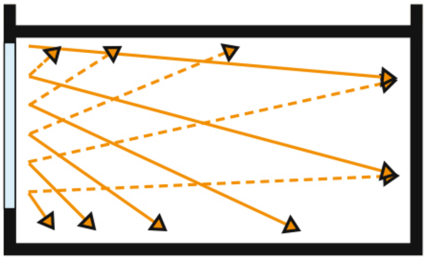
The daylight design of museums has some recommendations.
- In the northern hemisphere, a northern faced window has a consistent blue colour from the southern sky. A window faced south is directed towards the sunlight and the light will change with a warm colour tint as the sun moves from east to west. "*Colour and light in the museum environment*" says about this; "At nearly any time of day it is possible to illuminate an object with a particular color of light, formed by sunlight or skylight, by adjusting how the object is positioned relative to the sun."(10) For consistent light design with a natural light source, a window facing the northern sky is recommended.
- Direct sunlight usually causes undesirable risk of glare for a museum space and exhibition display, therefor this should be avoided.
- The ultraviolet exposure of the exhibition can cause object degradation, therefor the light should be filtered.

The properties of lateral windows and top lighting will be explained with the following typologies: Side window, clerestory, monitor skylight, central skylight, polar oriented skylight overall daylight diffusing ceiling, restricted daylight diffusing ceiling and wall lighting skylights.(figure 1.2)

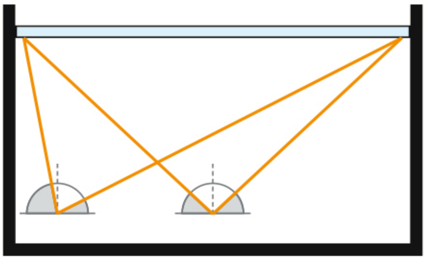
Side window
A common way of lighting a general space is lateral lighting. The sunlight and skylight enter the space from the side and the appearance changes during the day and year. Most of the light incidence comes from the horizon of the sky. (figure 1.3) The light will on average penetrate the room 1.5-2 times the height of the window but the illuminance decreases further into the space. (figure 1.4) For a museum space the direct light can cause unwanted glare, reflections and shadows. The sidelight can be combined with shading systems and components to control and alter the light such as; the light shelf, overhanging soffit, vertical shading, vertical surfaces to



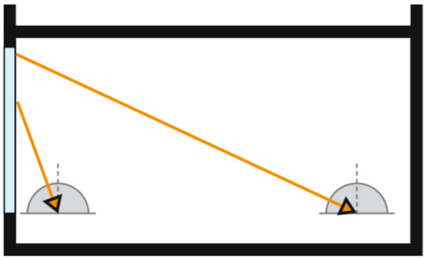
Daylight incidence from above through a luminous ceiling *(principle in cross-section of room)*



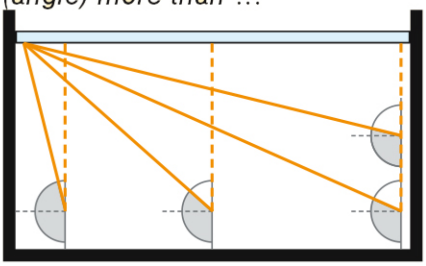
Daylight incidence from the side through a window *(principle in cross-section of room)*



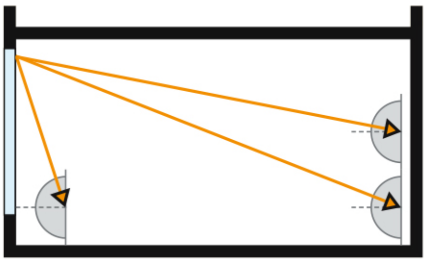
With light from above, more falls on horizontal surfaces in the middle of the room than on surfaces at the edge and always (angle) more than …



With light from the side, the further it has to travel from the window wall, the lower the illuminance on both horizontal surfaces …



… on vertical surfaces in the same place, on walls more than on free-standing partitions.



… and vertical ones, although vertical surfaces are better illuminated because of the more favourable angle of incidence.

1.3 Differences of daylicht incidence from above through a luminous ceiling and daylight incidence from the side through a window.
from: *Fördergemeinschaft Gutes Licht*

guide the direction of light and diffusing techniques.

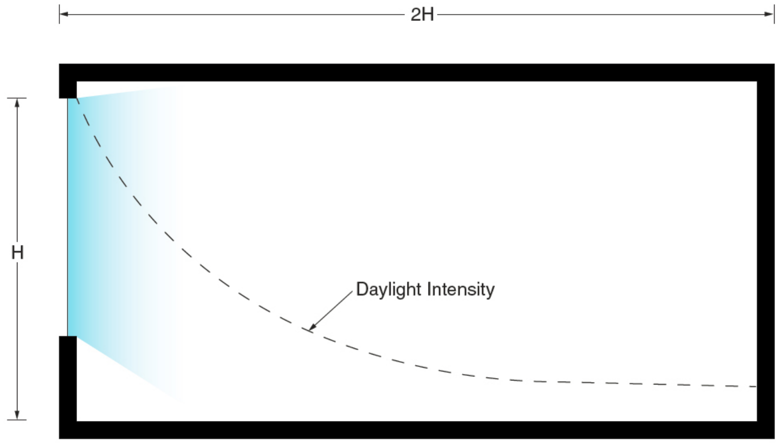
Clerestory
This type of window is a lateral opening on the upper part of the wall. The faces are oriented sideward and the light is entering the space from the top with a sideways distribution. A clerestory window can be combined with a skylight. The direction is often with a northern orientation but they can be used in all directions. (figure 1.5 & 1.7)

Skylight
The skylight is an aperture in the roof positioned with an upward direction, the incidence is from the zenith of the sky. (figure 1.6) The light incidence is more than five times that of lateral windows. Therefore the light needs to be optically controlled to prevent interference, uneven distribution, direct sunlight and glare from the ceiling. Considerations are a lower vertical illuminance and an absence of relation with the outside. "*Good Lighting for Museums, Galleries and Exhibitions*" states; "What all modern skylight solutions have in common is that they are expensive to design and construct for daylight direction, control and filtering."(11)

Monitor skylight
Monitors have a great influence on the building design from the outside, they are part of the shape of the building. The ceiling has an opening with a box on top that has windows in a lateral direction. (figure 1.5)

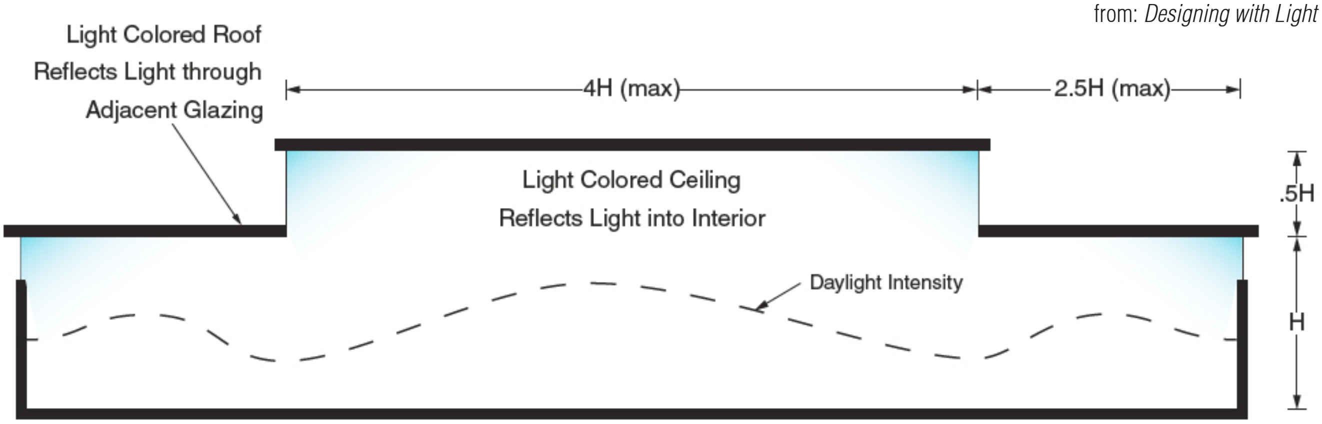
Central skylight
A central skylight is a large window opening in the centre of the ceiling. The spaces are high and often with a square plan, this ensures a veiling reflection zone on the walls. The vault and the floors have a relatively high illumination which creates a sense of lightness and spaciousness. (figure 1.8) *Light for Art's Sake* (2007) describes; "A skylight set into a roof may admit daylight directly into an interior space, or into a roof space which is connected to an interior space by a laylight."(12) A laylight is secondary skylight on top of a skylight to control the incidence of light.

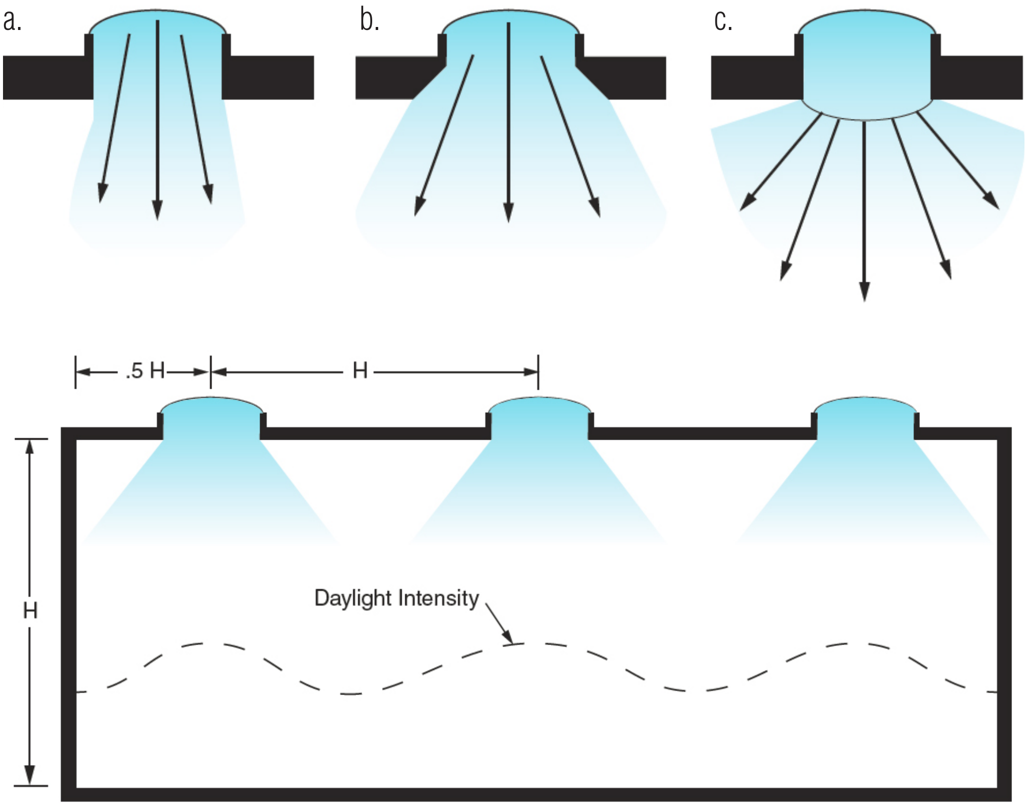
Polar oriented skylight
The window openings are aligned with the direction of the solar equinoxes. The polar oriented skylight is facing northwards and sloped at the latitude angle. This typology avoids direct sunlight illumination and provides cool northern hemisphere light into the exhibition space. (figure 1.7)



1.4 Light through a lateral window with illuminance curve.
from: *Designing with Light*

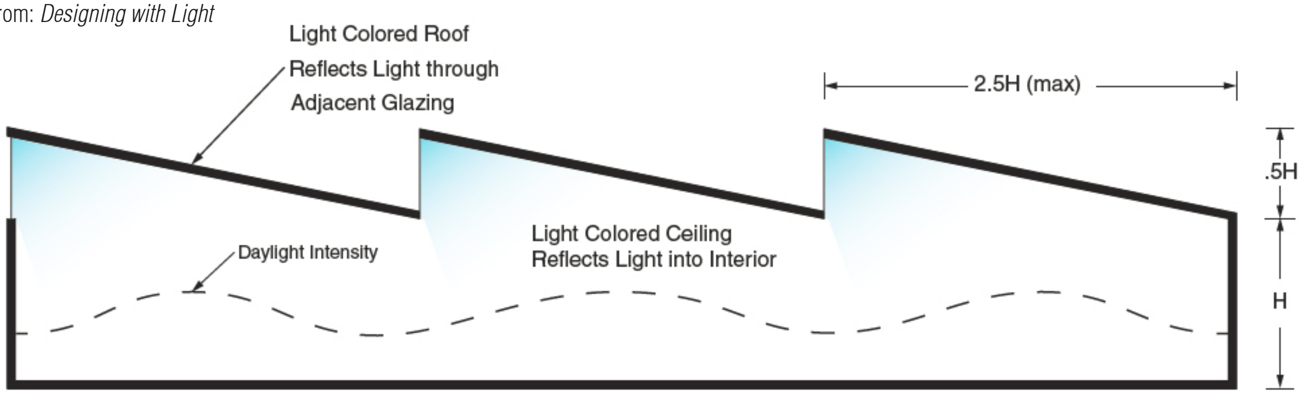
1.5 Light through a Clerestory and roof monitor with illuminance curve.
from: *Designing with Light*

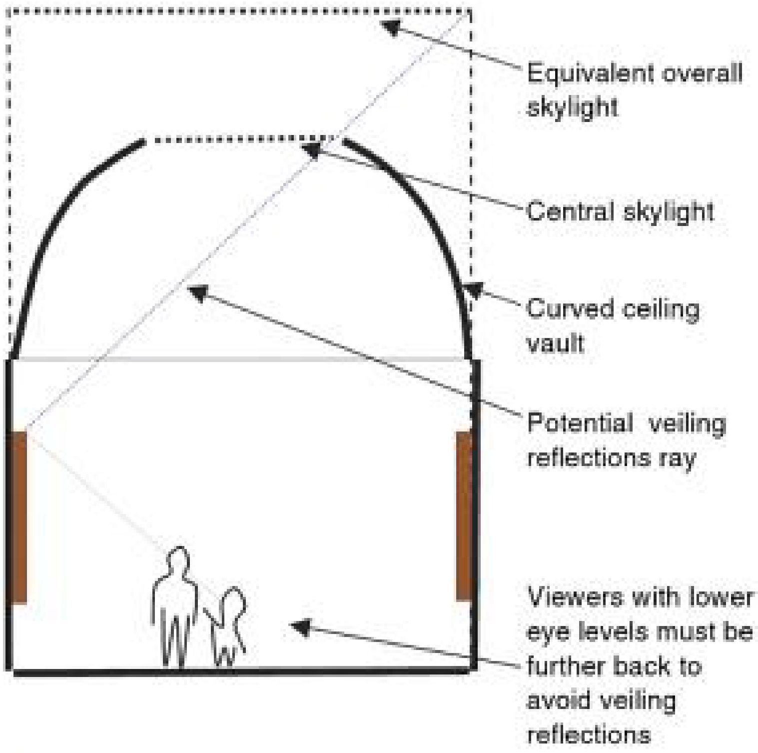




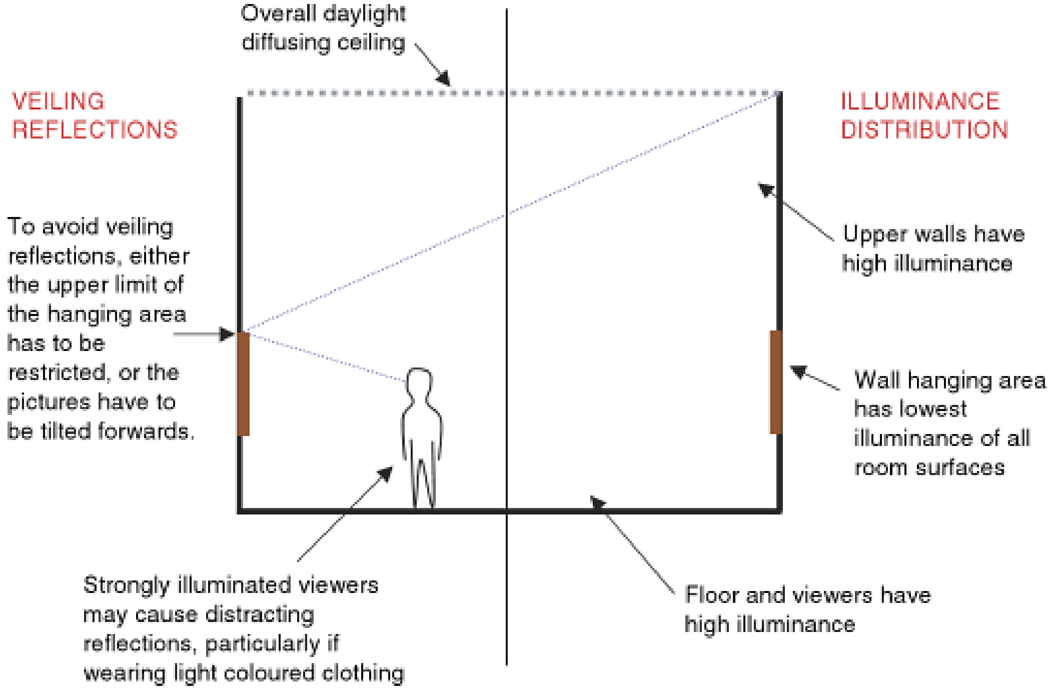
1.6 Light distribution from skylights with illuminance curve.:
a. Straight-sided skylight
b. Splayed skylight
c. Skylight with bottom diffuser
from: *Designing with Light*

1.7 Light through a Clerestory polar oriented skylight (sawtooth roof monitor) with illuminance curve.
from: *Designing with Light*





1.8 Comparison of the proportions of a gallery for wall objects, with either an overall daylight diffusing ceilings or a central skylight.
from: *Light for Art's Sake*

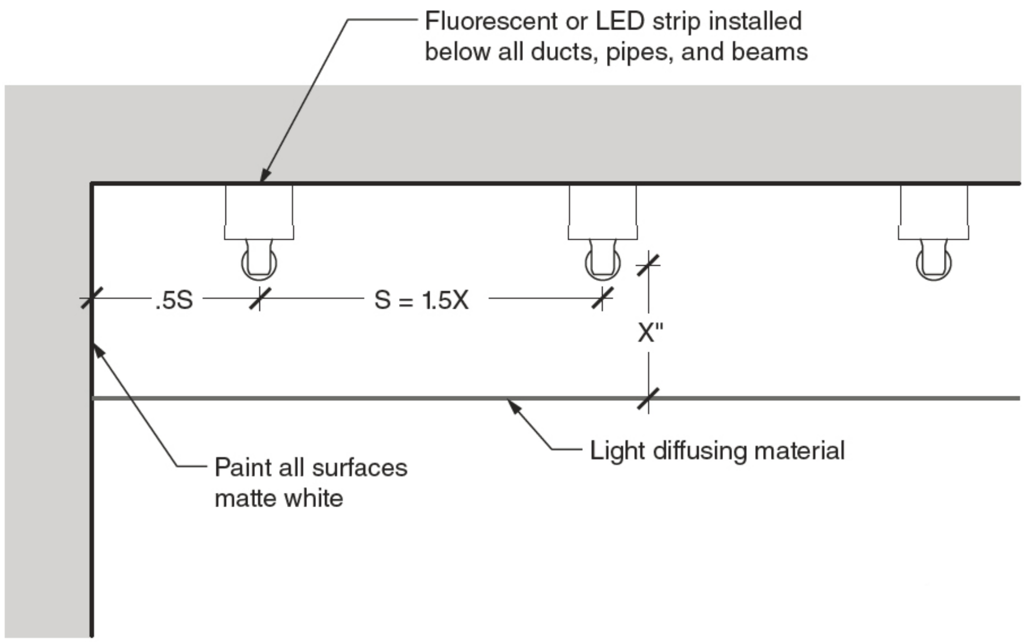


1.9 Potential veiling reflection and illuminance distribution problems for overall daylight diffusing ceilings in galleries.
from: *Light for Art's Sake*

Overall daylight diffusing ceiling
The disseminating daylight ceiling is commonly used in museum galleries. The translucent ceiling has the advantage of reducing reflections on the exhibition and casts an even illumination over the museum space. This type of daylighting is more suitable for objects in the centre of the space. (figure 1.8 &1.9)

Restricted daylight diffusing ceiling
The restricted daylight diffusing ceiling has modifications to the overall daylight ceiling. The addition of a velarium is a common technique, this is a piece of translucent scrim in the space to diffuse the light. Another option is a ceiling with a perimeter. This is a framework or panels in the centre of the space that redirect the light. The ceiling has window openings around this semi-closed centre with diffuse floodlighting downward inclined towards the walls.

Wall lighting skylights
There are various combinations and options to illuminate a space with ceiling openings. The wall lighting skylights target the light directly onto the walls. The wall is bright and the centre of the space has a lower incidence.



1.10 Typical luminous ceiling section.
from: *Designing with Light*

Artificial light typologies

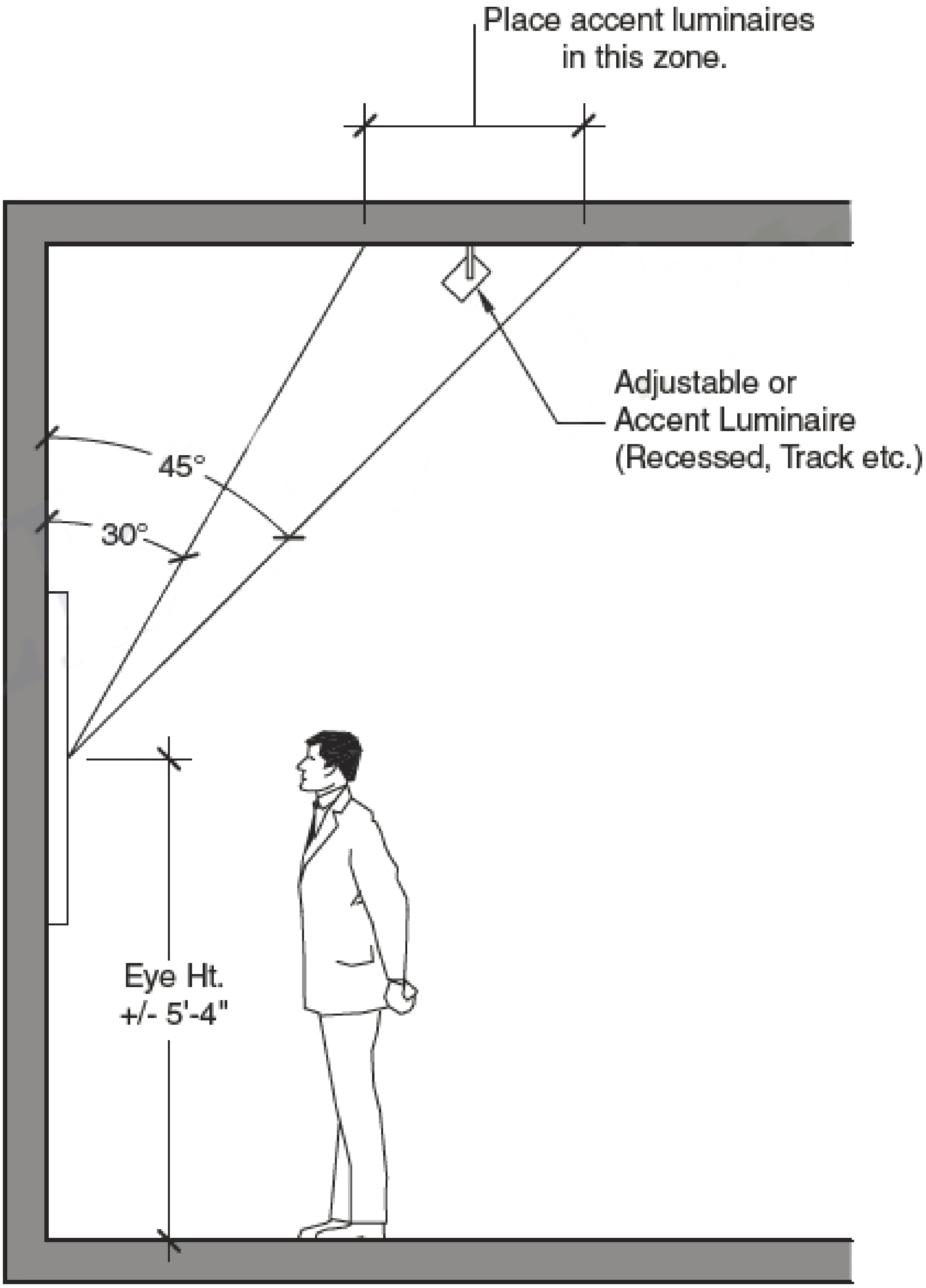
Artificial light is suitable for exhibition lighting because it is a controllable medium. There are many variables and options and no general solution for exhibition design. A lighting design can influence the museum presentation, therefore the light design must be coherent and complementary in relation to the exhibition. The optical control of light has three main categories; the accent lighting, floodlighting and backlighting. The categories have differences in spectral distribution, spill light, beam shape and attachments.

The accent lighting, floodlighting and backlighting will be explained with the properties of the different typologies; Luminous ceiling, indirect luminaires, cove luminaires, wallwashers and spot lighting.

Luminous ceiling
The space has a translucent ceiling with lighting behind it. The height of the space requires a ceiling of 6 meters or higher for an even distribution and to prevent too bright illumination in the field of vision. According to "*Good Lighting for Museums, Galleries and Exhibitions*","Luminous ceilings imitating natural daylight need to deliver a high level of luminance: 500 to 1,000 cd/m2, ranging up to 2,000 cd/m2 for very high-ceilinged rooms."(13) When the luminous ceiling is dimmed, it loses the daylight quality and the space looks grey and dark. The light sources are fixed above the glass that can be opal or translucent to create a diffuse light. With satinised and textured glass the ceiling can have diffuse and directional light. For a uniform lighting, the distance between the fixtures should be not larger then 1-1.5 times the distance to the glass and placed in a structural grid.(figure 1.10) The tubular fluorescent lamps with an extraction of the heat in the plenum, or LED lights are the usually applied types of light.

Indirect luminaires
The light of the indirect luminaire can radiate upwards to a ceiling or upper wall. The light is reflected and creates a diffuse appearance similar to a luminous ceiling. In exhibition spaces the diffuse lighting fixtures can be applied in the ceiling onto the tracking systems.

Cove luminaires
This is an indirect luminaire installed in the curve between the wall and ceiling. A recessed space with the body of the luminaire hidden from the eye. This solution is often used in museum space for general lighting and accent lighting. It creates a diffuse horizontal floodlight in the coving which can be free of shadow. Applied in the whole space it can make the ceiling float.



1.11 Accent lighting angles.
from: *Designing with Light*

Wallwashers
Luminaires that illuminate the wall with a uniform radiation, they create boundaries and reduce texture and three-dimensionality of the surface. This backlighting for objects, or floodlight for atmosphere in the space, can be mounted close or into the ceiling or floor. The wallwasher has reflectors, lensed apertures and filters with asymmetrical optics to direct light to the wall and prevent glare. A continuous row of wallwashers creates diffuse and directional lighting with deep shadows along obstacles. An individual point source creates a directional light and in addition also shadows along horizontal edges.

Spot lighting
The spot lamp is a type of accent lighting that created a punctual light with a defined beam direction. The spectrum and distribution of the light is small and focussed. The spotlight creates reflection, glare and shadows. Only spotlights create a dramatic effect therefor it is recommended to combine with diffuse lighting typologies. In museum lighting practice the spotlight is the most widely used luminaire. The fixtures have to be positioned and can be integrated or mounted on tracking systems with high flexibility. *Designing with light* (2014) states; “Most pleasing accent angles come from 30° to 45° from vertical.”(14)(figure 1.11) The spots can have optional filters, anti-glare flaps, reflectors, lenses and there are multiple options for light sources.

Light control

To control the previously described typologies of natural daylighting and artificial lighting, the options need additions for better visual properties. The intensity, distribution, colour and direction can be controlled with lighting design. Daylight has large fluctuations and the transmission and distribution has to be controlled to protect the collection and for comfort of the visitor.

Glare control
The high illuminance of direct glare and reflected glare needs prevention, although it cannot be eliminated it can be reduced. "Glare can interfere with visual performance to such an extent that reliable perception and identification become impossible." is stated by "*Good Lighting for Museums, Galleries and Exhibitions*" but "In exhibition rooms, reflected glare can be used to a limited extent as a design tool, for example where shiny exhibits with brilliantly reflective surfaces are bathed in dramatic directional light to maximise their impact."(15)
The direct glare from sunlight can be prevented with; blinds, baffles, louvres, laser cut sheets, lenses and filters. The fixtures can be static or adjustable with an option of automation to change with the position of the sun. Direct glare from artificial light depends on the direction of the lighting fixture. Attachments for spotlights to guide the light and shield the luminaire have options such as; antiglare cylinders, barn doors and honeycomb screens.

Heat control
A part of the wavelengths of daylight is infrared (IR) light. Some control options for natural daylight also reduce solar heat gain inside the interior. The solutions applied to the exterior have the best effect. Examples are louvres, blinds, light shelf, overhanging soffit and canopy. For exhibition displays the IR absorber filters are used. Artificial lighting fixtures also produce heat.

Colour rendering
The colour rendering properties influence the visual performance and comfort. A continuous progression in spectral distribution makes a good colour rendering. Lighting in museum exhibitions requires a minimum colour rendering index (CRI) of 90. (figure 0.18)
Museum Buildings, a design manual (2004) states; "There is a connection between light colour found to be comfortable and luminous intensity: according to Kruithof's curve (Weintraub 1990), at low illuminances, only warm tones or neutral-toned light sources are found comfortable, while at higher illuminances light sources with higher colour temperature are found more comfortable."(16)
The exhibition spaces require a white

light with a continuous progression that approaches natural daylight. This has minimal effect on the colour perception of exhibition objects. The light can be treated to block certain wavelengths with UV filters and colour filters. UV barriers, UV absorbers, IR absorbers or a combination is used for exhibitions. Colour filters are used for colour corrections on exhibition displays.

Direction

Attachments can adjust the direction of the light. The heliostat, prismatic sheet, mirror sections and light-deflecting devices can direct natural daylight in a changing direction into depths of the spaces. Making light diffuse is the spreading of light in all directions, this can be achieved with lenses and diffusers. examples are fritted glass, laminated glass, laser cut sheets, stretched film, textiles, screens, flood lenses and sculpting lenses.

Layering light

Task, accent and ambient lighting are used in the layering for light design. Museum lighting is a mix of diffuse and directional light. "*Good Lighting for Museums, Galleries and Exhibitions*" explains "The relative amounts and resulting mix of the two types of light determines the harshness of the shadows cast by picture frames and the three-dimensional impact of sculptures and spatial objects."(17)

The diffuse room lighting influences brightness and accents in horizontal plane. It has a little contrast and only a few shadows. When the lighting surface is larger, there are less shadows and the light will be perceived softer. The directional light creates accents and scenes on the collection, a bright focussed light without the power to light the space. The experience of the light is generally a reflection, therefore the surface is also of importance;

- Light faces reflects more light and dark faces absorb more light.
- Polished or mirror surface finishes can reflect direct light and images.
- Coarse or matt surfaces diffuse light.
- The colour of the wall depends on the colour rendering quality of the light source.

Automation

The lighting systems can be automated with a lighting management system. Components of the system are; programmed lighting scenes, presence dependent motion detectors, daylight dependent lighting level regulation and light sensors.

The lighting management systems in museums comprises of numerous ways, listed in "*Good Lighting for Museums, Galleries and Exhibitions*"(18);

- "Activate, dim or deactivate the artificial lighting in response to available daylight.

- daylight dependent control for sun-screens and anti-glare systems.
- Lighting production programming of stage lighting or dynamic effects.
- Set different illuminance levels in specific zones. With individual dimming for dramatic light or protection measure.
- Multifunctional exhibition use of individual interiors.
- reassigning existing luminaires without rewiring.
- Monitoring luminaires and report functional status.
- Log the operating status of the lighting installation and record radiant exposure of exhibits.
- Integrated emergency lighting”

Actions for protection

The exhibition space and exhibition require shielding from ultraviolet (UV) and infrared (IR) radiation for the preservation of the collection and the comfort of the visitor. Both daylight and artificial light can radiate these harmful wavelengths that effect the chemical and organic compounds of object materials. The characteristics of control mentioned above can protect the exhibits and visitors to a certain extend because some characteristics are contradictory. The characteristics of artificial lighting types are listed in (*Attachment A*).

Illuminance	Characteristic	Application
Natural daylight	The different characteristics depend on the balance between the vistitor, museum space, museum objects, weather and the sun.	Control the intensity, distribution, colour and direction of daylight.
Artificial light	Artificial light is more stable, reliable and controllable than daylight.	Control the intensity, distribution, colour and direction of artificial light.
Combination	There is a major role for daylight in museum design. Gradations in lighting between space and objects are important to avoid fatigue and improve the overall impression.	Many different combinations, mentioned under "Typology daylight" and "Typology artificial light"

Typology daylight	Application
Side window	Many considerations for museum lighting such as glare reflections and shadows.
Clerestory	Lateral opening with light entering high and illumination of vertical and horizontal surfaces.
Skylight	Incidence with zenith skylight with top illuminance.
Monitor skylight	Incidence with horizon skylight in the center of the space.
Central skylight	Relatively high illumination of floor and vault.
Polar oriented skylight	Skylight withoud incidence of direct sunlight.
Overall daylight diffusing ceiling	Ceiling with even light distribution that reduces reflections.
Restricted daylight diffusing ceiling	Transparent ceiling with shading properties.
Wall lighting skylights	Many different design options for illuminating art on bright walls.

Typology artificial light	Application
Luminous ceiling	With high illuminance and diffused ceiling panels.
Indirect luminaires	For diffuse lighting on wall and ceiling.
Cove luminaires	General lighting and accent lighting with diffuse light.
Wallwashers	Uniform wall lighting and object backlighting with diffuse and directional lighting.
Spotlighting	Accent lighting of objects with directed light.

Conclusion

1.12 - 1.15 Characteristics and application of Illuminance, Typology daylight, Typology artificial light and Light control.

Properties of the intensity, distribution, colour and direction of light with characteristics and application in museum spaces. Shown with the Illuminance, typology and control of daylight, and artificial light (figures 1.12-1.15).

Light control	Characteristic	Application
Glare	Direct glare and reflected glare is undesirable in museum spaces and should be dealt with.	For daylight: blinds, baffles, louvres, laser cut sheets, lenses and filters. For artificial light: fixtures, antiglare cylinders, barn doors and honeycomb screens.
Heat	Solar and artificial heat gain is undesirable in interior spaces.	For daylight: louvres, blinds, light shelf, overhanging soffit and canopy. For artificial light: fixture type and ifrared absorbers.
Colour	A continuous progression in spectral distribution for a good colour rendering index for objects.	lighting in museum exhibitions requires a bare minimum CRI of 90. Object protection: UV barriers, UV absorbers, IR absorbers or a combination.
Direction	Guiding direct light in a space or diffusing light in all directions.	For directing daylight: The heliostat, prismatic sheet, mirror sections and light-deflecting devices. For diffusing: fritted glass, laminated glass, laser cut sheets, stretched film, textiles and screens. For focussing: flood lenses
Layering	Lighting design with task, accent and ambient lighting.	Direct and diffuse artifical light and daylight combined liked to the space and collection. Surface texture and colour. Exhibition and object setup
Automation	A lighting management system to control the light	Components of the system are; programmed lighting scenes, presence dependent motion detectors, daylight dependent lighting level regulation and light sensors.
Protection	shielding UV and IR light for the preservation of the collection and comfort of the visitor.	Characteristics of control mentioned under “solutions” can protect the exhibits and visitors to a certain extend.

Characteristics of Light on Collections

Characteristics of Light on Collections

Introduction

A museum exhibition needs thoughtful design regarding the presentation and conservation. Light design influences the characteristics of the exhibition objects. The object can be damaged when the materials are exposed to light, a contradiction is that the objects should be visible for the visitors at the same time. The visual experience of the visitor is affected by the nature of the object. Museums have the responsibility for the conservation of the exhibition objects and prevention of damage.

Spectrum wavelength [nm]	Description	Relative damage factor
546	Yellow-green	1
436	Blue	22
405	Blue-violet	60
389	Violet	90
365	Ultraviolet	135

2.1 Characteristics of the damage factors dependent on wavelengths.
from: *Museum Buildings*

Type of materials	Maximum illuminance	Lux-hours/year
R3. Highly responsive displayed materials: Textiles, cotton, natural fibers, furs, silk, writing inks, paper documents, lace, fugitive dyes, watercolours, wool and some minerals	50 lux	50.000

*Approximately (50 lux) x (8 hours per day) x (125 days per year). Different levels (higher or lower) and/or different periods of display (4 hours for 250 days) may be appropriate depending upon material. In doubt, consult a conservator.

R2. Moderately responsive displayed materials: Textiles with stable dyes, oil paintings, watercolours, pastels, prints and drawings, wood finishes, dyed leather and some plastics.	200 lux	480.000

*Approximately (200 lux) x (8 hours per day) x (300 days per year). Lower levels may be appropriate depending upon material. In doubt, consult a conservator.

R1. Slightly responsive displayed materials: Oil and tempera painting, fresco, undyed leather and wood, horn, bone, ivory, laquer and some plastics.	Depend upon exhibition situation
R0 Non-responsible materials: Most metals, stone, most glass, genuine ceramics, enamel, most minerals	Depend upon exhibition situation

2.2 Four category classification of materials according to responsiveness to visible light. (after CIE 157:2004) The Recommended total exposure limits in terms of hours per year to limit damage to susceptible materials.
* All ultraviolet radiation (400nm and below) should be eliminated.
from: *IESNA*

Material responsiveness classification	ISO rating	Years for noticable fade	
		UV rich	No UV
R3. Highly responsive	1	1.5	2
	2	4	7
	3	10	20
R2. Moderately responsive	4	23	67
	5	53	200
	6	130	670
R1. Slightly responsive	7	330	2000
	8	800	7300

2.3 Years for noticable fade for object on display 3000 hours per year at 50 lux.
UV rich is a spectrum similar to daylight through glass
No UV is radiant power below 400nm
(after CIE 157:2004)
from: *Light for Art's Sake*

Responsiveness of the collection

Intensity and time

The lower wavelengths of the spectral composition have a higher energy intensity of radiation, the result is a more damaging characteristic towards the ultraviolet spectrum than the infrared spectrum. (figure 2.1) Visible light is in-between and can also damage the object. The duration of radiation determines the amount of damage. The longer the duration of exposure the higher the amount of irradiance in lux per hour, this results in a higher risk for damage. With the annual light exposure, a museum can determine the amount of damage that is tolerable each year. "*Good Lighting for Museums, Galleries and Exhibitions*" states; "Photochemical change is a slow process but light damage is cumulative and irreversible."(19) There are baseline values for visible discolorations, to determine the critical value of the light energy radiation but this is not a scientific solution. The method has maximum values of 50 lux for highly susceptible displayed materials and 150 lux for moderately susceptible displayed materials.(figure 2.2) It is related to the sensitivity of the human eye and neglects the spectral composition and radiant energy.

Material

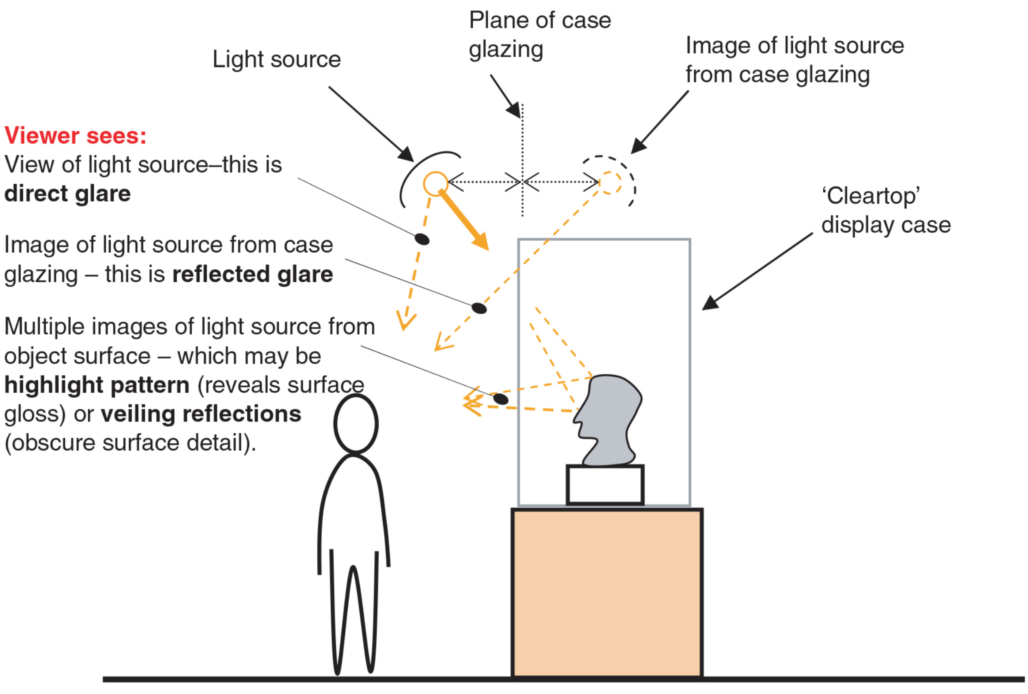
Damage is caused by the rays of radiation the material absorbs. The type of material determines the sensitivity to radiation and susceptibility of the material. *Light for Art's Sake* (2007) explains, "the less responsive materials have higher photon energy thresholds, and so are less affected by visible light."(20) Although not always noticeable, the materials degrade by the influence of light and UV should be excluded throughout the museum. The classification after "*CIE 157:2004 Control of Damage to Museum Objects by Optical Radiation*"(21) divides the responsiveness to light in four categories. R0 Non-responsive made entirely of permanent materials, R1 Slightly responsive made of durable materials, R2 Moderately responsive made of fugitive materials and R3 Highly responsive materials to light. (figure 2.2) "The damaging absorption of radiation depends on the degree of absorption or reflection of the material and its spectral classification." states *Museum Buildings, a design manual* (2004) "This means that the damage to a dark surface will be greater than to a light surface, and a reddish surface will be more damaged than a blue one."(22) The characteristics of photochemical reactions are; bleaching of colour, discolouring and destruction of material. *Light for Art's Sake* (2007) explains; "These reactions are permanent changes in the molecular structure of the irradiated object, for which the energy for the reaction is derived from the absorption of a photon."(23) This can lead to many different types of

chemical reaction.
The radiant heating of infrared light is a thermodynamic process with effect on the object surface including tension, stretching and crack formation.

Conservation
Museums have the responsibility to conserve the art pieces. One of the aspects of exhibition conservation is the sensitivity for light exposure. *Light for Art's Sake* (2007) describes; "any change in the physical condition or chemical composition of an object represents damage and must be avoided."(24) The moment visitors can see the object, it is exposed to light and even a minimal exposure can cause severe damage to an object that is responsive to light. Pre-exposure to light can slow down the degradation process and even put the object in an intermission state. The thermodynamic effects and photochemical degradation should be prevented. According to *Museum Buildings, a design manual* (2004), in practice the museum uses the following rules to protect the exhibition;
- "determination of different maximum values of luminous intensity in dependence on the source of light,
- limitation of the maximum duration of exposure,
- complete ultraviolet protection and dimming of light outside visiting hours and
- classification of the individual artworks according to categories of light sensitivity."(25)

Adjacent to these rules is research with empirical evidence on light protection for conservation. The absolute sensitivity of the object is important for the most suitable lighting solution types and their consequences. The response of the material to ultraviolet light is classified with an ISO rating in noticeable fading.(figure 2.3)
Daylight and various artificial lighting solutions with white light have spectral compositions with different intensities. UV blockers are not enough for conservation requirements. Filtering out harmful shortwave radiation is the most effective solution and there are filters for every application. The wide range of filters includes; glass filters, absorption filters, dichroitic filters, plastic lenses and foils. Wavelengths up to 380 nm can be filtered but this can affect the colour rendering index, 420 nm is conventional. Using the alternative of filters in showcase glass does not always provide better conservation conditions.
Thermodynamic processes mostly leads to drying of organic materials. The material loses volume, tensile strength and elasticity this is visible with deformation of the object. The radiation of thermal radiance is always

harmful to the object, therefore reducing the thermal irradiance in exhibition objects is essential. Solutions are IR filters, reduce radiation, limit exposure and discharge of heat. A combination of thermodynamic and photochemical processes simultaneously results in a faster degeneration.



2.4 Light incidence in the field of vision of the viewer.
from: *Light for Art's Sake*

Illuminate Collection

Lighting design is more than the recommended illumination levels."It requires the lighting designer to identify what are the visible attributes of the displayed objects, and to devise a distribution of lighting that will effectively reveal them." explains *Light for Art's Sake* (2007)."An optimum situation for a light-responsive object is one for which the lighting is specifically suited to the physical characteristics of the object, and provides for a visual experience that satisfies viewers with minimum light exposure of the object."(26)

Visual acuity

The human eye has a visual acuity that detects finer detail with higher lighting levels. According to *Light for Art's Sake* (2007);"To maximize the visibility of detail, luminance values surrounding the detail on which the viewer is fixating should not exceed the luminance of the detail."(27)

Glare

A high light density in the field of vision, with overlap on the subject of interest reduces visibility. The direct incidence from a light source or reflection makes no contribution and causes limitation of glare. Light sources can cause two types of glare; direct glare caused by direct illumination from a light source in the field of view or indirect reflected glare caused by a reflected image of the light source. (figure 2.4) Glare can be reduced with matte surfaces, indirect lighting and low light intensity but this is not favourable for lighting museum objects where detail is required. The high intensity illumination creates reflections which are desired for the perception of surface textures and qualities but it can also reduce colour perception. Three dimensional illumination of objects is recommended. Multiple low power spotlights outside the field of vision with a reduced brightness of reflections.

Direction

The lighting of the exhibition requires accents on the various objects. The size of the light source and the distance to the object determine the direction, length and distribution of the shadows. *Museum Buildings, a design manual* (2004) states "An object's own shadow engenders plasticity and there, it is a sign of the quality of good museum lighting."(28) Disturbing shadows have to be avoided, including any shadows casted by visitors, direct daylight and incorrectly positioned lighting fixtures. With a hard edged focussed directional light the characteristics can be presented, the object gains sharpness. Focussed light creates a dramatic effect with clear defined shadows on uneven three dimensional surfaces. The addition of diffuse lighting on the object creates more balance and spatial qualities, it has a more even distribution with few shadow. “The directional balance of the lighting is all-important for achieving the balance of diffuse and specular reflection that will reveal the chosen attributes.”(29) explains *Light for Art’s Sake* (2007). The directional light can cause disturbing cast shadows on adjacent objects. This can be avoided with a good balance of diffuse light, directional light and the positioning of the fixtures.

Layering light
The lighting of a three dimensional object with a directional flow can create three patterns.
- Shading pattern, there is variation in the surface form which leads to changing incidence and therefor exitance.
- Shadow pattern, different forms of the object create shadows on the surface of the object and surroundings.
- Highlight pattern, different forms of the object create reflections on the surface of the object and surroundings.
The lighting patterns improve the characteristics of the object. (figure 2.5) The lighting patterns create a distinction between object figure and the surrounding ground. The layering of these patterns of light creates a dynamic three dimensional object appearance. The visual effect of the contrast between the object and the background determines the accent factor.(figure 2.6) This can be influenced by the ratio between background lighting and spotlighting.

Lighting
Spotlights can form graded shading patterns, dense shadow patterns and highlights. For exhibition purpose, the LED and fibre optics have small fixtures and can be placed close to the object without obstructing the field of view. They produce accent lighting, improve the three-dimensional effect of details and the light can be free of thermal and ultraviolet radiation. This is advantageous for light and heat sensitive exhibits. LED light has several advantages;“Besides the facility to precisely define colour temperatures in the white spectrum from 2,700 K to 6,500 K, it is also possible to set the colour to any point in the colour triangle.” “*Zumtobel Light for Art and Culture*” explains; “The previously set colour temperature is accurately maintained even when the LED luminaire is dimmed and materials retain their natural appearance”(30)

2.5 Effects of lighting upon the appearance of a group of four objects: two black and two white, and two glossy and two matt.
a. Thoroughly diffused overhead illumination.
b. Flow of light from right, due to a large diffusing light source.
c. Flow of light from right, due to a compact, directional light source.
d. Multiple compact sources
from: *Light for Art’s Sake*

2.5a. Lighting condition is overhead and thoroughly diffused, and may be thought of as the indoor equivalent of an overcast sky. The only set to show any appreciable response to this situation is the glossy black set. The glossy white set must generate a similar specularly reflected pattern, but it is almost indistinguishable against its white surface. It appears dull, as do the two matt sets.

2.5b. Lighting condition adds the flow of light due to a diffusing light source. The actual source was what photographers call a 'soft box', and may be thought of as the effect of sunlight or spotlighting reflected from a light-coloured wall, or a patch of sky visible through a window. The two white sets have responded strongly, and the curved surface forms of the dishes are clearly revealed by distinctive shading patterns, but the appearance of the two black sets have hardly changed.

2.5c. Lighting condition produces a similar direction of flow to (b), but now the lighting has 'sharpness'. The 'soft box' has been replaced by a compact spotlight, and the effect is like sunshine breaking through the clouds. The appearance of the two white sets is dominated by dense and sharply defined shadow patterns, but the shading pattems and the modelling they produce are hardly affeclcd. It is obvious that the black spoons must be casting similar shadows, but these shadow patterns are barely evident. Instead highlight patterns dominate on the black sets, being intense and sharply defined for the glossy set and spread and diffused for the matt set. Although the lighting patterns appear distinctly different on both the black and white pairs and the glossy and matt pairs, the overall scene has coherence in that the 'flow of light' appears consistent throughout in terms of both strength and direction.

2.5d. Lighting condition is produced by multiple compact sources, and may be likened to the effect of a jeweller's shop window. There is a multiplicity of criss-crossing shadows, which although sharply defined, lack density. Highlights are apparent, particularly where curvatures are sharp so that small areas of surface gather specular images over wide angles. The glossy black set in particular shows this effect, but overall, the scene lacks a coherent flow of light.

a.

b.

c.

d.


a. Noticable visual effect
accent factor 2:1


b. Low theatrical effect
accent factor 5:1


c. Theatrical effect
accent factor 15:1


d. Dramaic effect
accent factor 30:1
Can only be achieved with low general lighting levels.


e. Very dramatic effect
accent factor 50:1
Can only be achieved with low general lighting levels.

2.6 Accent factor, contrast between object and surroundings, and modelling shadow effects on the object itself.
a. Noticable visual effect
b. Low theatrical effect
c. Theatrical effect
d. Dramaic effect
e. Very dramatic effect
from: *Philips*

Presenting collection

Ethics
The visual experience is essential for the visitor to experience the museum objects. "The keys to resolving this are understanding how much light is needed for the human visual system to operate satisfactorily, and how this light may be distributed for optimum visual effect."(31) is explained by *Light for Art's Sake* (2007). This is a situation where the curators have to determine a balance between the photosensitivity of the objects and the visual appeal. A skilled lighting designer can appraise the critical values of the object and install lighting that reveals this. This is sort of manipulating the characteristics and therefor the ethics of the lighting designer are of importance. "Visitors want not only to see the object, but to gain an understanding of its nature and the artist's intention in creating it." *Light for Art's Sake* (2007) states. "The underlying concept of this book is that lighting does not merely make things visible, but that it influences the appearance of everything we see."(32) The exhibition designer can decide what to reveal in the characteristics of the object. When the exposition lighting is the same as the light in which the work was conceived the presentation comes closer to the intention of the artist. It is a challenge for the lighting designer to find equal colour rendering although it is not possible to fully reproduce the original settings. "*Colour and Light in the museum environment*" states; "Proper lighting will optimize the viewer's ability to see nuances of artistic intent without distraction or eye fatigue and at the same time will minimize detriment to the physical state of the work."(33) The total museum exhibition can be coherent because light can connect objects with different origins.

Colour
Museum space have colour rendering index (CRI) A1, this is the highest light quality rating. The overall colour appearance of the light also depends on the correlated colour temperature (CCT), the dominant colour tone in white light. *Light for Art's Sake* (2007) describes: "The CRI system depends on viewers being fully adapted to the light source, so that if all light sources are closely matched for CCT and all of them have CRI values in the 90s; then it may be expected that appearance of coloured materials will seem natural."(34) When combining artificial light with daylight it is hard to match the same light with artificial general lighting in evening situations. Lighting designers and conservators attempt to identify the lighting needs of the object. Only careful observation and adjustment can give a natural appearance.

Object
The lighting design substantially influences the properties of the objects. The characteristics of an object surface are revealed with the reflection of specular and diffuse light. Light designing with natural daylight gives changes in colour composition casted on the object. The intensity and colour rendering of natural daylight can be completed with artificial light. Object can be presented in display cases with UV blocking to protect the object from ultraviolet light. The case can have internal or external lighting and the surface reflectance plays a major role in the light design.

Background
The direct surroundings of the object need to avoid a chance of reflected glare. This can be prevented with a matt or dark surface. A high contrast between the object and background can enhance the object. According to *Light for Art's Sake* (2007);"It is necessary to distinguish between contrasts which reveal fine detail in the displayed objects, and contrasts between the objects and their surroundings."(35) The colour and texture design of background walls depends on the design intent, distracting shadows and patterns should be avoided.

Responsiveness	Characteristic
Intensity	Lower wavelenghts (UV) have a higher more damaging energy intensity of radiation than higher wavelengths (IR).
Time	The duration of radiation determines the amount of damage.
Material	Less responsive materials have higher photon energy thresholds, and so are less affected by visible light.
Conservation	The annual light exposure is the tolerable damage each year. This is determined on the basis of responsiveness.

Illuminate collection	Characteristic
Visual acuity	The human eye has a visual acuity that detects finer detail with higher lighting levels, where the radiant power is insufficient, the acuity of detailed sight declines fast.
Glare	A high light density in the field of vision, with overlap on the subject of interest can cause limitation of glare.
Direction	The size of the light source and the distance to the object determine the direction, length and distribution of the shadows.
Layering light	Pattern types; shading, shadow and highlight, creates a distinction between object ground and figure to improve three dimensional object appearance.
Lighting	LED has small fixtures, is free of IR and UV radiation, has precisely defined colour temperatures in the white spectrum from 2,700 K to 6,500 K and this is maintained when dimmed.

Presenting collection	Characteristic
Ethics	Curators have to determine a balance between the critical values of the object and the visual appearance. Coherent illumination and colour rendering show artistic intent and connect exhibition objects.
Colour	Museum space have colour rendering index (CRI) A1 and closely matched correlated colour temperature (CCT) for a natural appearance.
Object	The appearance and balance of three dimensional form, texture colour and detail of the surface are revealed with the reflection of specular and diffuse light.
Background	The direct surroundings of the object need to avoid a chance of reflected glare. Contrast between the object and background can distinguish the object.

Conclusion

Properties of the intensity, distribution, colour and direction of light with the characteristics on the model collection. shown with the Responsiveness of the collection, Illuminate collection and Presenting collection (figures 2.7 - 2.9).

2.7 - 2.9 Characteristics of Responsiveness of the collection, Illuminate collection and Presenting collection.

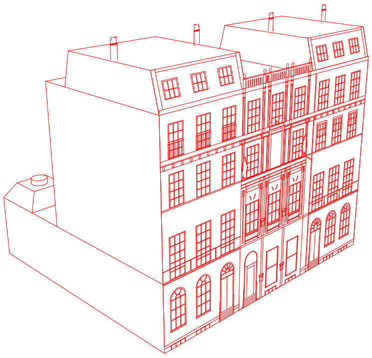
Museum Light Design in Practice

Museum Design in Practice

Introduction

This chapter is a case study of six museum designs by different Architectural offices. The Museums that will be analysed are;
- Sir John Soane's Museum - Sir John Soane
- Vitra Design Museum - Frank O. Gehry
- Kimbell Art Museum - Louis I. Kahn
- Kimbell Piano Pavilion - Renzo Piano
- De Young Museum - Herzog & de Meuron
- Kunsthaus Bregenz - Peter Zumthor

The architects and have been chosen for their expertise in museum and light design. They are well known figures in the professional work field, have a major impact and great influence. Most of the offices can be traced back to the research of *A Architecture, the influence of an Architectural model in the design process*. The Kimbell Art Museum designed by Louis I. Kahn is added because of it's relation with the Kimbell Piano Pavilion and the element of natural light.
All the Museums have a different solutions for daylight into the gallery spaces. The characteristics of Light Design in the Museums is analyzed according to their plans, sections, incidence and technical properties. The casestudies are made for a better understanding of the light design. The result of this analysis is an enumeration of different design solutions of renown architects which will be implemented in the next chapter for the design of a daylight opening in the Architectural Model Museum.



3.2 Isometric pictogram of façade Sir John Soane's Museum.

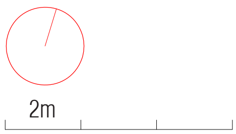
Sir John Soanes Museum - Sir John Soane

Description Museum
The Sir John Soane's Museum is located at 12, 13 and 14 Lincoln's Inn Fields in the centre of London. Sir John Soane was an influential British architect who lived from 1756 to 1837. He was an architectural innovator in his time and has been called "master of space and light"(36) in the book *John Soane, Architect* (2015). Soane bought three plots and demolished the existing houses where in between 1792 and 1833 he build his own residence. During his life he kept on altering and adding spaces to show his growing collection of paintings, antiquities and works of art. Soane experimented designs in his house for his public buildings. After his death, the house came in the hands to a board of trustees who maintained the museum according to an Act of Parliament. The "*Sir John Soane's Museum*" sais they "preserve the house and collection in the state it was left, for the benefit of amateurs and students in architecture, painting and sculpture."(37) The house is a multilayer sequence of interconnected spaces. The design of the museum rooms form an integral whole with the exhibits in this building. All rooms have different characteristics with different colours, forms, ceilings, daylight openings, mirrors, furniture and artwork. The building has many lighting effects and idiosyncratic arrangements. The work and exhibition spaces in the back of the house (Picture room, Dome, Students room) have natural daylighting from lateral window openings and many different types of skylights. In 1829 Soane created a model room in the front attic with a long skylight. With a model stand in the center of the space. "The effect of these Models, to be duly appreciated, should be seen under the influence of sunshine" according to "*Kate Clark Associates*".(38)

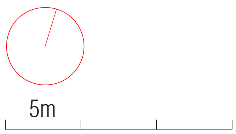
3.1 Façade Sir John Soane's Museum. Lincoln's Inn Fields 12, 13 and 14.

Technical building properties
The building techniques of the eighteenth century are outdated today but the vision of the museum is to maintain the original characteristics and settings of that time. A house museum has many operational challenges. *Sir John Soane's Museum Conservation management plan 2008* (2008) states; "If the building were to be upgraded to modern standards, this would require the installation of equipment to control temperature and humidity which would have an unacceptable impact on the historic appearance and significance of the building and on the museum experience for visitors."(39) The main activity of control is the monitoring of light, temperature and relative humidity. The result is a better understanding how the building use should react on fluctuations of climatic conditions. The windows have a UV film on

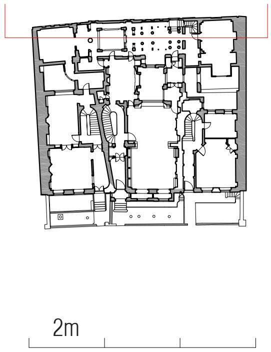
1. West Chamber
2. Sepulchral chamber
3. Crypt
4. Monk's Parlour & Monk's cell
5. New court
6. Former Catacombs
7. Basement Ante room
8. Monument court
9. Monk's yard
10. Visitors toilets & storage
11. Rear kitchen
12. Classroom & education workshop
13. Warding staff room
14. Front kitchen
15. Classroom & education workshop
16. Study room
17. Dome
18. Colonnade
19. Picture room & 4r. Recess
20. Moorish Ante room (1889 Wild)
21. Breakfast room
22. Breakfast room
23. Dining room / Library
24. Education office
25. Museum shop
26. Entrance hall #12
27. Entrance hall #13
28. Entrance hall #14
29. Gandy Room
30. Soane gallery
31. North drawing room
32. Research Library
33. Soane gallery
34. South drawing room
35. Research Library
36. Students room



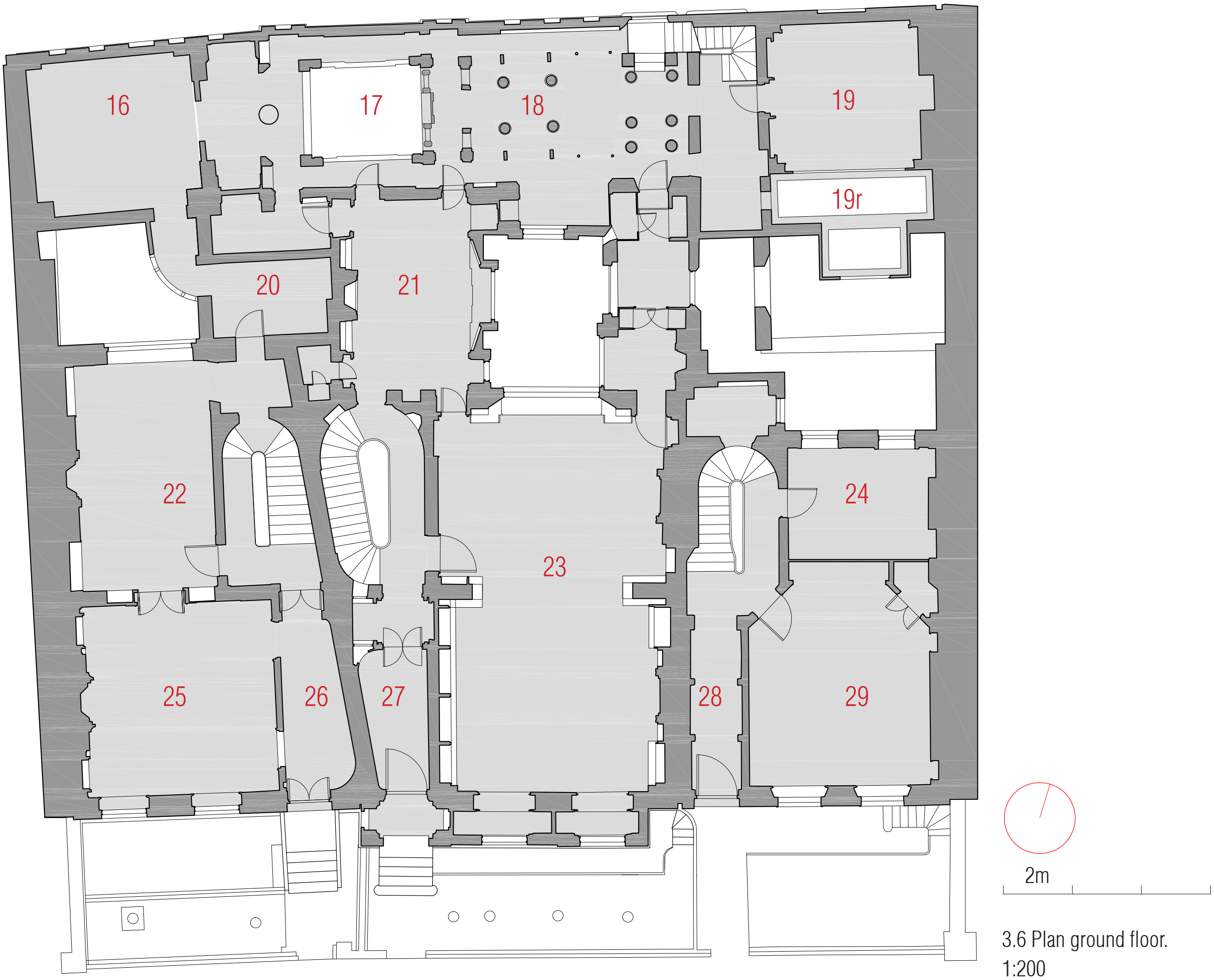
3.4 r. Plan basement floor. 1:200



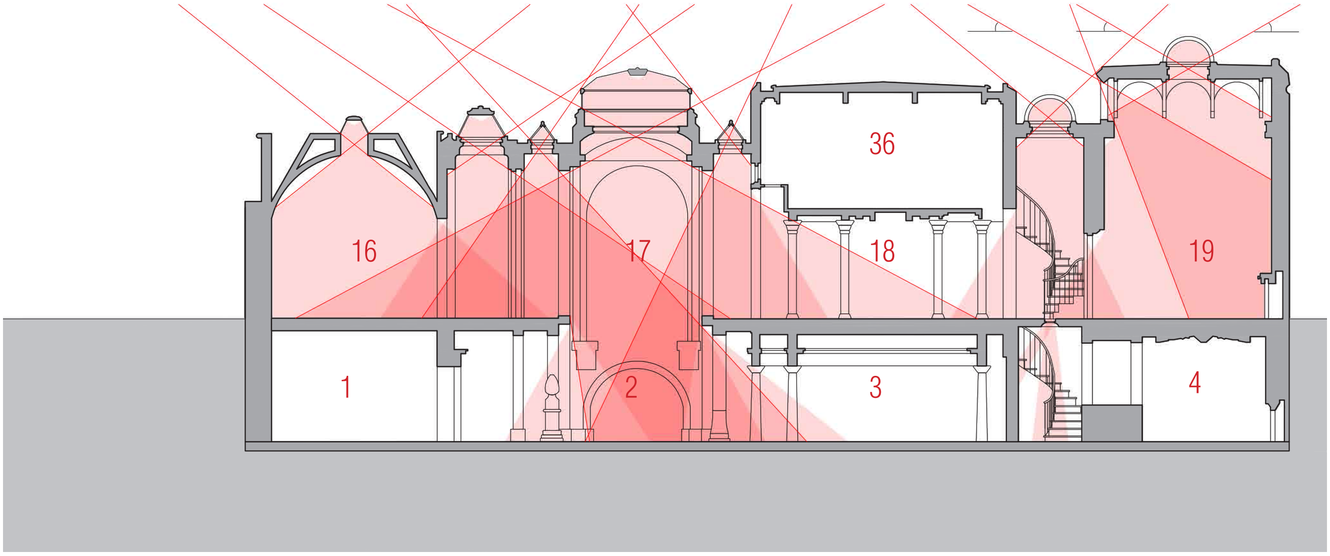
3.3 l. Surroundings with plan ground floor on Lincoln's Inn Fields 12, 13 & 14. 1:500

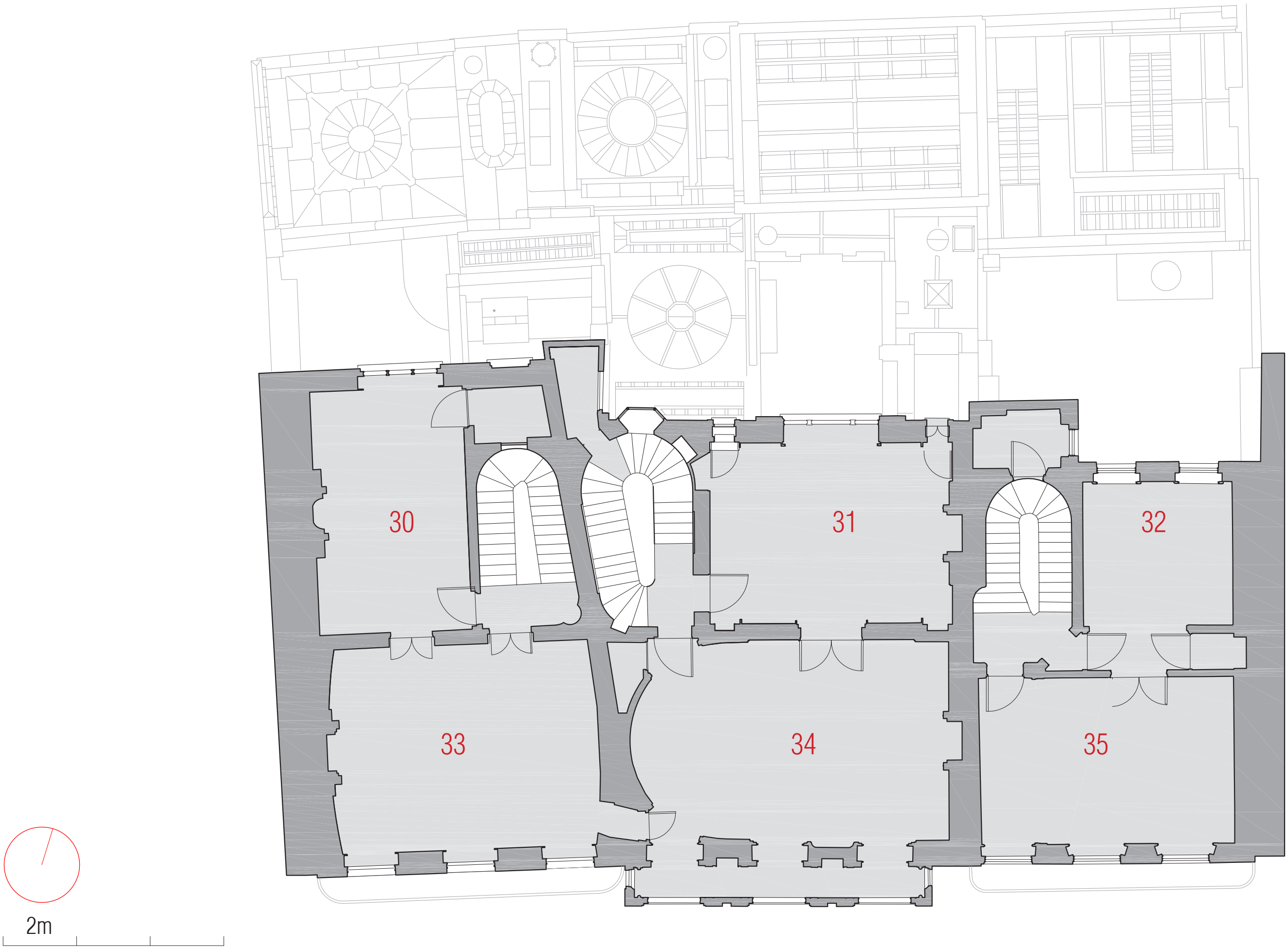


3.5 Section with the diffuse radiation of daylight openings. 1:200

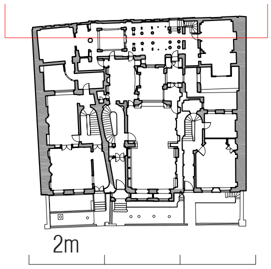


3.6 Plan ground floor. 1:200





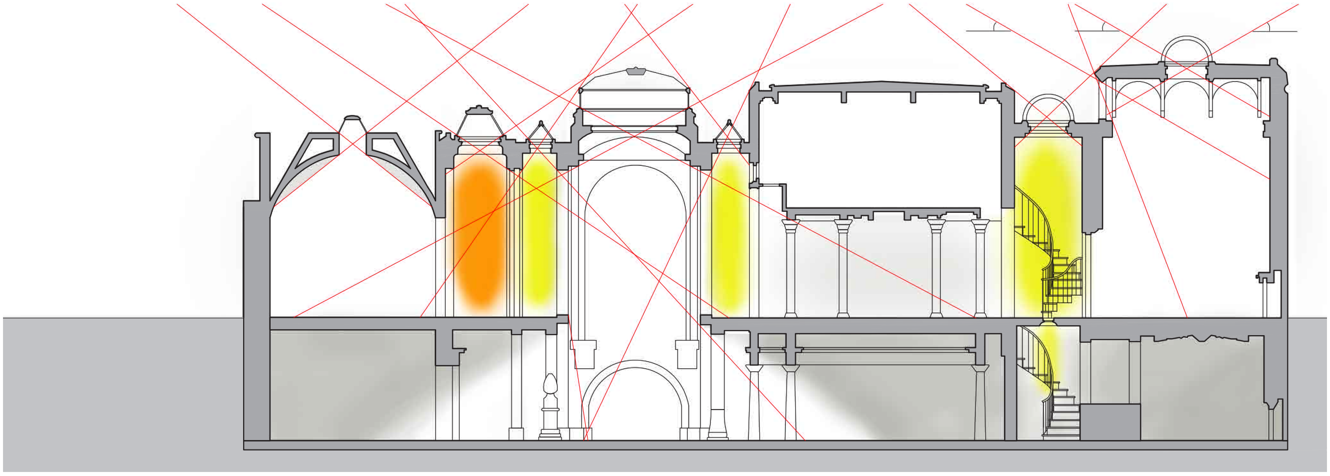
3.7 Plan first floor.
1:200



3.8 Section with coloured glass of daylight openings. 1:200

the historical glass that preserves the view over Lincoln's Inn Fields and illuminates the room with natural light. The historical blinds and shutters are actively used to reduce radiation. According to *Sir John Soane's Museum Conservation management plan 2008* (2008);"Collections need to be kept in stable environments, with relatively constant temperatures and humidity (generally between 45-60%)."(40) The museum has a relatively stable climate but deviating values increase the risk of mould, dry, wet rot and distortion.

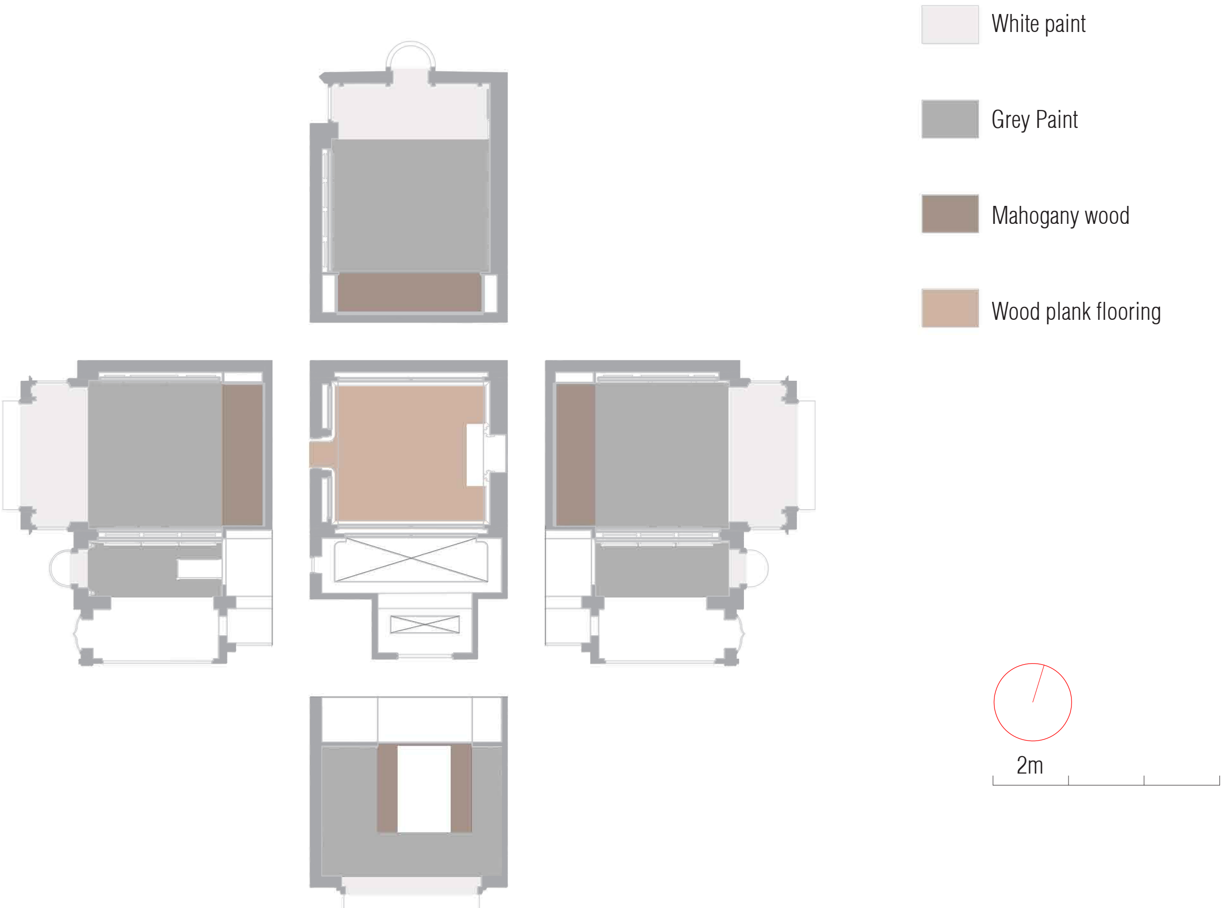
Light properties on exhibition
Soane uses different types of architectural features to present the objects in the exhibition spaces. Every space has it's own characteristics defined with candles, daylight, colour filters, mirrors, lateral openings, skylights and architectural effects.
The *Study room* has a dome with a lantern skylight in the centre. It is small daylight opening in the ceiling with a closed top. The space has temporarily exhibited models before they were moved to the model room. The model room is on the front side of the building on the second floor of and only has a lateral daylight opening.
The *Dome* area has a large conical skylight and triangular ridge skylights with yellow stained glass. It is a display area for plaster casts and items from Sir John Soane's grand tour. Light enters the Sepulchral room in the basement beneath through a void in the center. The sarcophagus is visible from above
The S*tudents room* has a triangular ridge skylight on both longitudinal sides of the space. The space is well lighted suitable for study. The light enters the Colonnade beneath through openings on the sides of the space. The collection of the space are architectural plaster casts and drawings.
The *Colonnade* is a space beneath the Students room. The collection has fragments of antique mouldings, friezes and capitals. Sepulchral chamber. The space is lighted by skylight from the Students room.
The *Picture room* has paintings and drawings mounted on shutters and walls. All glazing in the frames has an ultraviolet film to prevent fading and some drawings are replaced by replicas. The daylight enters the space through a monitor skylight, a canopied square shaped lantern. It is open on three sides with a north, west, south orientation and has an additional half round rectangular skylight on top. Direct daylight is coming monitor openings in the ceiling, later altered with an addition of translucent panels. The windows have an outside UV filtering film attached. Artificial light is installed high up round the perimeter of the central skylight box on a minimal metal floating frame and illuminates every wall in dark days or evenings. The



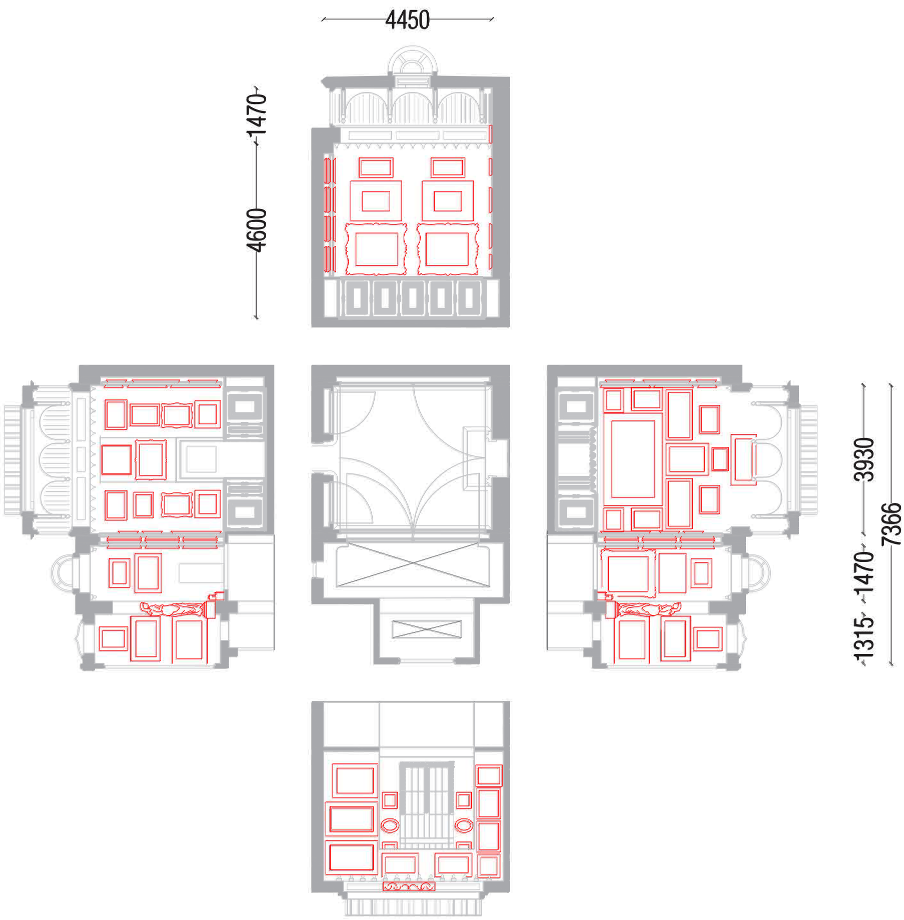
dimensions of the space in meters are (3.8x4.2x4.7 lwh), of the monitor (3.6x4.0x1.5 lwh), of the glass surface monitor (12x1 wh) and skylight (2.7x1 lw). The ratios in square meters between plan, monitor opening and glass surface are; (16 : 14.3 : 14.7)
The adjacent *Picture room recess* has some models, busts and plaster castings. This small extension of the Picture room is a diorama with a void that connects to the Monks Parlour. The space has lateral daylight openings connected to the Monk's Yard with stained glass, a half round rectangular skylight and a circular skylight. Both the skylights have yellow glass. It could be the replacing of cold northern London light with golden warm Mediterranean light. Soane was interested in "lumière mystérieuse"(41) ,a mysterious light that filters through the building which enhances the atmosphere and appearance of his collection. The dimensions of the space in meters are (1.5x4.8x3.5 + 1.6x2.5x3.3 lwh), glass surface of the lateral opening (1.4x2.9 wh), rectangular skylight (0.8x3.5 lw) and circular skylight (0.8 d). The ratios in square meters between plan, ceiling opening and glass surface are; (11.2 : 4 :7.4). The ration of the height between exhibition space, monitor and glass are (4.7 : 0.5 : 1).

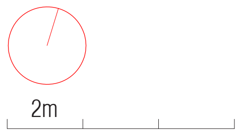
3.9 r. Model of Picture room, Recollection graduation studio 2014. from: *Ilse Kampers*.

3.10 l. Picture room and Recess with yellow light. from: *Trustees of Sir John Soane's Museum*.

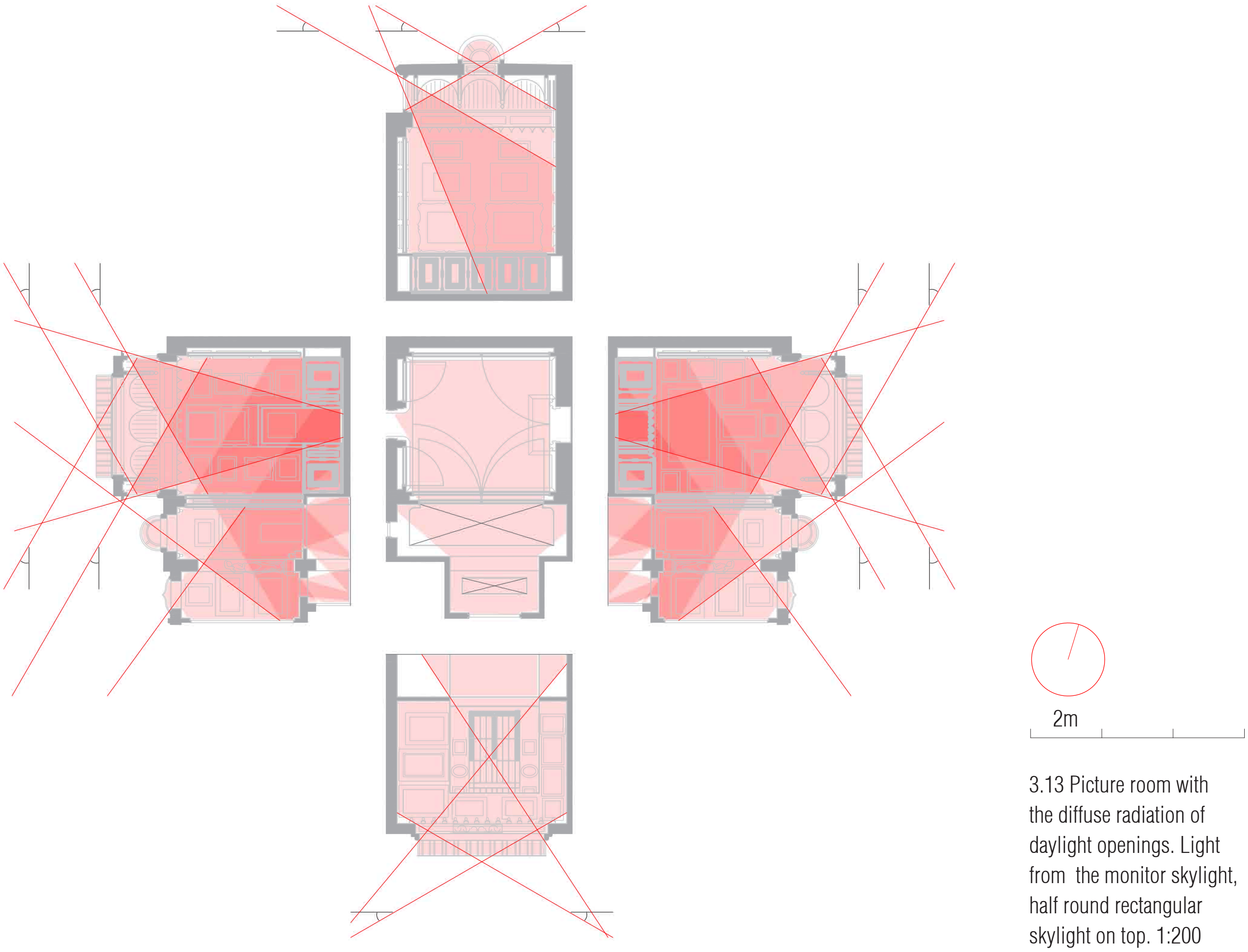


3.11 Picture room with materials. 1:200

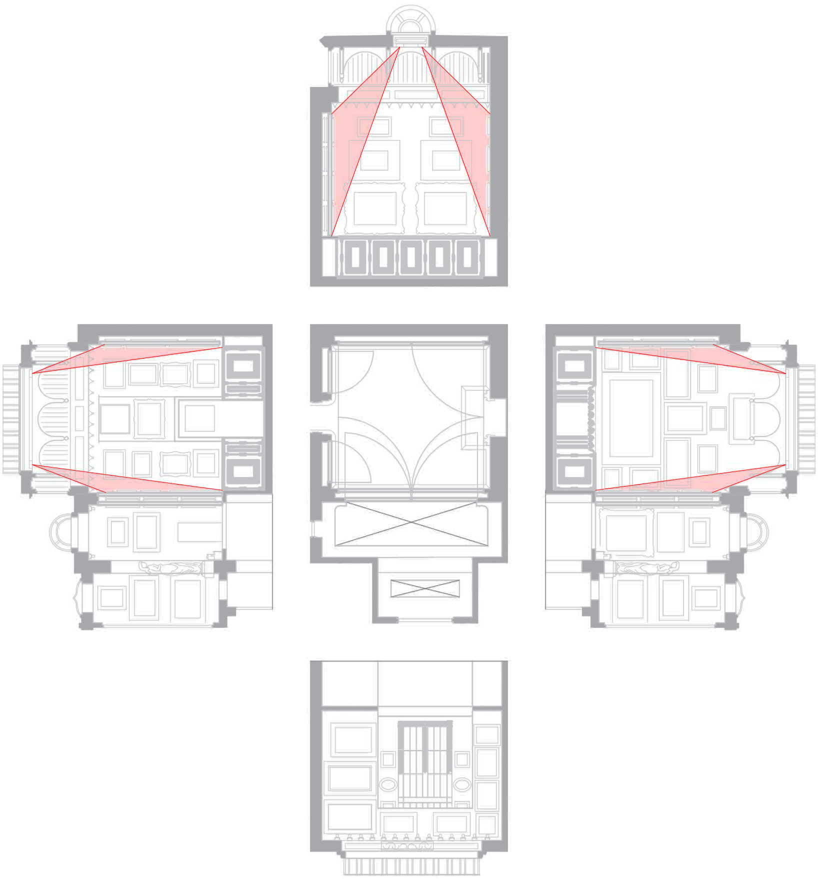


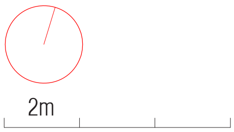


3.12 Picture room with a permanent collection. 2D objects on the walls and shutters, 3D objects in the recess of the space on shelving. 1:200



3.13 Picture room with the diffuse radiation of daylight openings. Light from the monitor skylight, half round rectangular skylight on top. 1:200

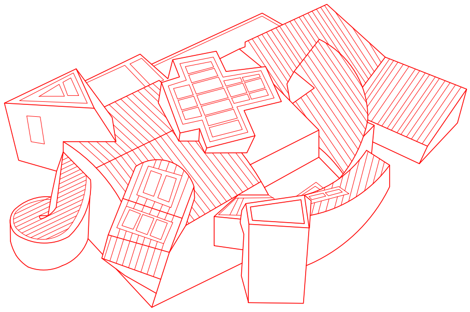




3.14 Picture room with artificial lighting. Installed high up round the perimeter of the central skylight box on a minimal metal floating frame. 1:200


FRANK O.
GEHRY
SINCE
1997
02.10.10–13.03.11

3.17 Isometric pictogram of façade Vitra Design Museum.



3.15 Façade Vitra Design Museum.
from: *Ivar Hagendoorn.*

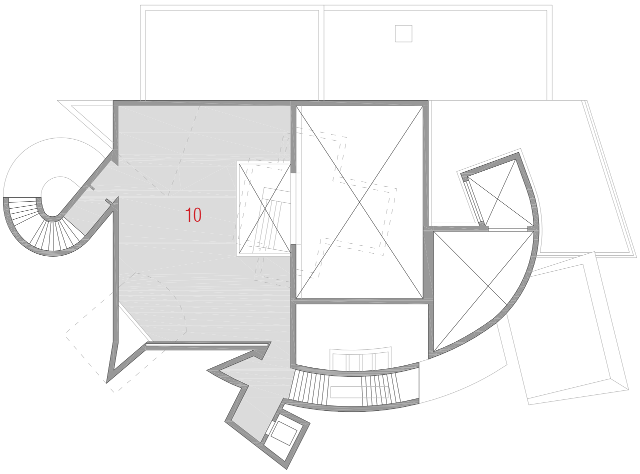
3.16 Façade entrance Vitra Design Museum.
from: *Tumblr.*

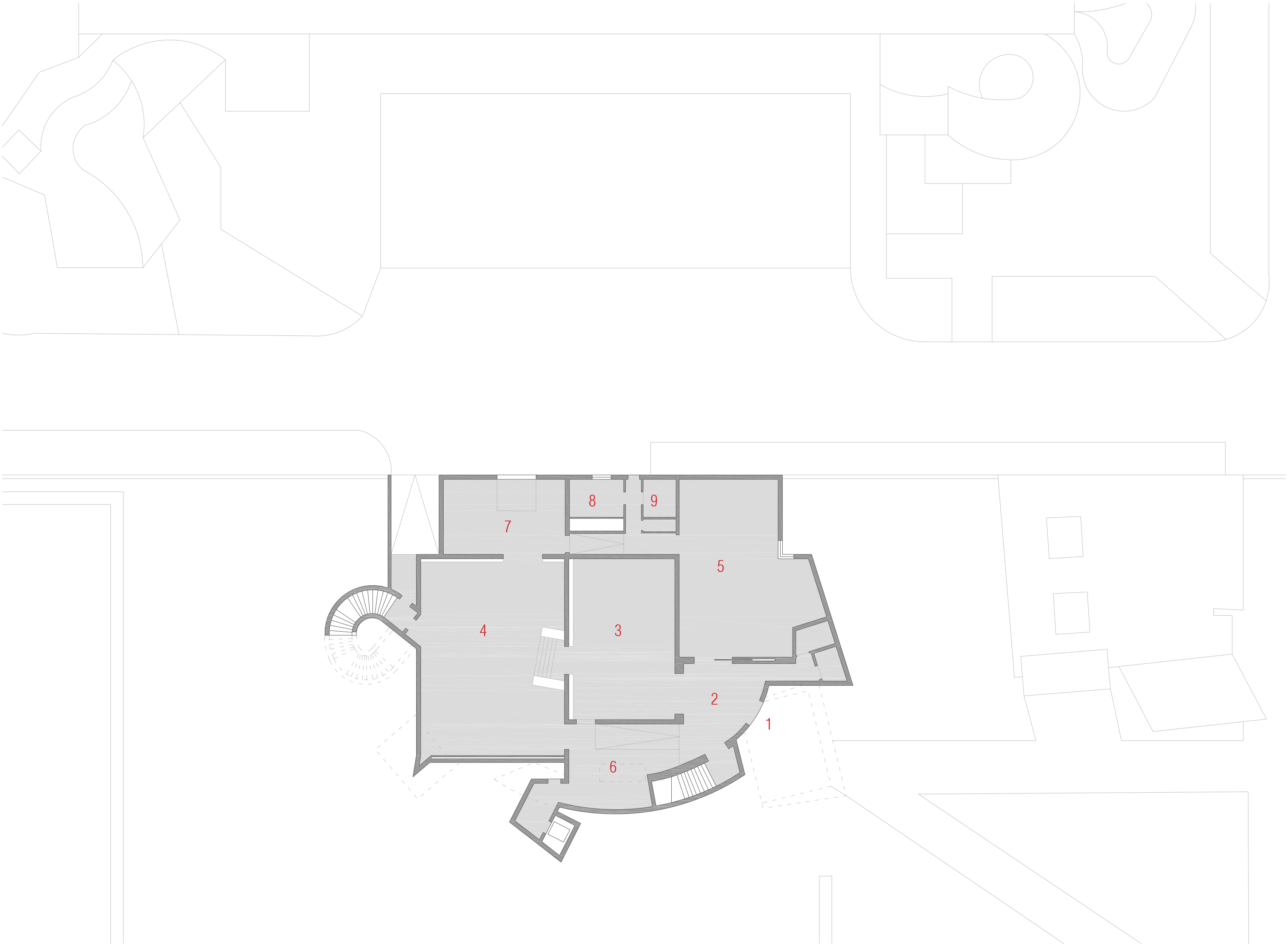
Vitra Design Museum - Frank O. Gehry

Description Museum
The Vitra Design Museum is located on the Vitra Campus in Weil am Rhein, Germany. The Vitra company collaborates with renowned architects to build unique architecture in the surroundings of the production facilities. Build in 1989, the museum was the first project in Europe of Frank O. Gehry. The museum volume is a conglomeration of architectonic elements with a simple geometric form that create a volumetric totality, a junctaposition of interlocking disparate forms. The exterior expresses the function of the volumes in the form of a sculpture. The "*Vitra company*" states; "The aesthetic of the Vitra Design Museum was instrumental in the emergence of the stylistic concept of "Deconstructivism" and marked a new phase in Gehry's oeuvre that he continued to develop in major projects over the following years"(42) The four large exhibition galleries of the museum with a total of 700 square metres have white plaster walls and ceiling. The museum has a collection of chairs and a changing contemporary exhibitions developed with renowned designers.

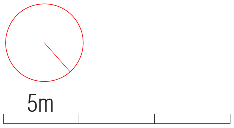
Technical building properties
The building exterior has a white plaster façade and zinc roof. The interior has a wooden floor and white plaster walls. Additional information on building technical features is not found.

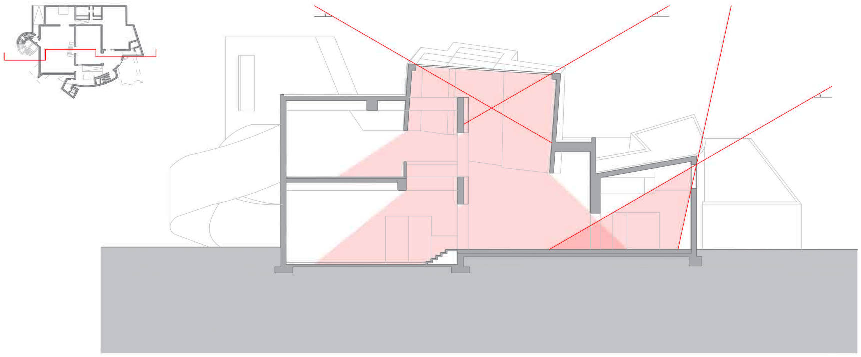
Light properties on exhibition
Daylight is the main source of light in the gallery spaces. Window openings with elemental forms are positioned on top of the galleries. A central cross shape window is inserted into the roof and provides most of the light in all of the exhibition spaces. The daylight from the cross shape window enters the spaces without any treatment. Artificial light is integrated in the vaulted ceiling with directable spots. On a construction which is suspended from the ceiling are hanging spotlights directed to the exhibition objects. A third type of artificial light are the integrated ceiling fixtures which illuminate a larger area of the spaces.
The dimensions of the space in meters are (11.4x15.6x3.0-4.9 lwh), the cross shape monitor (9.6x8.5x6.1 lwh) and glass surface of the skylight (9.0x7.7 lw). The ratios in square meters between plan, cross monitor opening and glass surface are; (152 : 75.4 : 61.5).



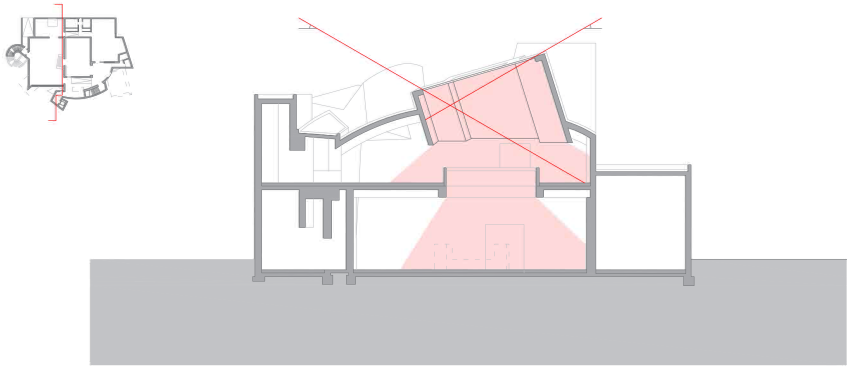


1. Entrance
2. Foyer
3. Central exhibition space
4. Large exhibition space
5. Exhibition space/ Conference room
6. Cafetaria
7. Storage space
8. Office
9. Kitchen
10. Exhibition space

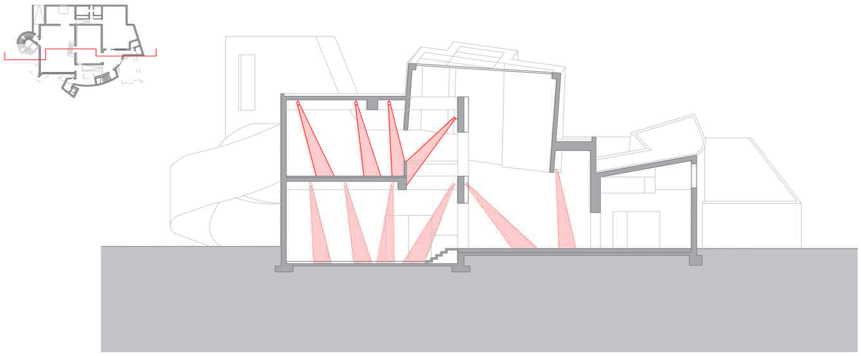




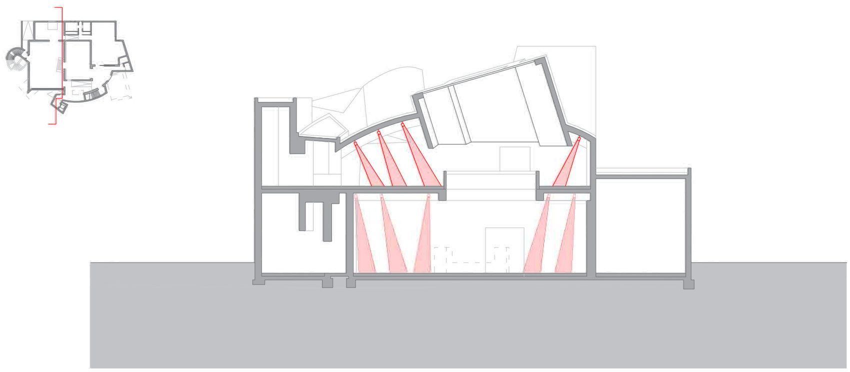
3.18 l. Plan first floor.
1:500

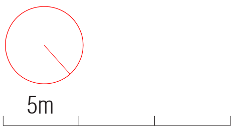


3.20 r. Museum section with daylight openings: Daylight is coming from transparent skylights penetrating the ceiling with a cross shape tube. 1:500

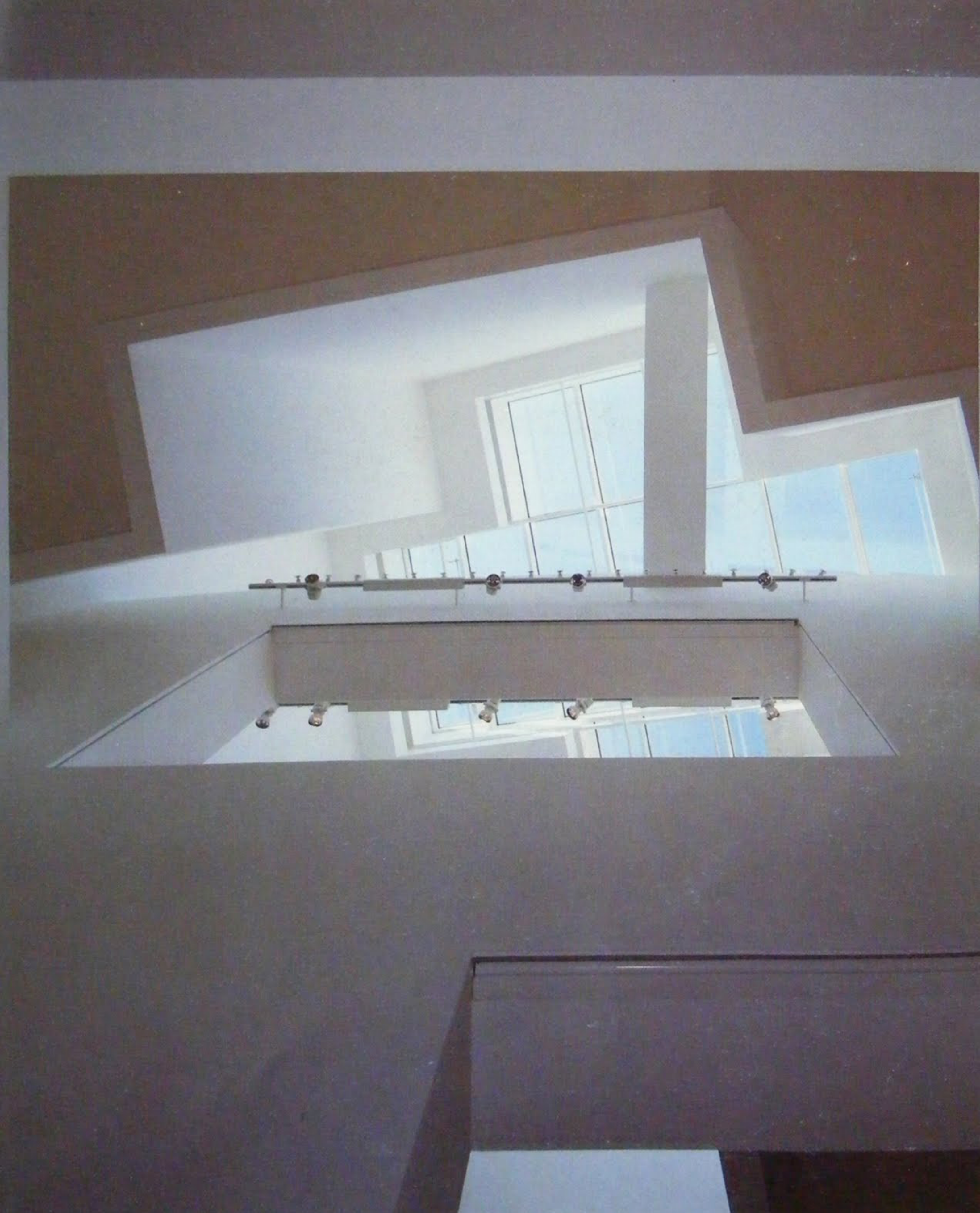


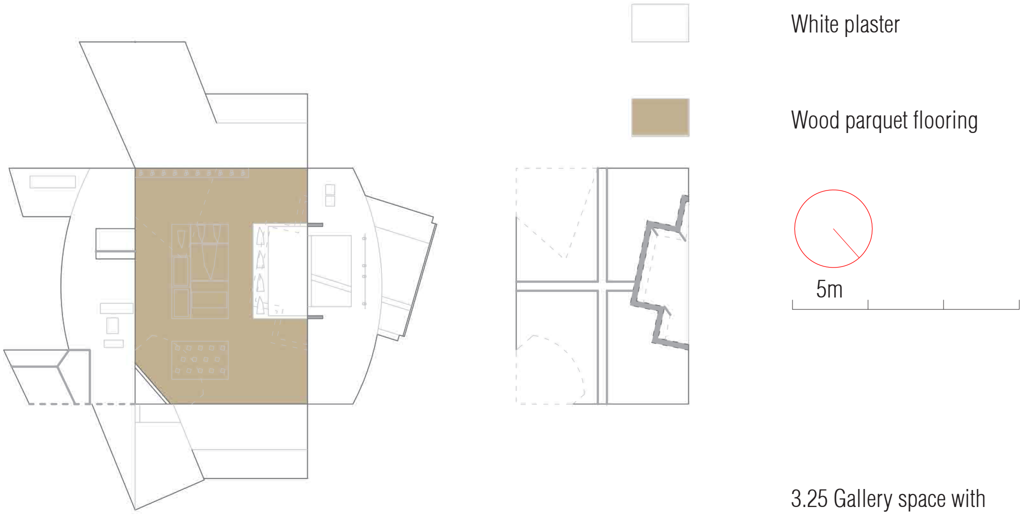
3.21 r. Museum section with artificial lighting fixtures. Spotlights directed downwards. Adjustable to the exhibition. 1:500



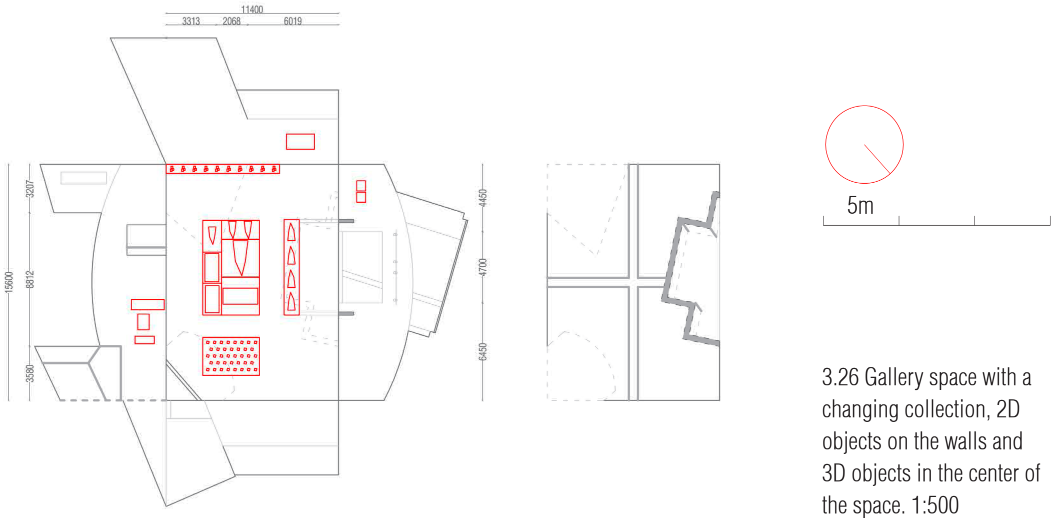


3.19 l. Plan groundfloor.
1:500



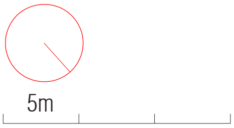


3.25 Gallery space with materials. 1:500

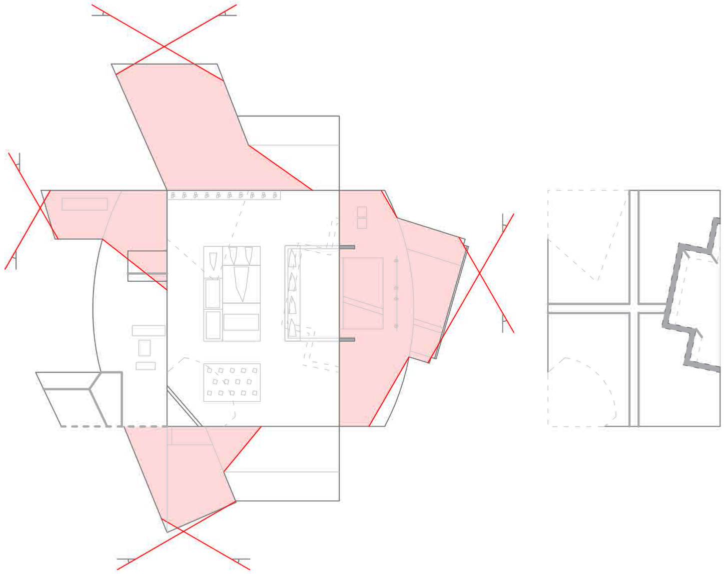


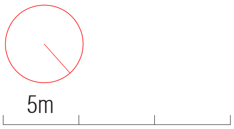
3.26 Gallery space with a changing collection, 2D objects on the walls and 3D objects in the center of the space. 1:500

previous page:
3.22 Cross shape skylight inserted into exhibition space. from: *The Vitra Design Museum*
3.23 Upper floor gallery space. from: *Phaidon*.
3.24 Model exhibition in gallery space.
from: *Phaidon*.

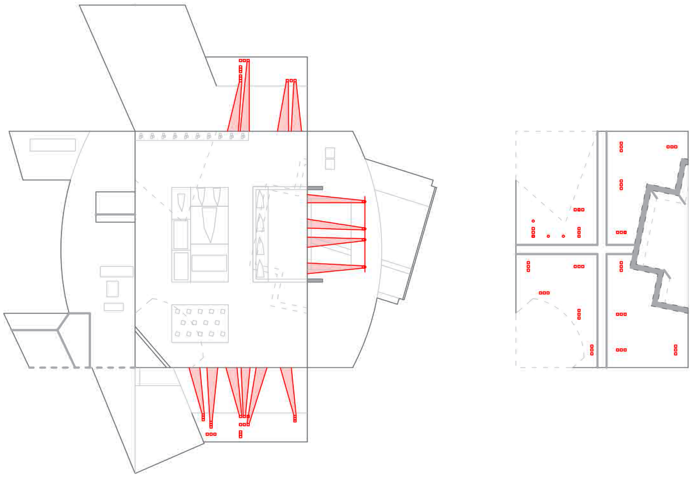


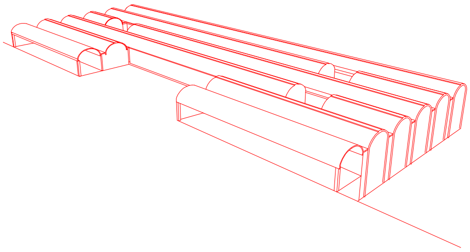
3.27 Gallery space with daylight openings: Daylight is coming from transparent skylights penetrating the ceiling with a cross shape tube. 1:500





3.28 Gallery space with artificial lighting fixtures. Spotlights directed downwards, mounted on the ceiling on variable fixed integrated contacts. Adjustable to the exhibition. 1:500





3.31 Isometric pictogram of façade Kimbell Art Museum.

3.29 Exterior Kimbell Art Museum.
from: *Library of Congress*.

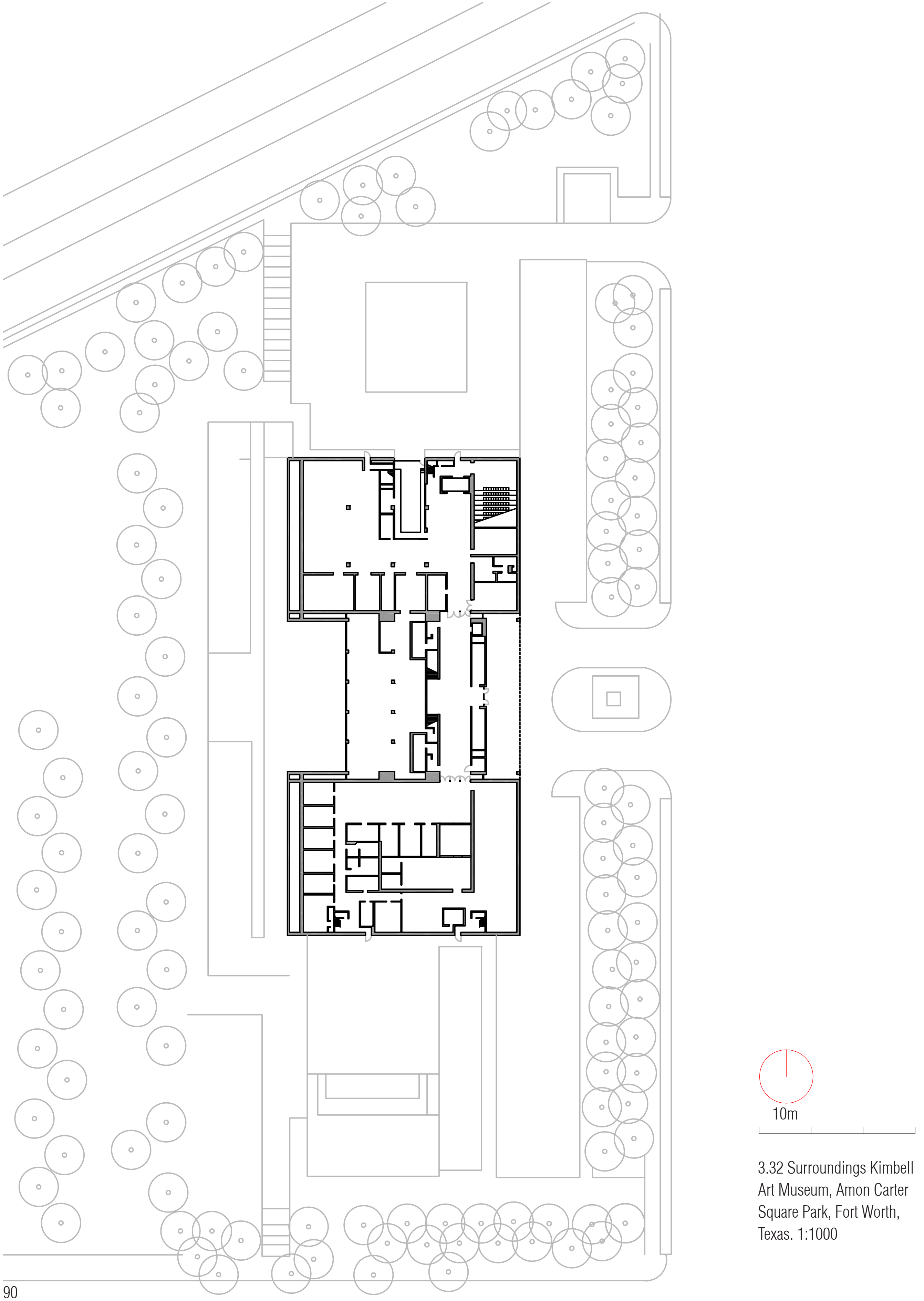
3.30 Exterior Kimbell Art Museum.
from: *Kimbell Art Museum*.

Kimbell Art Museum - Louis I. Kahn

Description Museum
The Kimbell Art Museum is located in Amon Carter Square Park in Fort Worth, Texas on a sloped site and is completed in 1972. The architect Louis I. Kahn is known for clear structural systems, geometrical order in composition, use of pure abstract materials and intelligent use of natural light. The architectural features of the Kimbell Art Museum are; the relationship between building and site, vaulted roofs with a cycloid shape, inner courts and natural day lighting. The building has an axial approach with symmetry in the façade and plan. It is a spatial composition of 16 vaults, there are six vaults on both the north and south side and four in the centre. According to "*Kimbell Art Museum*"; "The building evolved as a family of rooms with a simple plan based on classical proportion, repetition, and variation."(43) The building has two entrances on this central axis on both of the floors because of the height difference of the terrain. The museum has permanent and temporary exhibitions with objects ranging from antiquity to the twenty-first century.

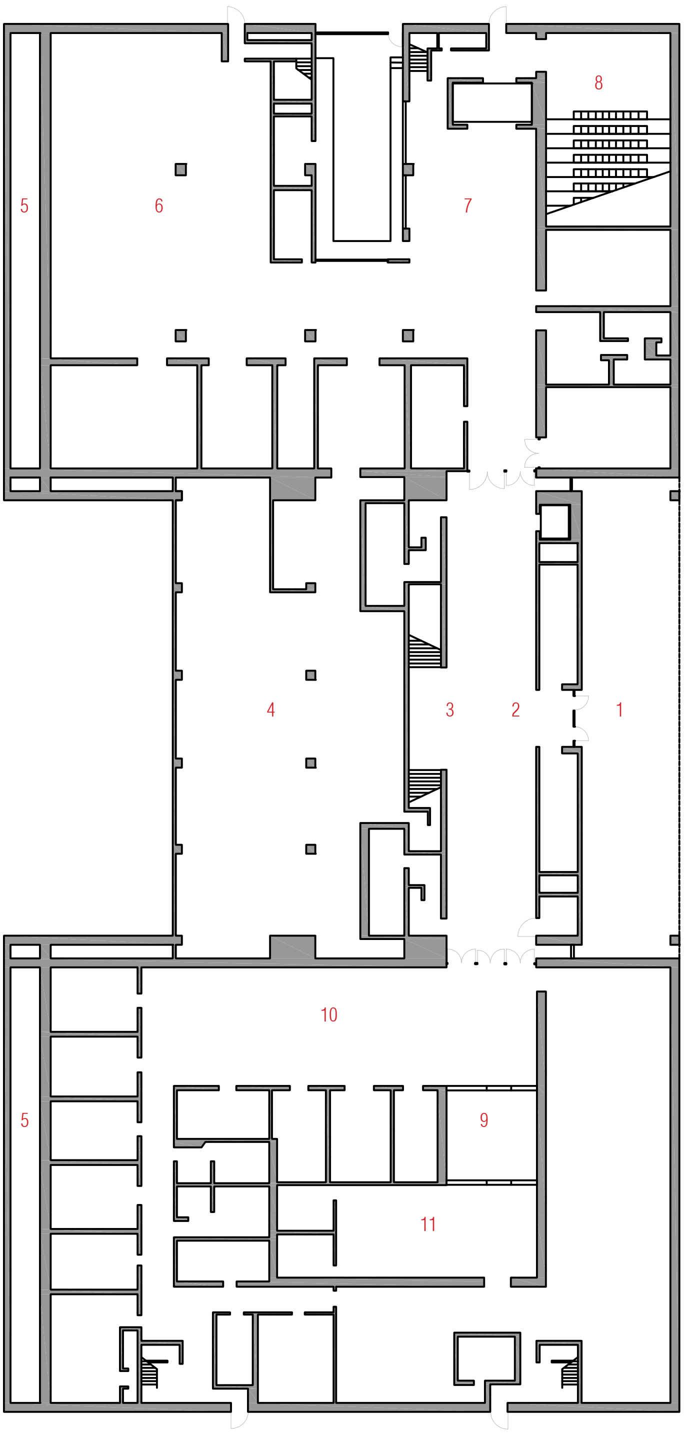
Technical building properties
The building has 16 independently supported structural vaulted roof units. The geometrical forms of the vaults are derived from a cycloid shape. The roof is a clear-span cycloid concrete shell with post tensioning cables and this geometric form can support it's own weight. The vault is supported by four reinforced concrete corner columns and therefore it has a very flexible floor space. The movable walls allow multiple configurations for the needs of the museum presentation. Travertine is a type of limestone applied as a decoration of the interior floors and walls. The slabs are pre cut and 5/8 inches thick. The soffits and reflectors are made of anodized aluminium with high reflectivity.

Light properties on exhibition
The design is based on natural light in the illumination of the gallery spaces. Kahn's concept was the idea of a room with a vaulted ceiling and natural daylight from above. "According to the conventions then consolidated, natural light distracted the visual experience of the spectator from the observation of works of art: Kahn refuted this theory, demonstrating how integrated design, which would require a preliminary survey of the daylight, enabled the achievement of effects of natural zenithal light, diffused and reflected, which enhanced the objects on show and made the visual experience of the spectator unrepeatable and comfortable." is explained by *Assessment of Daylight Performance in Buildings* (2015) (44); Natural daylight is dynamic and changing constantly,



3.32 Surroundings Kimbell Art Museum, Amon Carter Square Park, Fort Worth, Texas. 1:1000

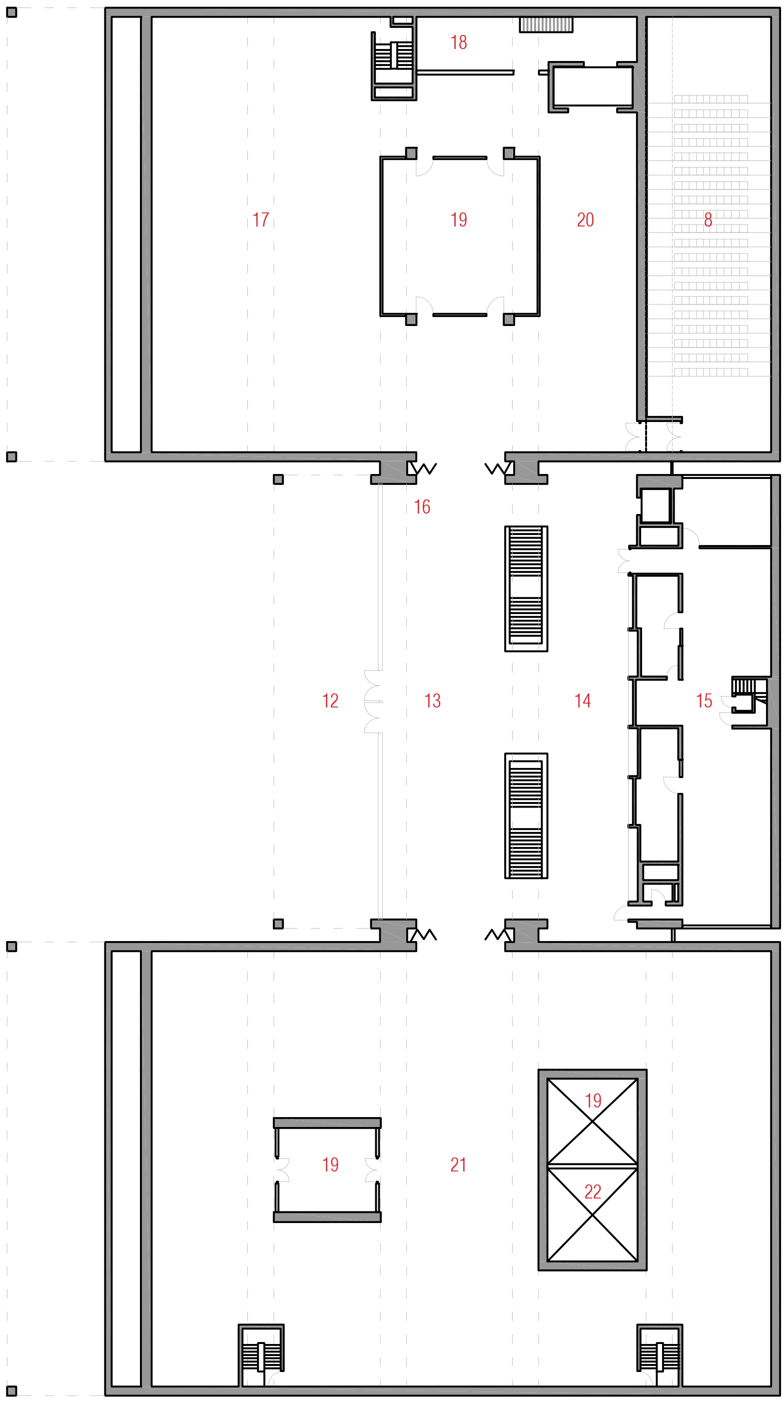
it creates a mood with a relation to nature and illuminates the space. "*Kimbell Art Museum*" states; "Natural light enters through narrow plexiglass skylights along the top of cycloid barrel vaults and is diffused by wing-shaped pierced-aluminium reflectors that hang below, giving a silvery gleam to the smooth concrete of the vault surfaces and providing a perfect, subtly fluctuating illumination for the works of art."(45) On either side of the vault is a slender lunette for more light and it separates the building elements. The museum has three open air light courts with a different dimension and transparency. The light in the museum spaces is a combination of toplight and sidelight which creates a balanced soft, diffused, and uniform luminous environment. The art is indirectly illuminated by the natural light and avoids glare, the light on the works is a reflection of daylight in the space. There is an amount of contrast between the objects and the monotone background. "The geometry creates a shape that naturally washes light downward along it's face and creates a visually foreshortened spatial effect." explains *Process: Material and Representation in Architecture* (2014).(46) The natural light is complemented with artificial light, spotlights mounted on the aluminium reflectors. The spotlights add an additional emphasis on the objects. The exhibition space in one vault has dimensions in meters of (28.8x7.6x6.4 lwh) and the short side is north-south oriented. The radius of the flattened semicircle vault has a height of 2.4 meters. The roof of the vault has a longitudinal daylight opening slit (28.8x0.76 lw) with perforated metal reflectors under the light slit. The curved metal element reflects the light via the ceiling into the space. The end face has a small lateral daylight slit with a total surface of 1 square meter
The ratios in square meters between plan, ceiling opening and glass surface are; (219 : 219 : 23).

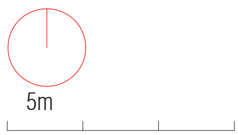


5m

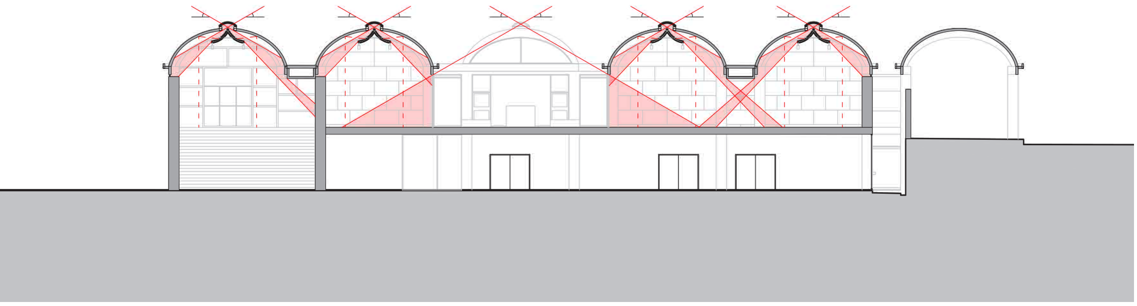
3.33 Plan ground floor, lower level. 1:500

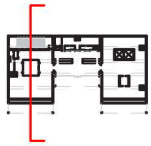
1. East entrance porch
2. East galley
3. Information desk
4. Mechanical space
5. Light well
6. Shop area
7. Receiving
8. Auditorium
9. Storage
10. Administration
11. Conservation
12. West entrance porch
13. Lobby
14. Shop
15. Library
16. Information desk
17. North gallery
18. Kitchen
19. Light court
20. Dining area
21. South gallery
22. Light well





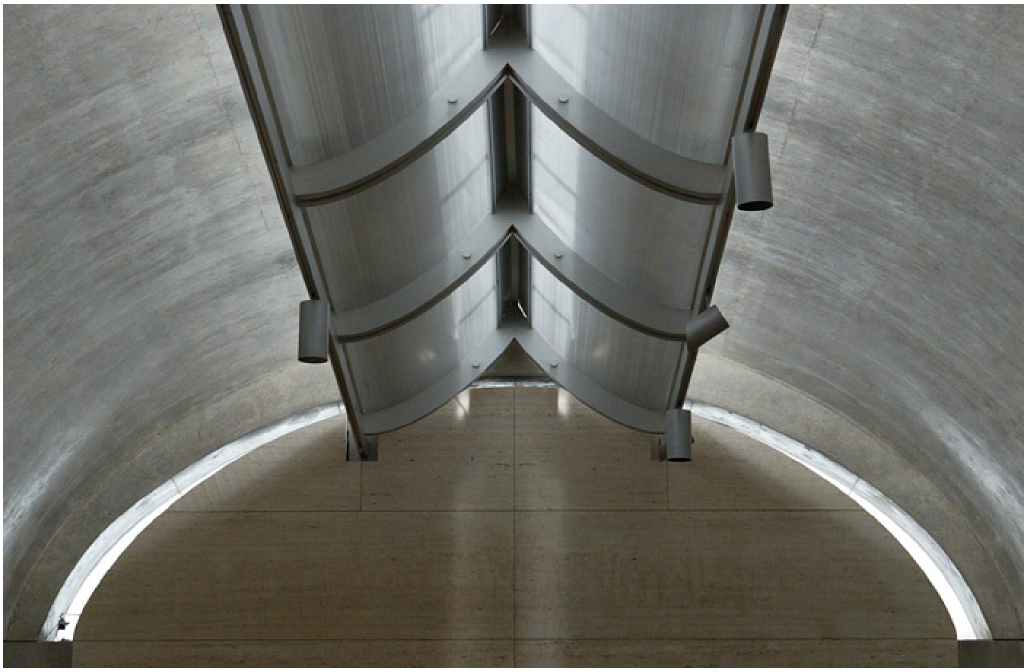
3.34 Plan first floor, upper gallery level. 1:500





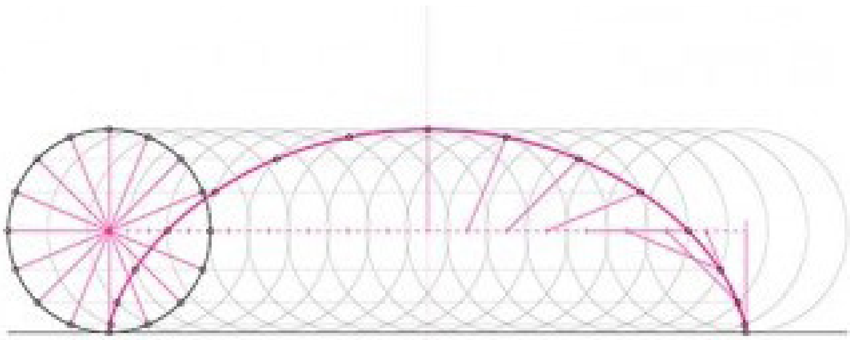
5m

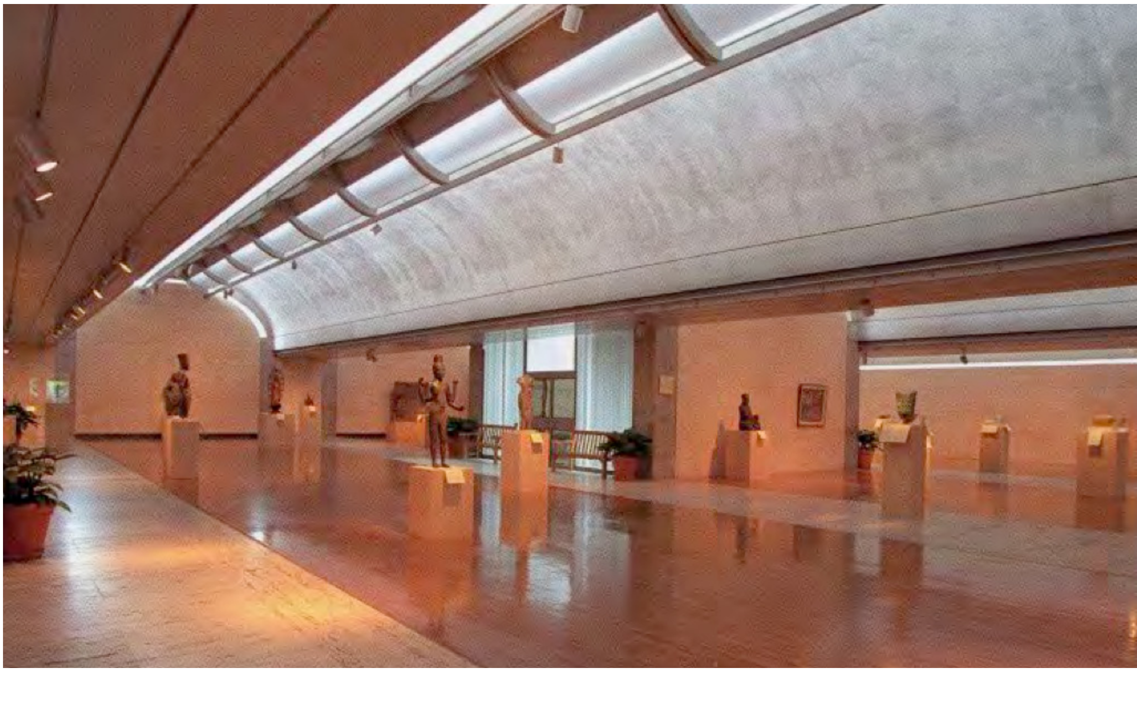
3.35 Section. representation of the cycloid arch and section through the vault. 1:500



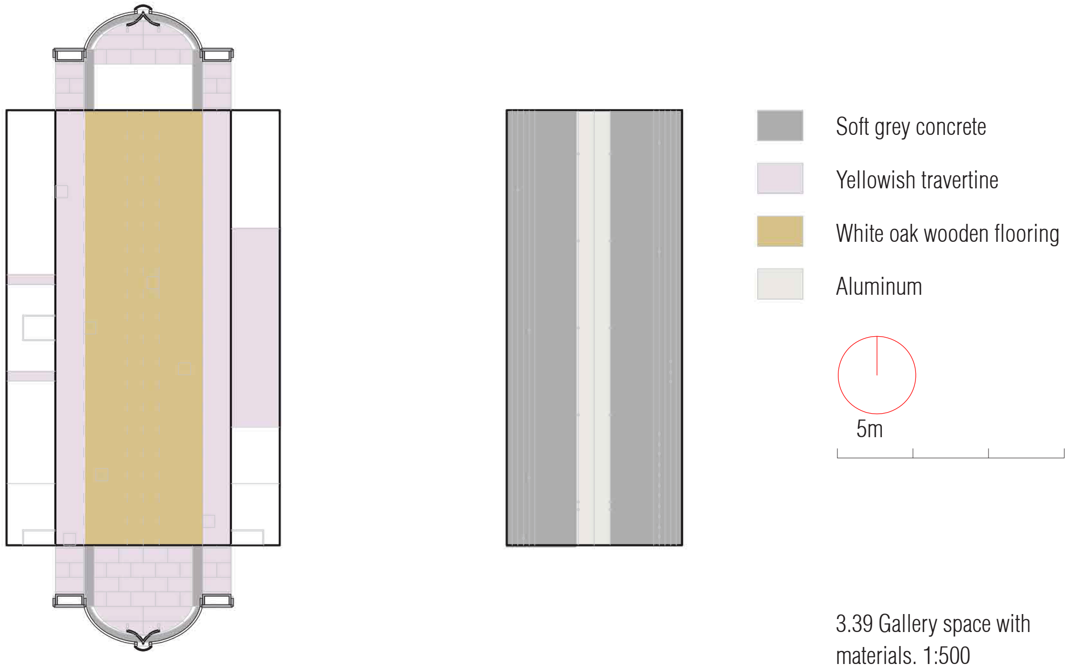
3.36 Cycloid vault with curved aluminum panels reflecting the light to a curved concrete ceiling. from: *Liao Yusheng*

3.37 Cycloid vault. A geometry with mapping of a fixed point on the circumference of a circle, the figure is rotated and shifted simultaneously.
from: *Process: Material and Representation in Architecture.*

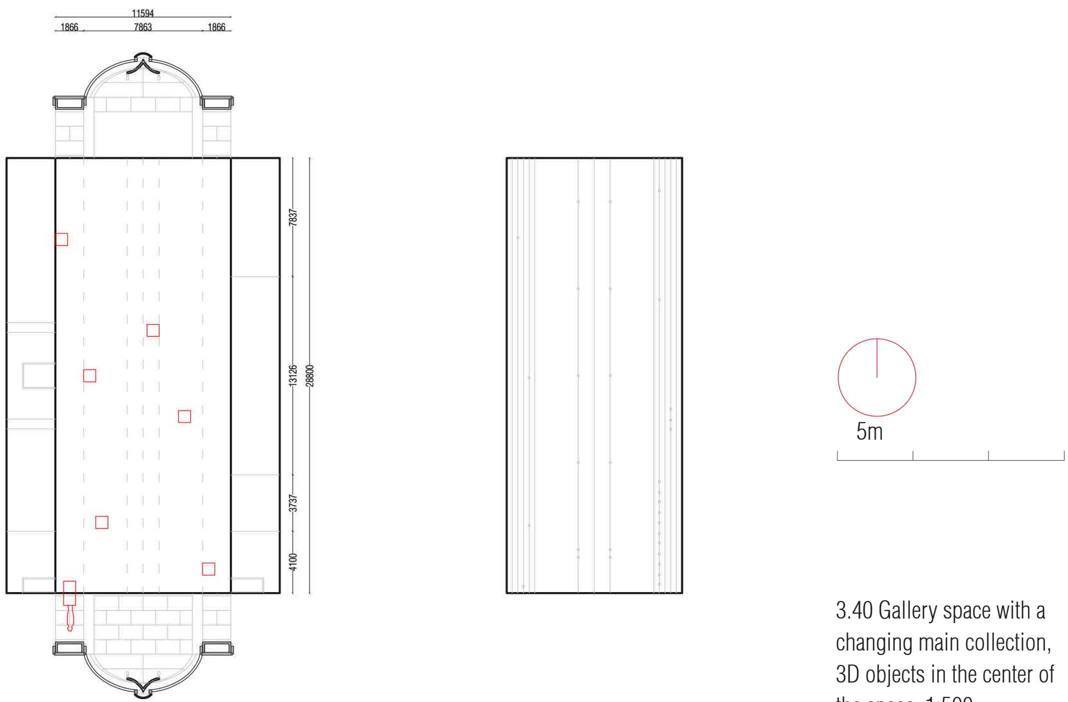




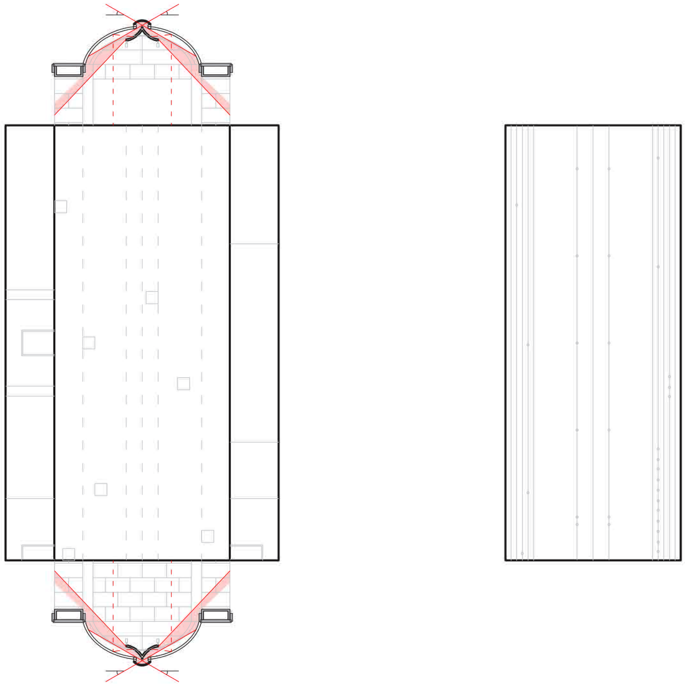
3.38 Gallery space with daylight and artificial light on 3D objects.
from: *Als3ax*

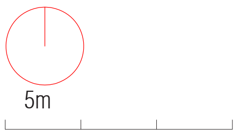


3.39 Gallery space with materials. 1:500

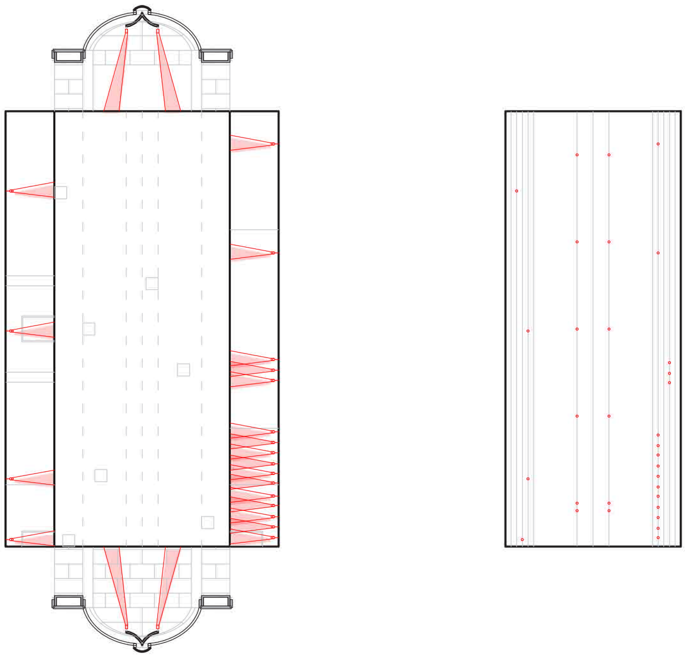


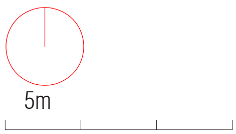
3.40 Gallery space with a changing main collection, 3D objects in the center of the space. 1:500



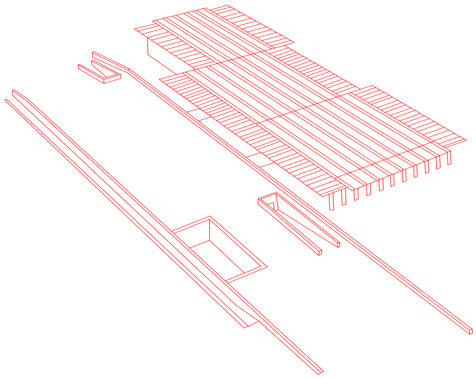


3.41 Gallery space with natural daylight openings: Daylight is coming from above, reflected and casted on the ceiling. 1:500





3.42 Gallery space with artificial lighting fixtures. Spotlights directed downwards, mounted on the ceiling on variable contacts. Adjustable to the exhibition. 1:500



3.45 Isometric pictogram of façade Kimbell Art Museum Piano Pavilion.

3.43 Exterior Piano Pavilion gallery. from: *Archdaily*

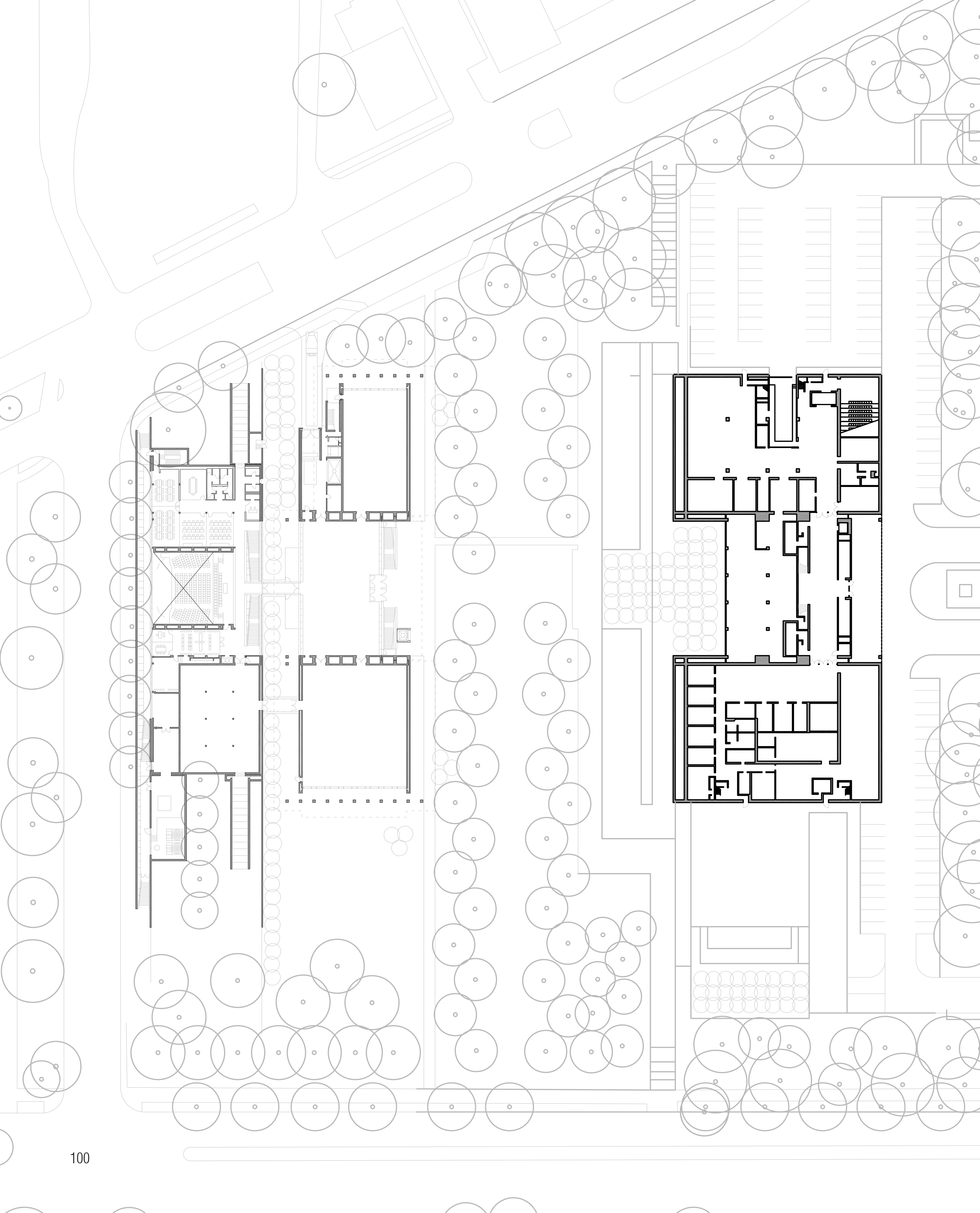
3.44 Aerial view Kimbell Art Museum and Piano Pavilion. from: *Phaidon*

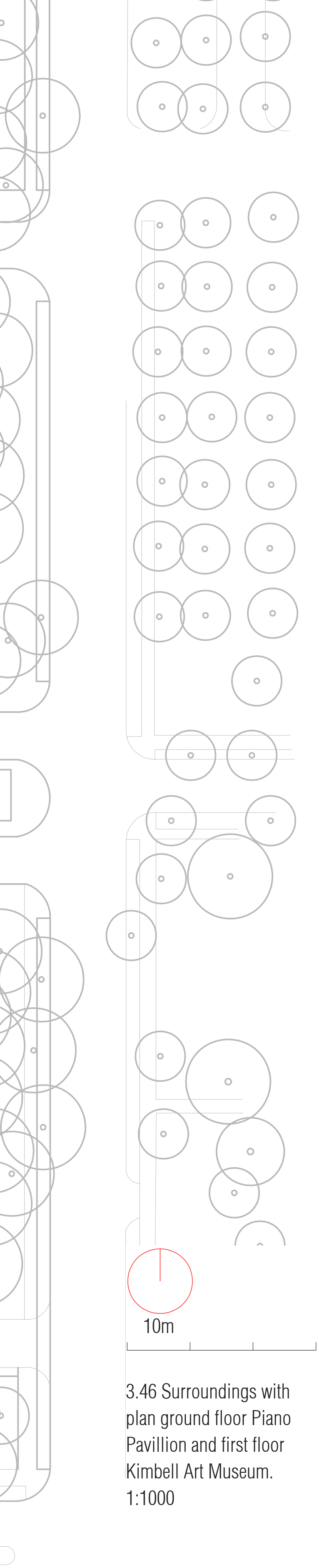
Piano Pavilion - Renzo Piano

Description Museum
The Piano Pavilion is an addition to the kimbell Art Museum of Louis Kahn. It is located in Amon Carter Square Park in Fort Worth Texas, in line with the Kimbell Art Museum. The Piano Pavilion opened in November 2013 after three years of construction. Architect Renzo Piano has redesigned the site and a new gallery building with a sixty meters distance from the original vaulted museum. The Piano Pavillion has an eastern part with a glass roof and a west part coverd with grass, both are connected with a glass passage. The building has a glass canopy hanging over a colonnade and acknowledges the design of Louis Kahn with related height, concrete as main building material and use of natural daylight and orientation to the main west entrance. According to "*Architectural Review*","Renzo Piano could be categorical in listing its intent: discreet, subdued, modest, reverential and deferential towards the original architecture."(47) The museum has art galleries, an education centre, auditorium, conservation sections and an underground parking garage. The exhibition galleries showcase paintings, sculptures and ceramics part of the Kimbell Art Museum collection complemented with temporary exhibitions.

Technical building properties
The glass roof system is supported by a structure with twenty-nine, thirty meter long douglas fir laminated wooden beams with steel connections and concrete columns. The walls are made of nine meter long light poured in place grey concrete walls with just a few tie-bar holes and transparent curtain glass. The main design feature is the engineering of the roof system with curved glass panels, aluminium louvres with integrated solar cells and internal translucent stretched scrims to condition the light in the gallery spaces. The louvres can protect the glass roof from seasonal hail storms by closing. The white oak floor has small gaps with an installation underneath, this functions as a vent to condition the climate. The thin inner exhibition walls are fixed to the floor but movable to maintain flexibility and tranquillity. The low energy use of lighting, air conditioning and the geothermal wells contribute to the energy efficiency of the building. This is partly influenced because only a third of the building is above ground.

Light properties on exhibition
The west wing of the Piano Pavilion has galleries with a closed roof for the exhibition of light sensitive objects. Renzo Piano experiments in the museum design with natural daylight. The north-east and south-east galleries have a glass ceiling with





3.46 Surroundings with plan ground floor Piano Pavillion and first floor Kimbell Art Museum. 1:1000

adjustable north opening louvres which can control the light flow of sunlight. He adds a layer of stretched translucent scrims to diffuse the light into the gallery. The illumination on the exhibition is improved by decreasing and diffusing the daylight levels. The wooden roof beams cast a dynamic shifting pattern of shadow upon the walls and enhance the characteristics of natural light. The transparency of the curtain walls allow daylight to enter the space, enables sightlines and a relation with the outside circulation areas. Artificial LED lighting complements the natural daylight. The spotlights are mounted under the wooden beams and directed towards the art works.

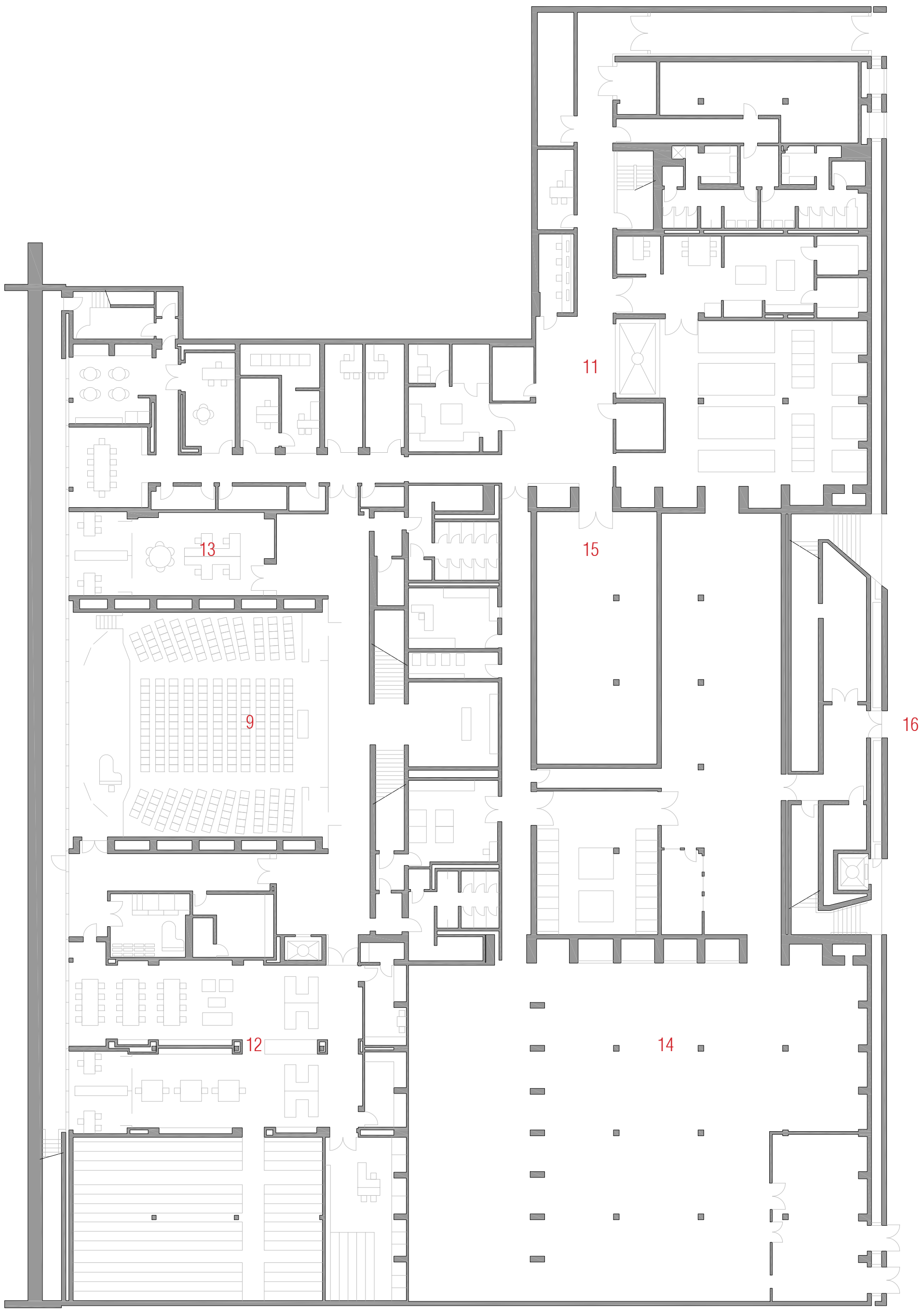
The exhibition gallery space has dimensions in meters of (26x22.3x4.6 lwh). The roof has wooden beams longitudinal direction with eight openings of (26x2.1 lw) with louvres and translucent scrims in and over the openings. The north facing wall has a full surface of curtain glass (22.3x6.3 lh) continuing between the wooden beams. The east and west wall have a small strip of glass above the concrete wall (26x.4 lh). The ratios in square meters between plan, ceiling opening and glass surface are; (580 : 437 : 590).

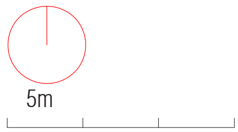
Comparison Kimbell Art Museum and Piano Pavilion

“Hoping to start what he calls a conversation between old and new, Piano kept the basic organization of Kahn’s building: a 324-foot-long horizontally slung shed divided lengthwise into three equal bays with the entrance on centre.” explains “*Architectural Record*”(48) The Piano pavilion has a more open and transparent character allowing a sight relation between inside and outside. Daylight can enter the gallery spaces through lateral curtain glass daylight openings. The relation also has a contradiction with a flat open glass roof versus the cycloid vault with a small light slit. Both museums correspond with their alignment and the thoughtful design of daylight entering the gallery spaces.

The way in which the light is entering the gallery space in both museum designs is totally different. Kahn implemented a reflection of light on the vaulted ceiling to create a diffuse illumination in the gallery. The daylight opening is very small and spread over the length of the space. The roof of the Piano Pavilion south-east gallery is, with exception of the beams, completely transparent. Piano lowers the illumination with louvres and diffuses the light through translucent scrims. Large lateral daylight openings allow light to enter the spaces, where Kahn only allows small slits and openings in the courtyards.

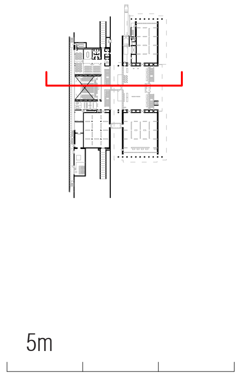
3.47 Plan ground floor, lower level. 1:500





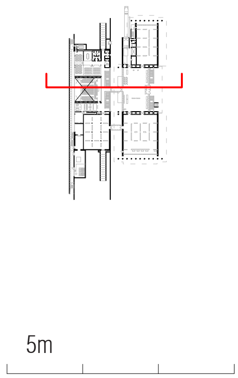
3.48 Plan first floor, upper gallery level. 1:500

1. Entrance
2. Lobby central gallery
3. Café
4. Shop
5. North gallery
6. South east gallery
7. South west gallery
8. Membership
9. Auditorium
10. Eductation
11. Back of house
12. Library
13. Education offices
14. Mechanical
15. Vault
16. Parking garage



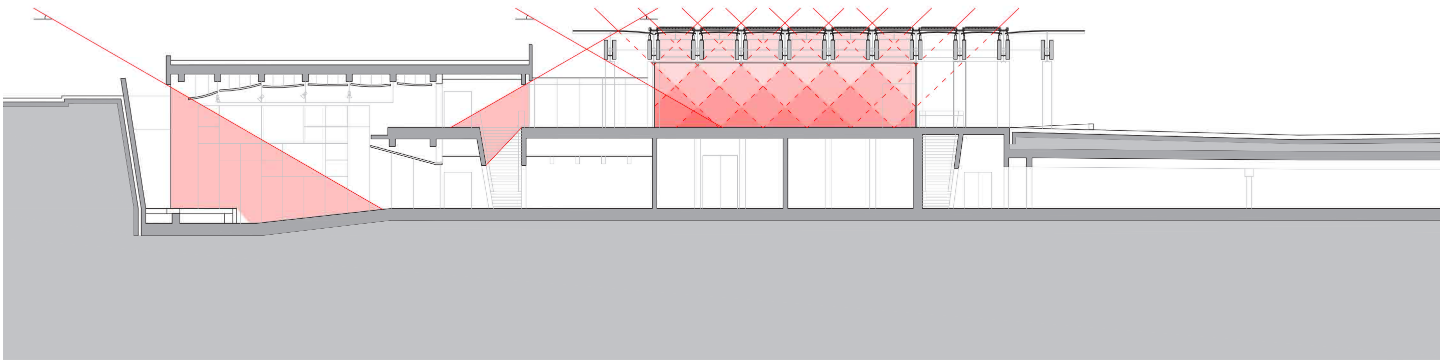
3.51 r. Section, daylight inside entrance lobby, cental gallery and auditorium. 1:500

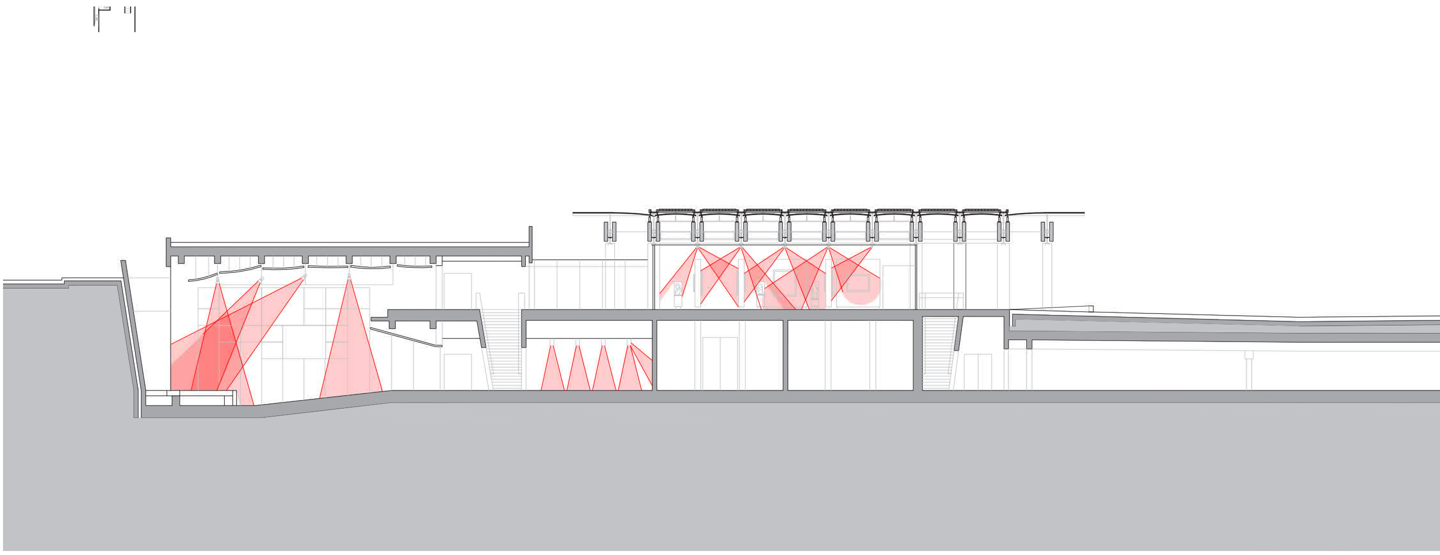
3.49 l. Interior view ceiling exhibition space. from: *Picsant.*

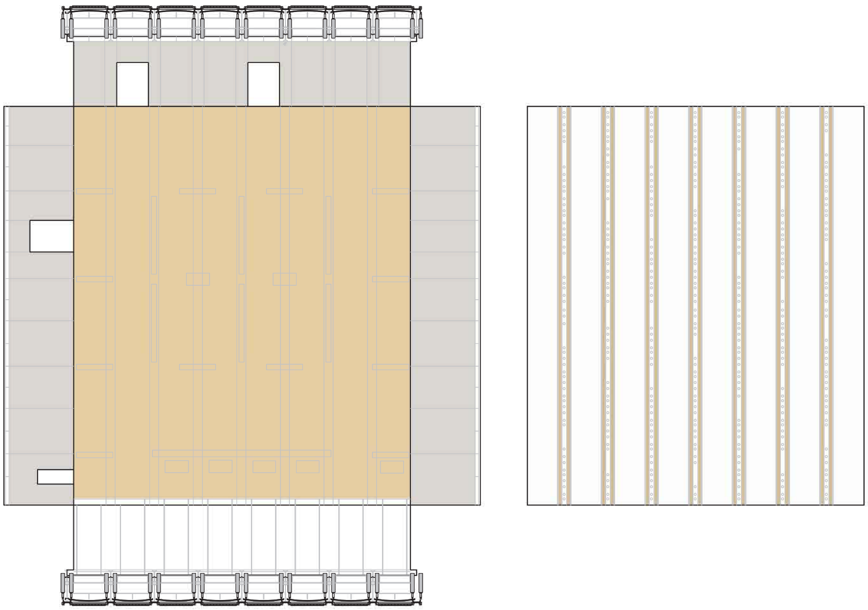


3.52 r. Section, artificial light inside entrance lobby, cental gallery and auditorium. 1:500

3.50 l. Interior view exhibition gallery. from: *Archdaily.*





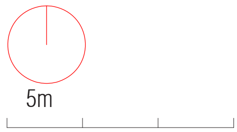


White oak wooden flooring

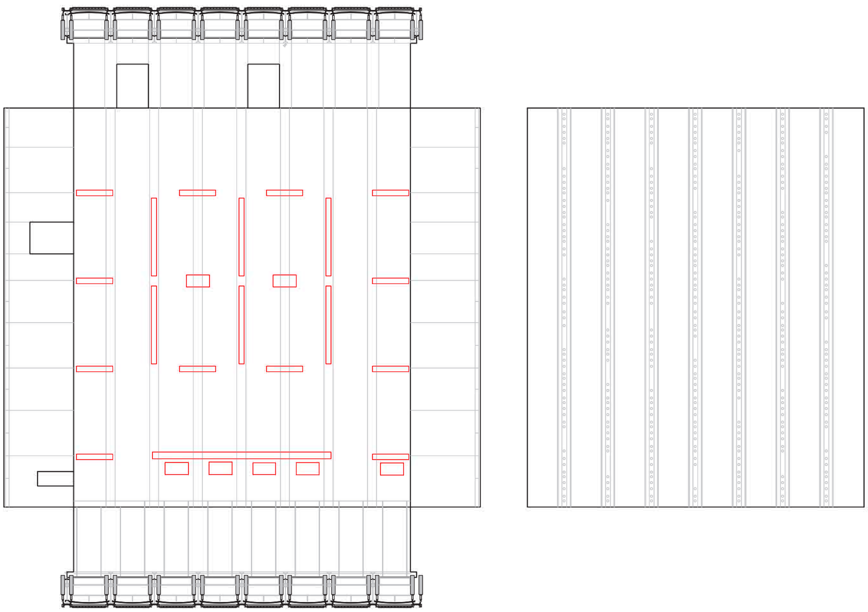
Concrete

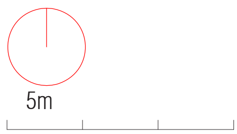
Wood beams with off white laminate polish

Translucent scrims

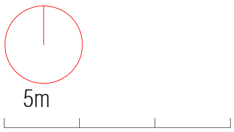


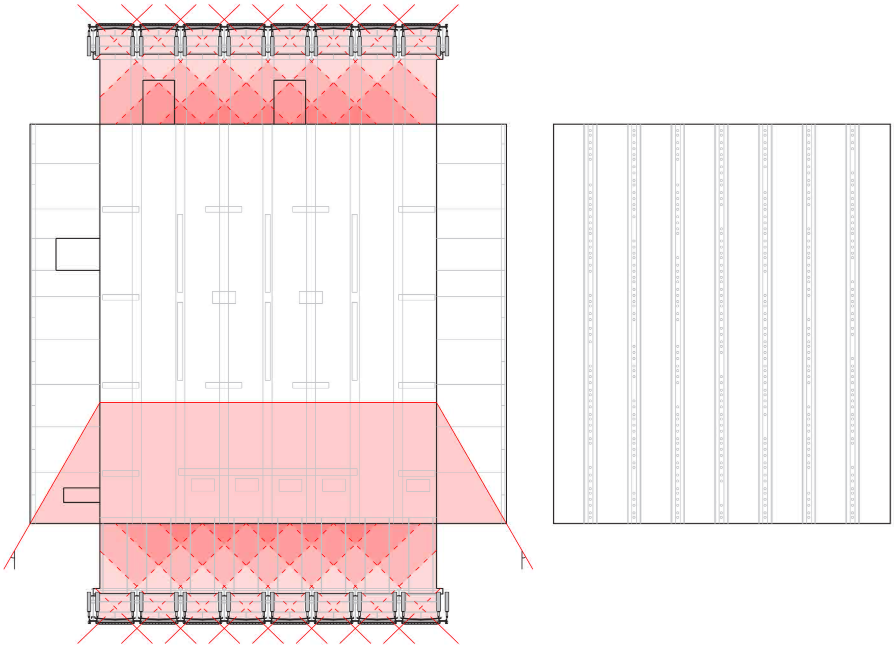
3.53 Gallery space with materials. 1:500



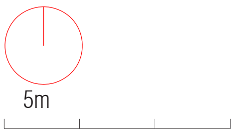


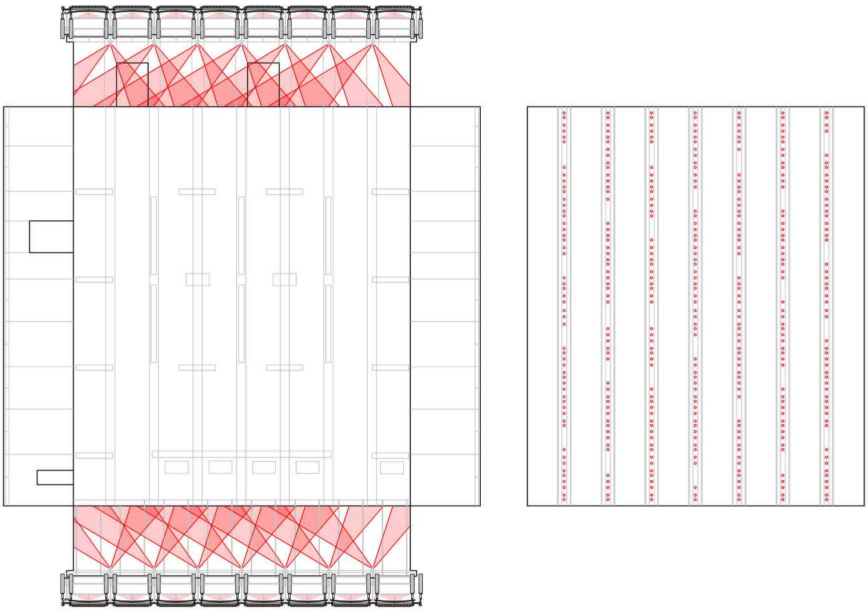
3.54 Gallery space with a changing main collection, 2D and 3D objects in the center of the space on panels and pedestals. 1:500





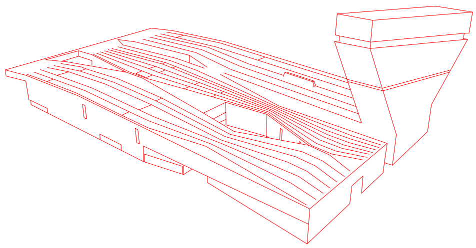
3.55 Gallery space with natural daylight openings: Daylight is coming from above through translucent layers and from south orientated windows. 1:500





3.56 Gallery space with artificial lighting fixtures. Spotlights directed downwards, mounted on the ceiling on variable contacts. Adjustable to the exhibition. 1:500


THE THERIOT FAMILY



3.60 Isometric pictogram of façade de Young Museum.

3.57 Façade of the de Young Museum

3.58 Aerial view de Young Museum, Golden Gate Park, San Francisco

3.59 Gallery space with light box rooflight

M.H. de Young Memorial Museum - Herzog & de Meuron

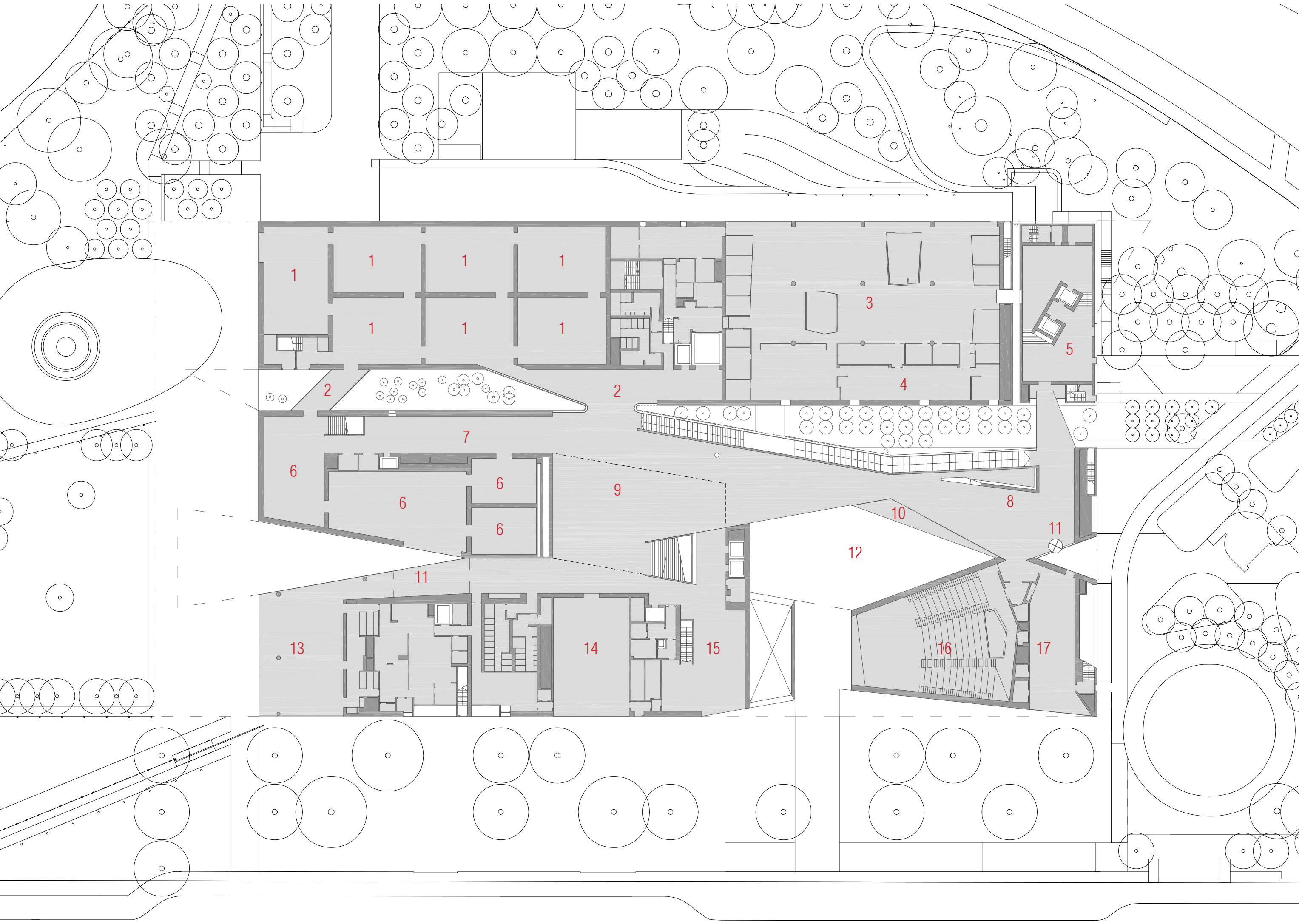
Description museum

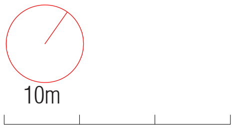
The building for the new de Young Museum is designed by Herzog & de meuron Architekten with principal Fong and Chan Architects. The construction of the building in the Golden Gate Park, San Francisco, California, USA began in 2002 and was completed in 2005. The Fine Arts museum has numerous collections of different cultures around the world. "*Herzog & de Meuron*" explain their vision of the design: "In curatorial terms, we tried to provide a variety of exhibiting conditions, resulting in a kind of typology of exhibition spaces. We wanted to define different types of exhibition spaces that reflect the differences in background and evolution of the works of art."(49) The concept of the building is three parallel bands where the park reaches the space in between and creates inner courtyards. The bands are interconnected and interrelated so that space interferes, it represents the friction, equality and coexistence of cultures in the de Young Museum. The architectural strategy was to make the building open and permeable this resulted in a ground floor with functions that are non-ticket for visitors and an open view panorama deck. The second strategy, "*Herzog & de Meuron*" explain "involves the large roof, which expresses the collective gesture of people gathering together."(49) The third strategy is the landmark element of the education tower that creates a link between the museum and the city. "*Archdaily*" states: "the new design consists of a bold striking structure that is as much part of the exhibit as the art it contains."(50)

Technical building properties

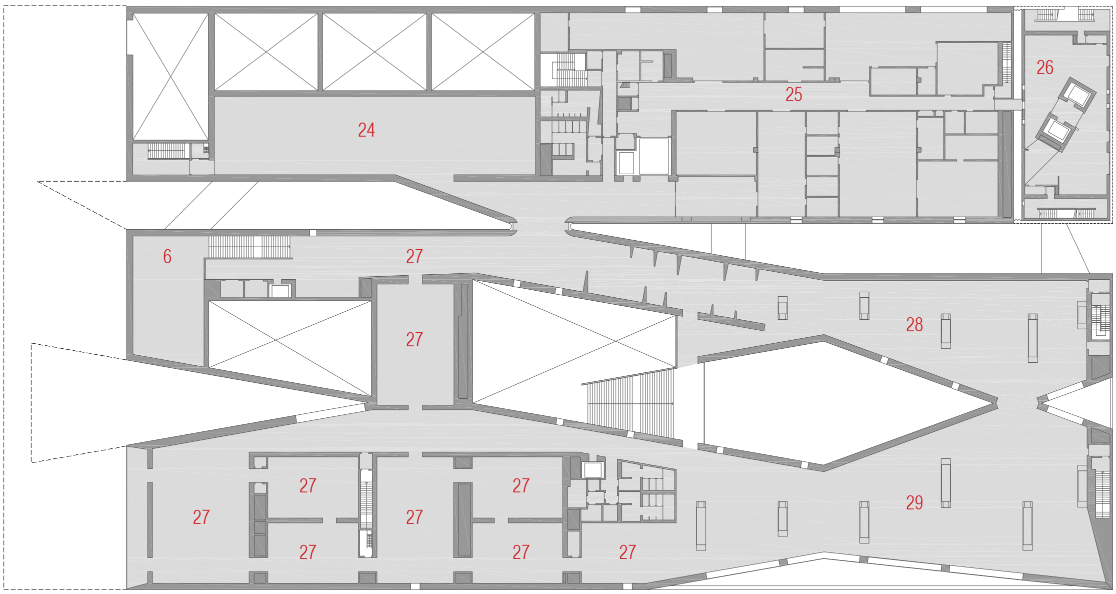
In *The de Young in the 21st century* (2005),(51) the building is described. The foundation has a construction separated from the building with a base insulation to withstand earthquake vibrations. The structure of the main building has a steel frame that rests on 76 elastomeric bearings and 76 slider bearings inside a moat. The building has multi story vierendeel trusses to cover the deep interior vistas and large glass walls. "*Fine Arts Museums of San Francisco* (*FAMSF)*" explains; It "provides open and light-filled spaces that facilitate and enhance the art-viewing experience."(52) The floors are made of reinforced poured concrete with natural stone for circulation areas and Sydney Blue Australian hardwood floor finishing for the galleries. The interior walls have a plaster finish. The material of the façade is made with 7,200 unique copper panels that will oxidize in time with 1,500,000 embossings that formed the pattern of light through trees. The roof is the fifth façade also made of copper with solid panels, expressed copper fins disguising the drainage system following

1. American Art 20th century
2. Interstitial 20th century
3. offices & conference space
4. Library
5. Hamon education tower lobby
6. Native American Art
7. Native Interstitial Art
8. Main lobby, membership & information center
9. Wilsey main court
10. Main entrance
11. Entrance
12. Entry court
13. Museum café
14. Family room, Piazzoni murals
15. Museum store
16. Koret auditorium, lecture room
17. Kimbell children's education gallery
18. Conservation spaces
19. Herbst exhibition galleries, temporary exhibitions
20. Storage artworks
21. Information desk
22. Media room
23. Parking garage entrance
24. Textile gallery
25. Storage
26. American Art curatorial & study center
27. American Art 18 -20th centuries
28. African Art gallery
29. Pacific Art gallery



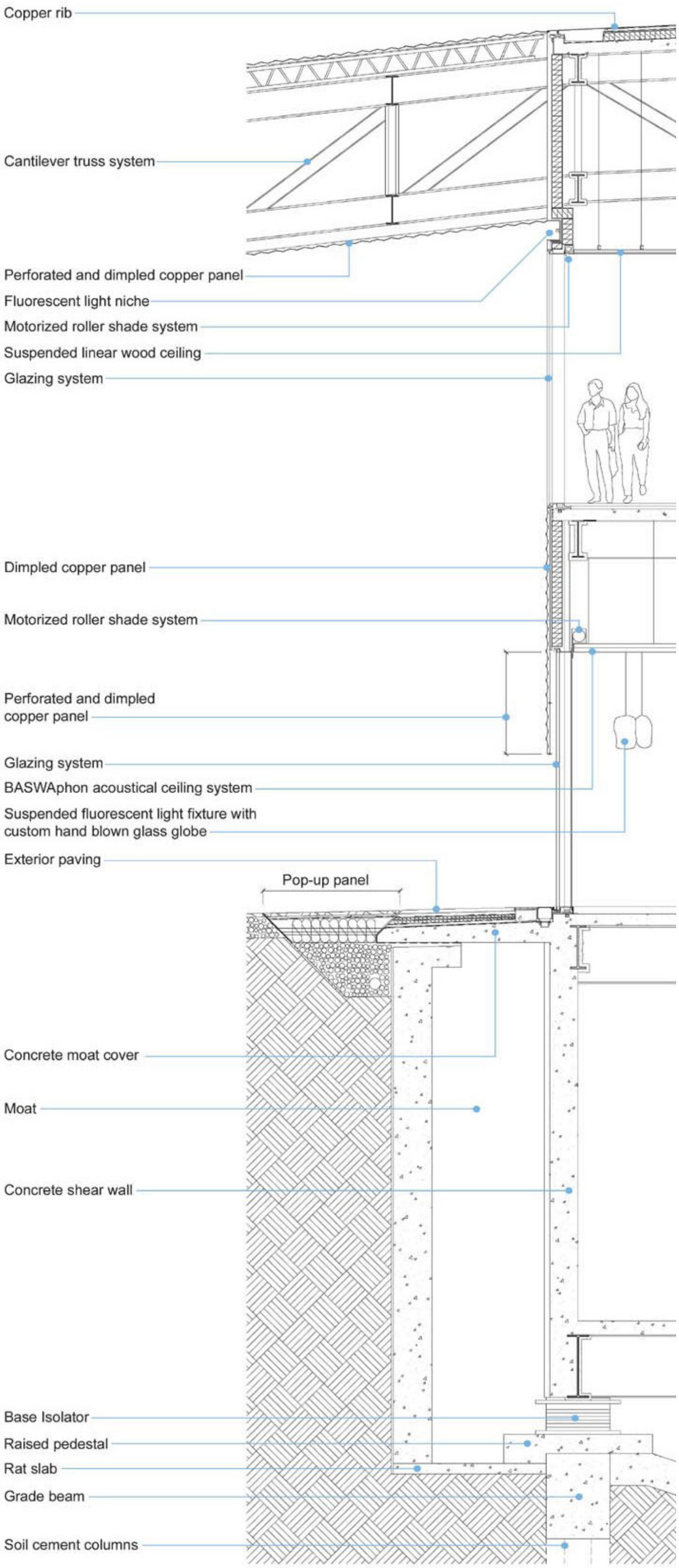


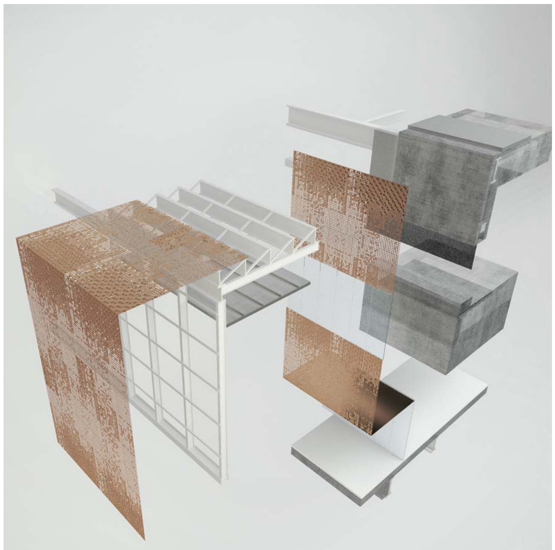
3.62 Plan basement floor,
Exhibition level 1:1000



3.63 r. Plan first floor,
upper gallery level 1:1000

3.61 l. Plan ground floor,
concourse and park level
1:1000


Copper rib
Cantilever truss system
Perforated and dimpled copper panel
Fluorescent light niche
Motorized roller shade system
Suspended linear wood ceiling
Glazing system
Dimpled copper panel
Motorized roller shade system
Perforated and dimpled copper panel
Glazing system
BASWAphon acoustical ceiling system
Suspended fluorescent light fixture with custom hand blown glass globe
Exterior paving
Pop-up panel
Concrete moat cover
Moat
Concrete shear wall
Base Isolator
Raised pedestal
Rat slab
Grade beam
Soil cement columns



3.64 Section of the façade.
from: *David Cameron*

3.65 Exploded view façade.
from: *David Cameron*

3.66 Technical section.
from: *Archweek.*

the lines of the building and integrated glazed skylights. It is one of the most anti-sustainable buildings in San Francisco because of the copper runoff that is poisoning the environment. The climate in San Francisco has hot summers therefor the building needs shade and ventilation. It has pronounced winters, therefor it needs insulation and reduced filtration. The relative humidity is 83.8 - 59.4. For the ventilation system, "*Arup*" "proposed and designed a constant volume underfloor air distribution system to meet museum-quality standards for ventilation, temperature and humidity control."(53) The mechanical system operated with a 3 degree temperature and humidity fluctuation. The exhaust ducts on the roof are sheathed in a copper fin. The integrated ventilation system is able to ventilate through the perforation of the panels. The building has a minimal insulation.

Light properties on exhibition

The collection of the de Young Museum consists of paintings, sculptures, decorative arts objects and contemporary installations. Most of the gallery spaces have a permanent collection. "*Herzog & de Meuron*" explain: "The new de Young Museum offers classically proportioned rooms or galleries with fixed walls and overhead lighting. These are ideal for viewing and studying the paintings, sculptures, and furniture of the 19th and 20th century collections of American art."(49) The large natural light box skylights maximize the daylight within the building and allow natural light to animate the interior through translucent material. The monitor in the centre of the ceiling is a scaled shape of the gallery. The skylight seems to float because of the dropped ceiling, this is contructed with a second skylight above it. Inbetween this space are mechanical systems. "*Arup*" states; "Automatic blinds mix available daylight with artificial light to produce the required gallery illumination levels."(53) The advantage of this type of illumination of the space is the indirect lighting where the light can be filtered. This has a positive effect on the experience of the art because the diffuse light is more uniformly distributed. The artificial lights focus direct spots in the art. The totally costom architectural lighting design and lighting control system was made in collaboration with "*Arup and Cupertino Electric Inc.*"(54) The lighting system has a 2 inch wide multi-functional lighting slot system, it has multiple rows that incorporate 277V fluorescent general lighting and art lighting 120V track heads with a dimming system. "The slot system also provides the return air for the mechanical systems, which had specific requirements for how much air had to be exhausted through the fixture into the plenum space above."(54) This fixture is the primary light source in all the galleries and is mounted around the skylights. "*Arup*" explains; the de Young Museum has "its façade is perforated to imitate dappled light, so protecting gallery spaces from direct sunlight."(53) In front of the façade windows is a motorized shade control system. "*Herzog & de Meuron*" state;"Other galleries with a freer, more open arrangement and primarily artificial illumination are intended for objects from Central and South America, Africa, and Oceania."(49)

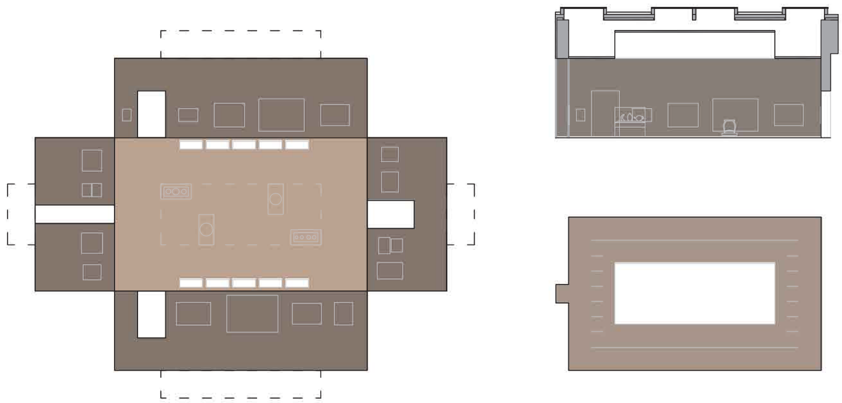
The background colour is also of importance for the art. "At the de Young, black-and-grey paintings are displayed against Topeka taupe, a medium-dark shade of brown." sais "*de Young curator Lynn Federle Orr*." "When you place dark paintings against a light surface, the eye closes up, details of the painting become lost. Deeper-tone, midrange colours relax the eyes, enable the viewer to see more of the painting. A restricted, restrained colour scheme brings out the painting's palette, brown is especially marvellous as a background."(55)

The dimensions of the space in meters are (16.7x10.1x5.3 lwh), glass surface of the lateral opening (1.2x5.3 wh), monitor opening (29.2x1.6 lh) four skylights above plenum (39x2.6 lw). The ratios in square meters between plan, ceiling opening and glass surface are; (169 : 42,4 : 53,1). The ratios of the height between exhibition space, monitor and glass are (5.3 : 1.8 : 1.5).

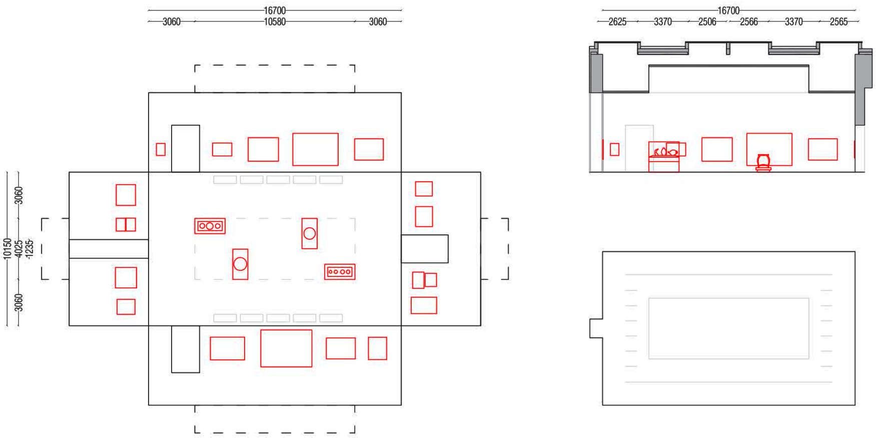
3.67 Section de Young Museum with incidence of daylight in indoor exhibition spaces. Dashed lines are diffuse light in all directions, inbetween lines most intense. 1:500

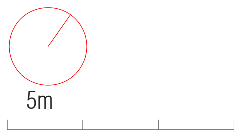
3.68 Gallery space de Young Museum with skylight and lateral light. Topeka taupe, medium-dark brown background enable to see more of the art.
from: *Jorge Bachman*


30°

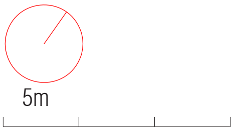


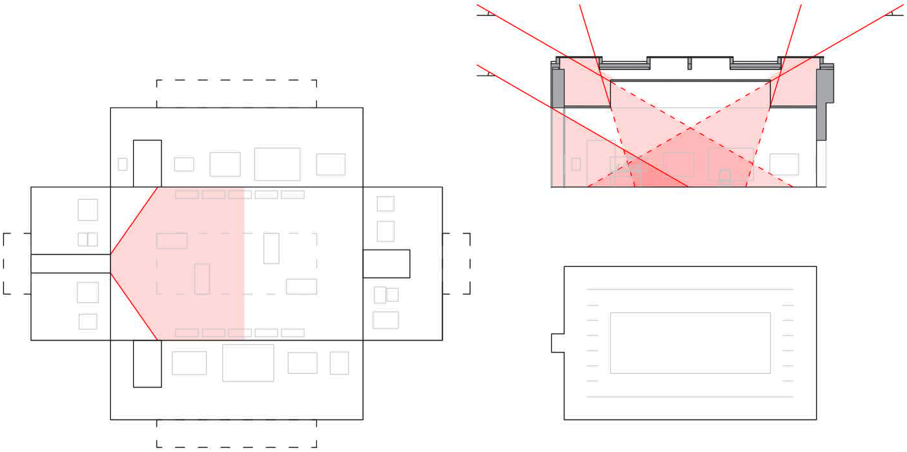
3.69 Gallery space with materials. 1:500



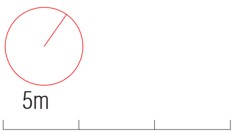


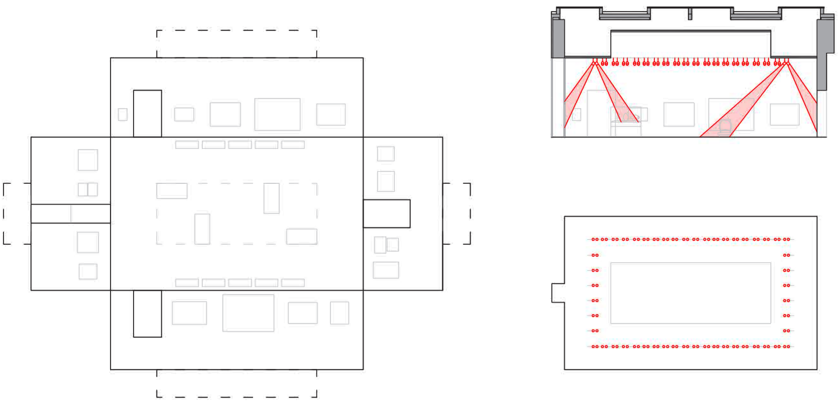
3.70 Gallery space with a permanent collection, 2D paintings on the walls and 3D objects in the center of the space.
1:500





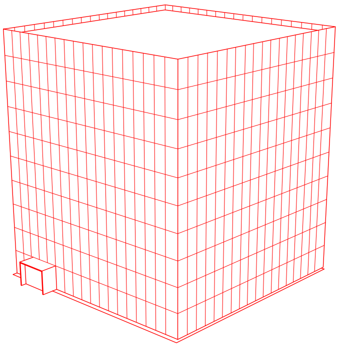
3.71 Gallery space with natural daylight openings: The dashed lines are diffuse light coming from the translucent skylight openings in the ceiling. Lateral light is coming through a transparent façade opening. 1:500





3.72 Gallery space artificial lighting fixtures. Spots with a direct focus on the art objects on the walls and the objects in the center of the exhibition space. 1:500


HOLZER



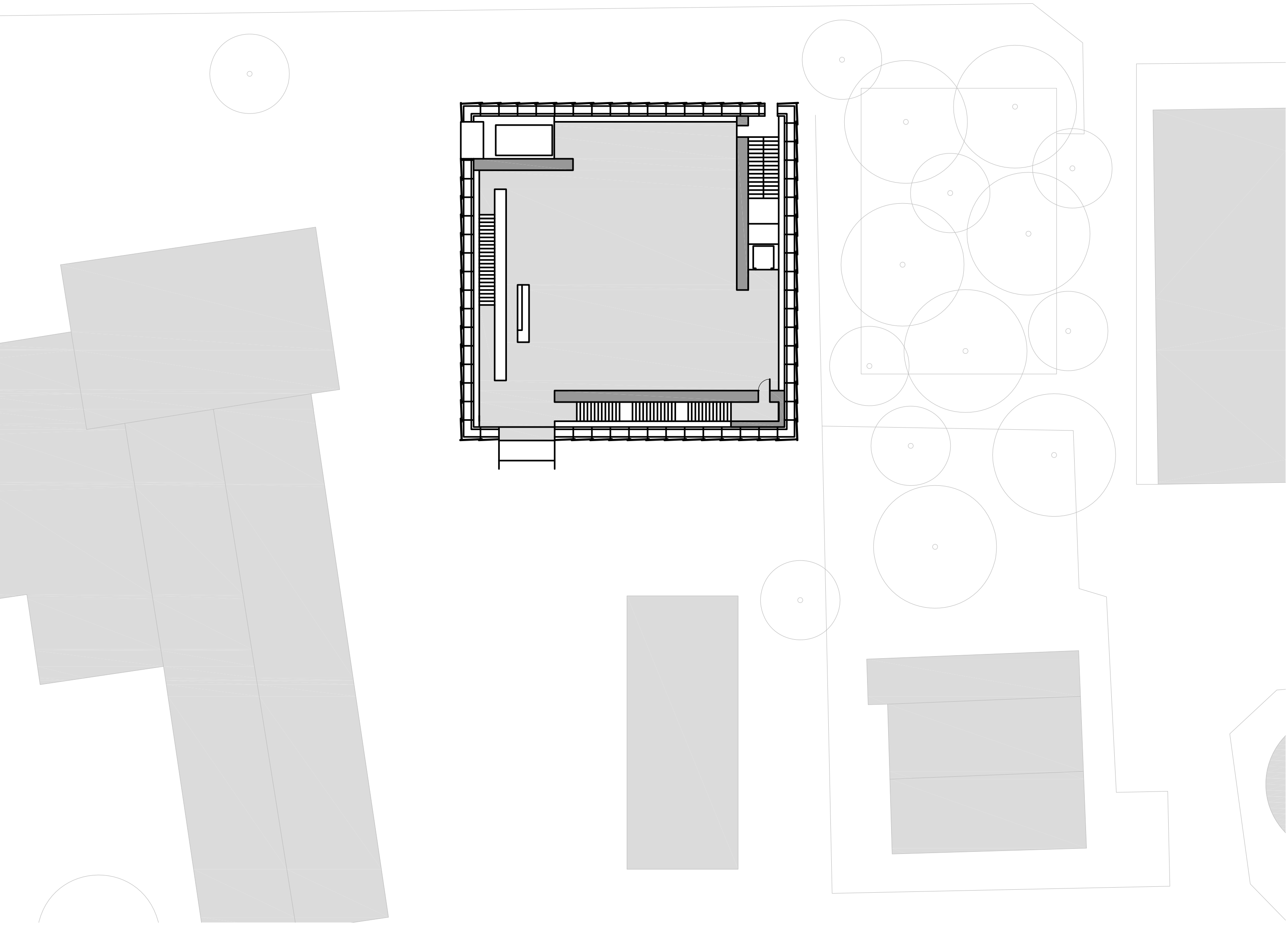
3.74 Isometric pictogram of façade Kunsthaus Bregenz.

Kunsthaus Bregenz - Peter Zumthor

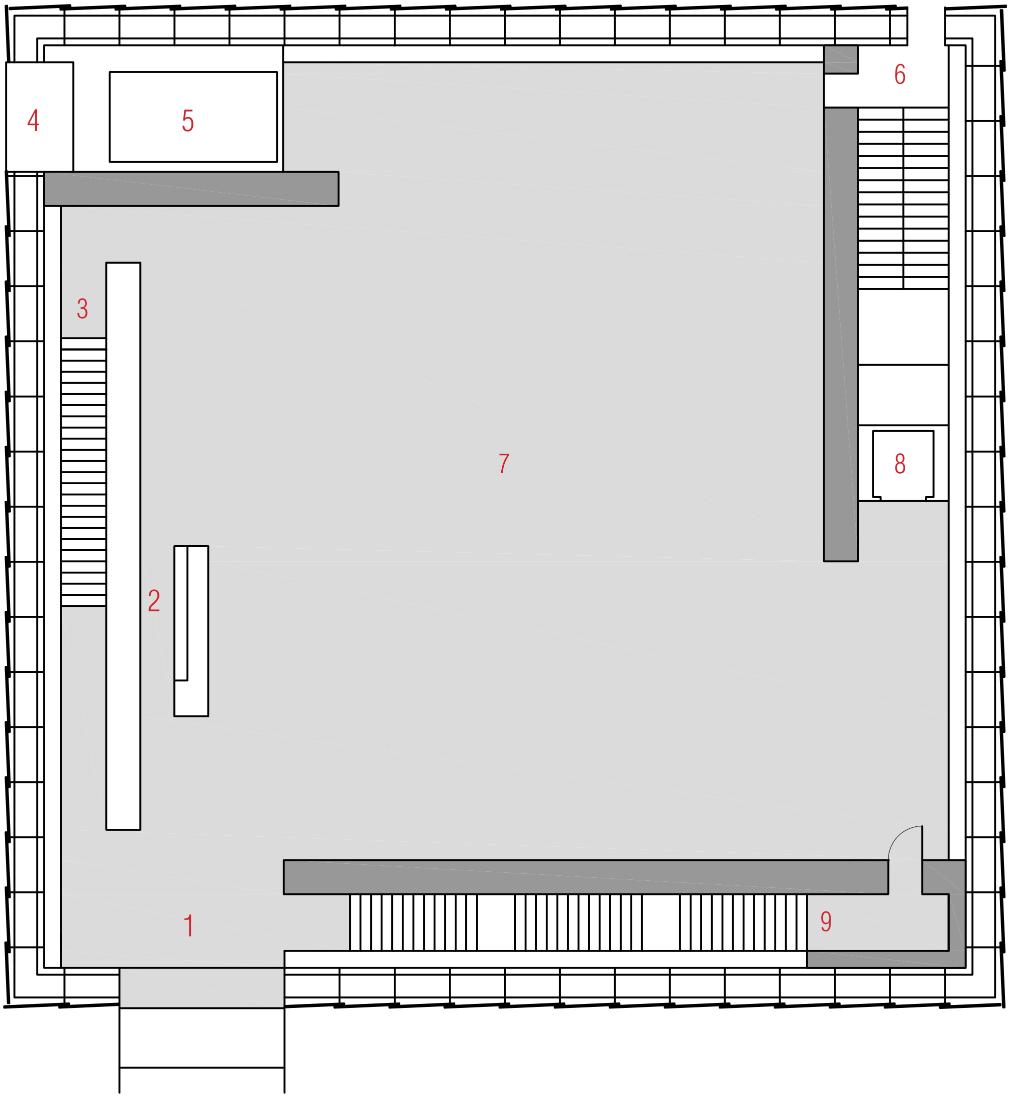
Description Museum
Kunsthaus bregenz is a contemporary art museum on the shores of Lake Constance in Bregenz Austria, it opened in 1997. The competition winning design by Peter Zumthor is a standalone building with only galleries strictly for showing art. The administration, museum store and cafe are organized into an adjacent building on an open urban square. The box volume museum has a glazed translucent façade that distributes the light into the large gallery spaces on each of the five exhibition floors. "*Kunsthaus Bregenz*" cites Peter Zumthor explains; "It absorbs the changing light of the sky, the haze of the lake, it reflects light and colour and gives an intimation of its inner life according to the angle of vision, the daylight and the weather."(56) The routing of the visitor is a circular movement around the structural walls and through the gallery spaces in the building.

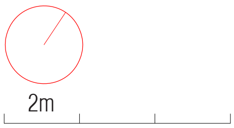
Technical building properties
The construction has three asymmetrical cast concrete walls embracing the gallery space and continuing from two levels below to the third floor roof. The cast concrete walls are made with flat shuttered panels. The free standing façade has a self-supporting stainless steel frame structure with a frosted matte glass shingles cover. This 90 centimetre wide structure behind the façade separates the inner and outer skin. It allows light and air to pass, "achieving the functional goals of limiting direct sunlight and heat gain within the museum, this discreet isolation contributes significantly"(57) explains *Light Construction* (1995). The façade allows light into the plenum, an interstitial space in between the concrete floor above and the translucent matte ceiling of the exhibition space. Incoming light is controlled in this cavity for the best exhibition circumstances. The top floor has a deviant bigger height in relation to the daylight conditions. The electrical, heating and climate control systems are located in the lowest subterranean level. The climate systems is an integrated piping system of 28 kilometres laid in concrete during construction through the walls and floors of the building. The base of te construction is below the groundwater level and heatpumps circulate heat or cold water through the pipes. A gas heater warms up the water in the winter and according to *Light Construction* (1995) "Climbing temperatures in the hot summer months can be kept in check by additionally cooling with incoming air."(58) Cool air is inserted in the spaces from the floor and hot air is extracted in the ceiling.

3.73 Façade of Kunsthaus Bregenz.
from: *Florian Glöcklhofer*

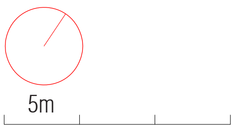


1. Entrance
2. Ticket & information desk
3. Staircase to
   subterranean level
4. Service entrance
5. Freight lift
6. Emergency staircase & exit
7. Exposition space
8. Passenger lift
9. Staircase to
Gallery space



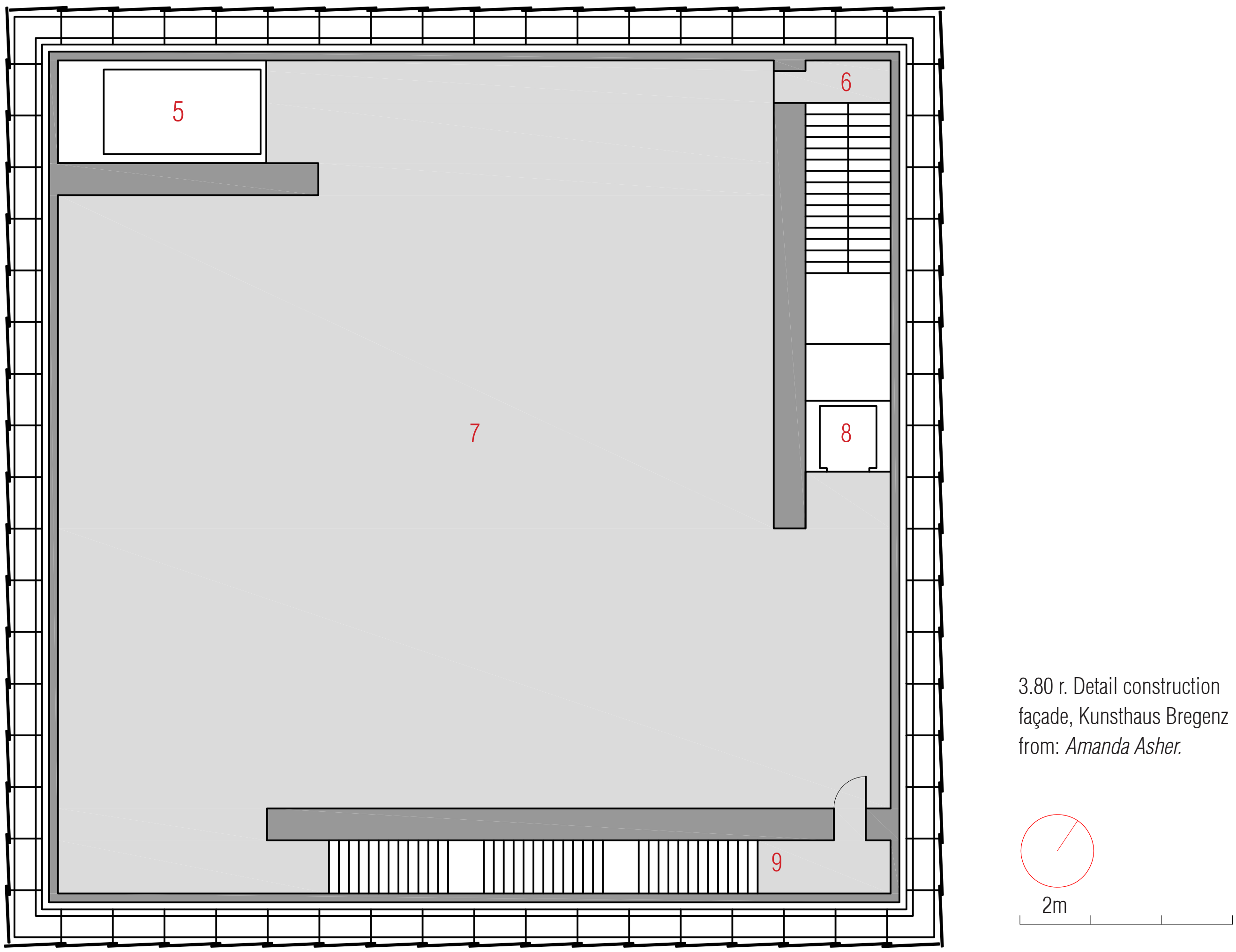


3.76 r. Plan ground floor, entrance level, Kunsthaus Bregenz 1:200



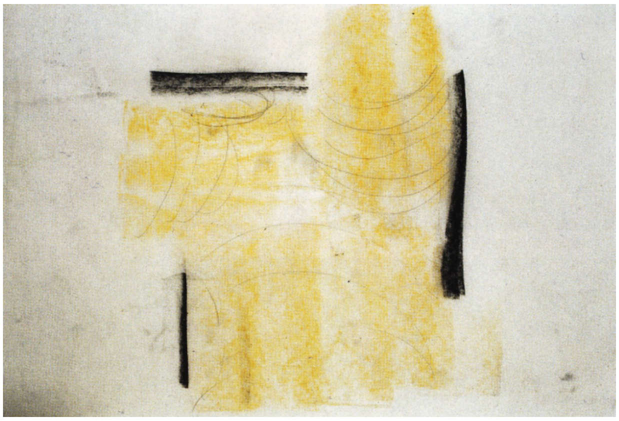
3.75 l. Surroundings with plan ground floor, Kunsthaus Bregenz 1:500

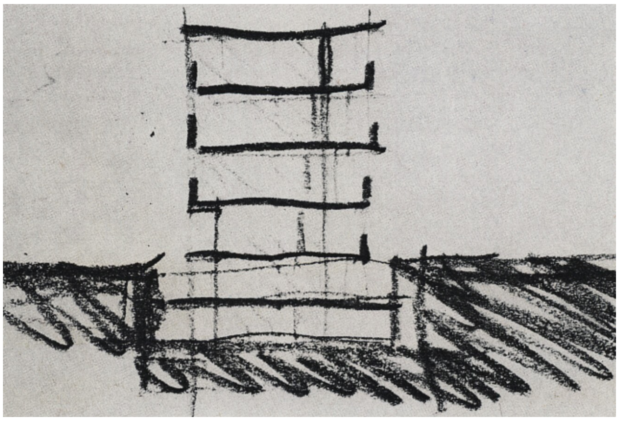
3.78 & 3.79 Hand drawings Peter Zumthor from: *Architecture Sketch Blog*



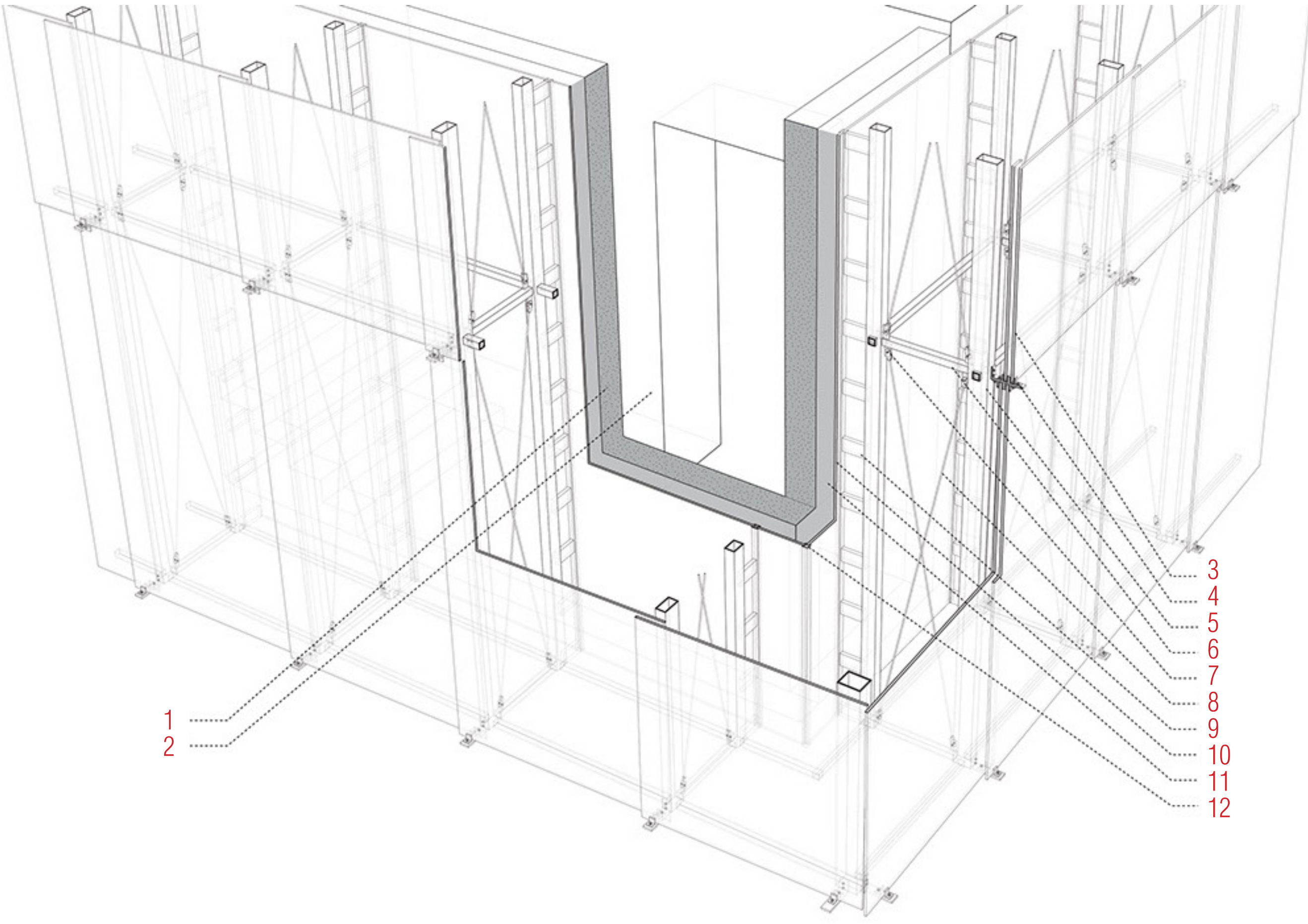
3.80 r. Detail construction façade, Kunsthaus Bregenz from: *Amanda Asher.*

3.77 l. Plan level 1, 2 & 3, gallery level, Kunsthaus Bregenz 1:200





1. Non structural concrete
2. Structural concrete wall
3. Exterior glass panels
4. Costum metal brackets
5. Primary structural frame
6. Structural frame supports
7. Pin joint for x-bracing
8. X-brace
9. Steel connection to curtain wall
10. Curtain wall glass
11. Cavity
12. Mullion



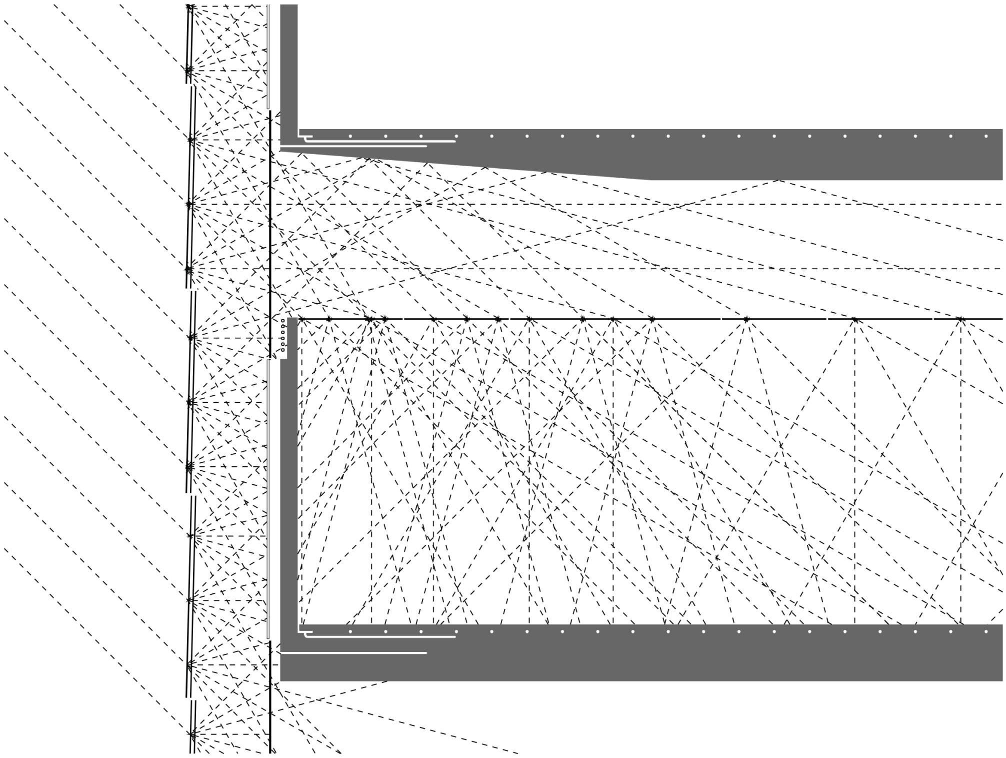
3.82 Model with opened façade to show a section, Kunsthaus Bregenz. from: *Affinita' Elletive*

3.81 Image exhibition space, gallery level, Kunsthaus Bregenz. from: *Kunsthaus Bregenz.*

Light properties on exhibition

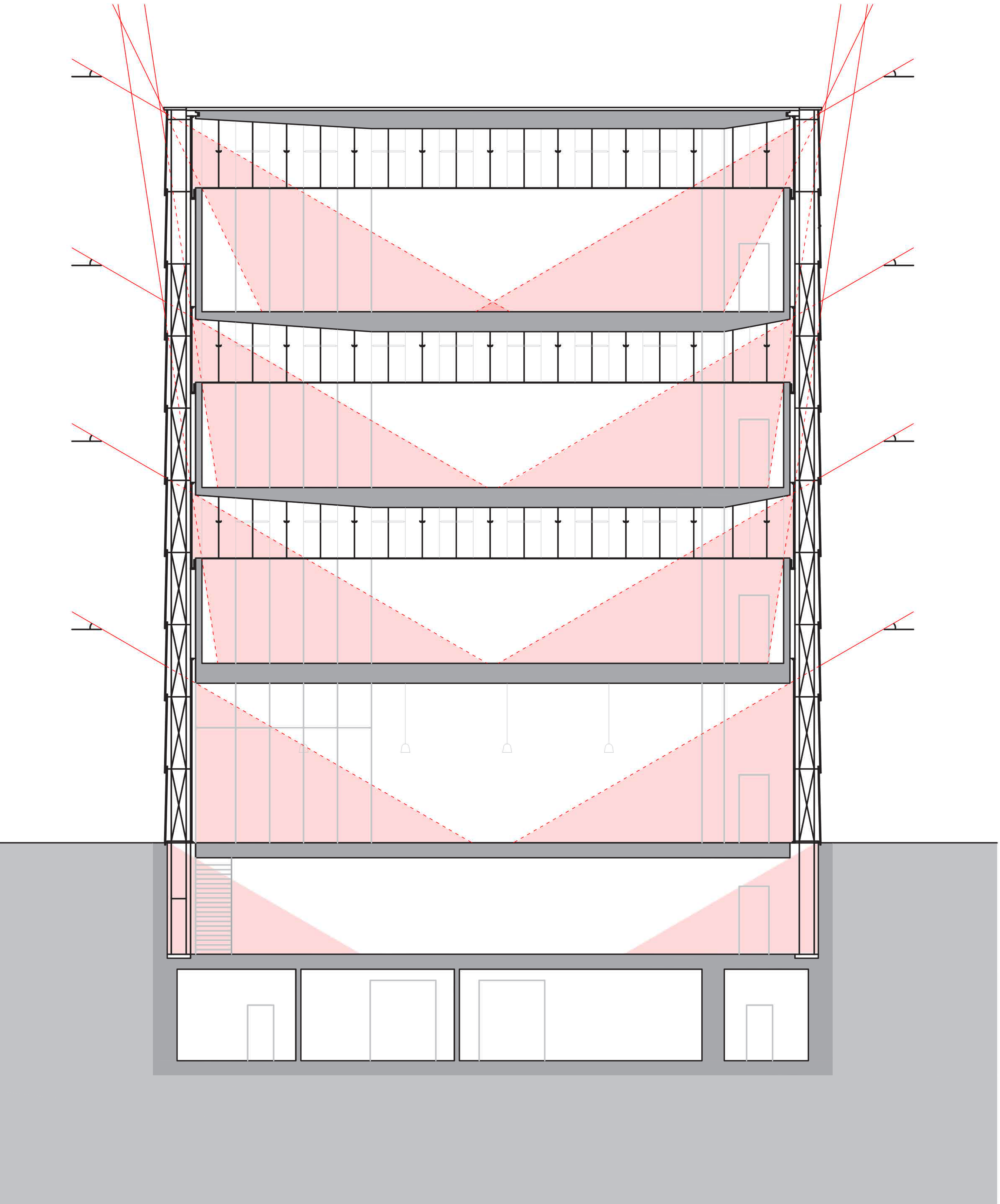
The frosted matt glass building façade distributes diffuse daylight into the building. Three exhibition levels surrounded by concrete walls have a translucent ceiling with an interstitial light space above. The filtered daylight falls through lateral openings inbetween a concrete ceiling and matt square translucent ceiling panels of the exhibition space. The concrete ceiling has light reflecting materials to deflect the daylight and artificial light from lighting fixtures onto a light disseminating ceiling into the exhibition space. The characteristics of changing daylight affects the appearance of the spaces and exhibitions. "The changing times of day are perceptible to visitors, to a lesser extent in the middle of the room, so that their attention is directed to the room boundaries."(59) states *Museum Buildings* (2004). The artificial lighting is controlled with an exterior light sensor on the roof. The pendulum lamps hang in pairs above the translucent ceiling and have 58 Watt fluorescent fittings with diffusing attachements. The lighting complements the daylight and can be dimmed and controlled separately. The terrazzo, grey polished cast concrete, floor finishing reflects diffuse light from the luminous ceiling back into the space. "Although the light has been refracted three times (glass facade, insulating glasswork, illuminated ceilings), it illuminates the halls differently depending on the time of day or year. In this way, a natural lighting atmosphere is created although the building has no visible windows."(60) explains "*Kunsthaus Bregenz*". The ground floor has translucent walls where the light enters the space and the ceiling is an unfinished cast concrete. The space has pendulum lighting fixtures with a downward lighting direction. At night the spaces illuminate artificial light out to the city.

The maximum dimensions of the space in meters are (23.5x23.5x4.2 lwh) and (23.5x23.5x5 lwh) for the upper gallery, transport spaces need to be subtracted from this. The ceiling is translucent and has the same form and dimensions. The light plenum in between the translucent ceiling and the construction above has a gradient (2.4-2.8 h) with lateral daylight openings and artificial lighting. The glass surface of the daylight opening is (50x2.8 wh). The ratios in square meters between plan, ceiling opening and glass surface are; (438.5 : 438.5 : 140). The ration of the height between exhibition space and plenum are (4.2 : 2-2.5) and for the upper gallery (5 : 2.4-2.8).



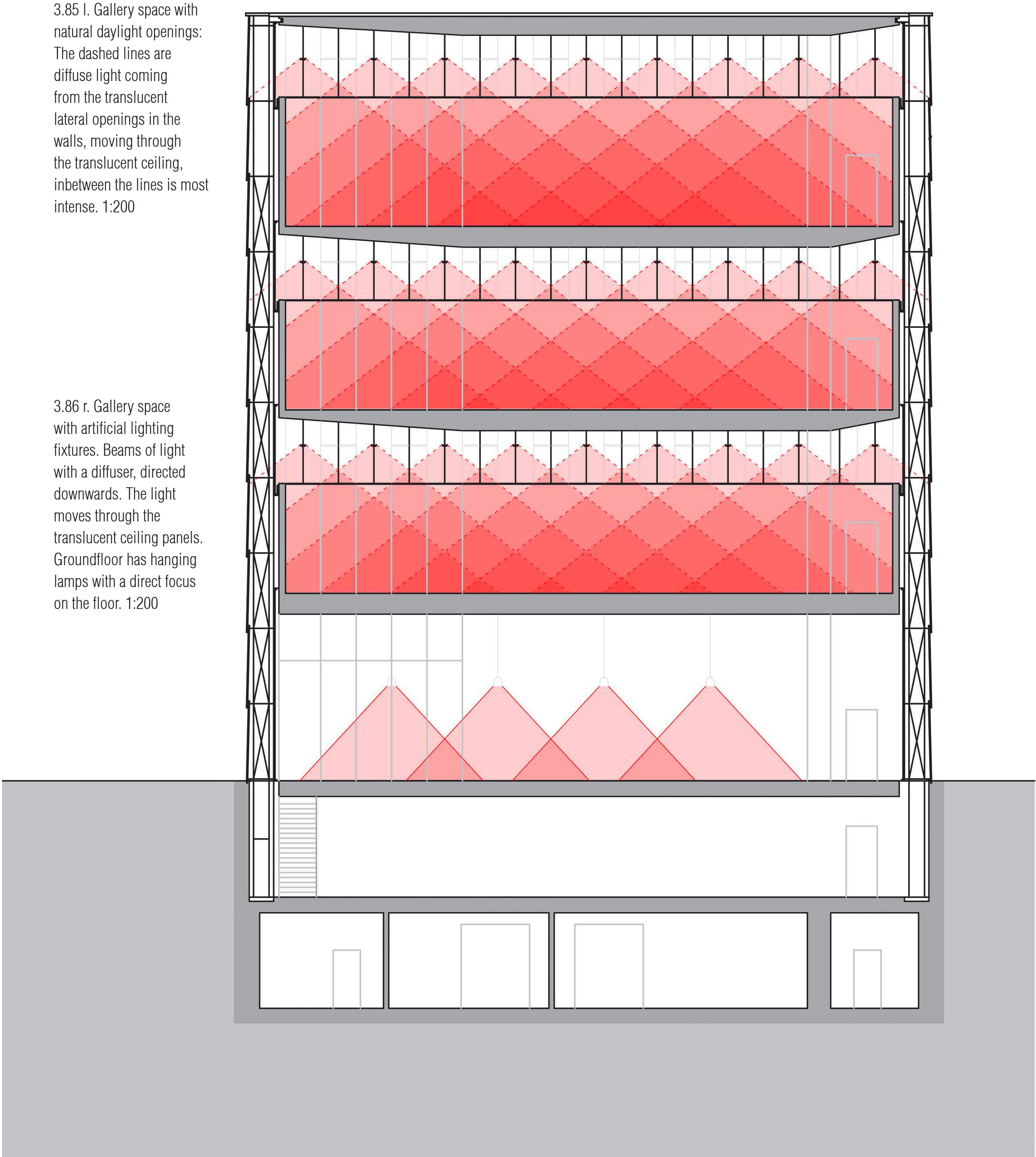
3.83 Detailled section
with scattering of daylight
into the gallery space,
Kunsthaus Bregenz.
from: *Sean Grummer.*

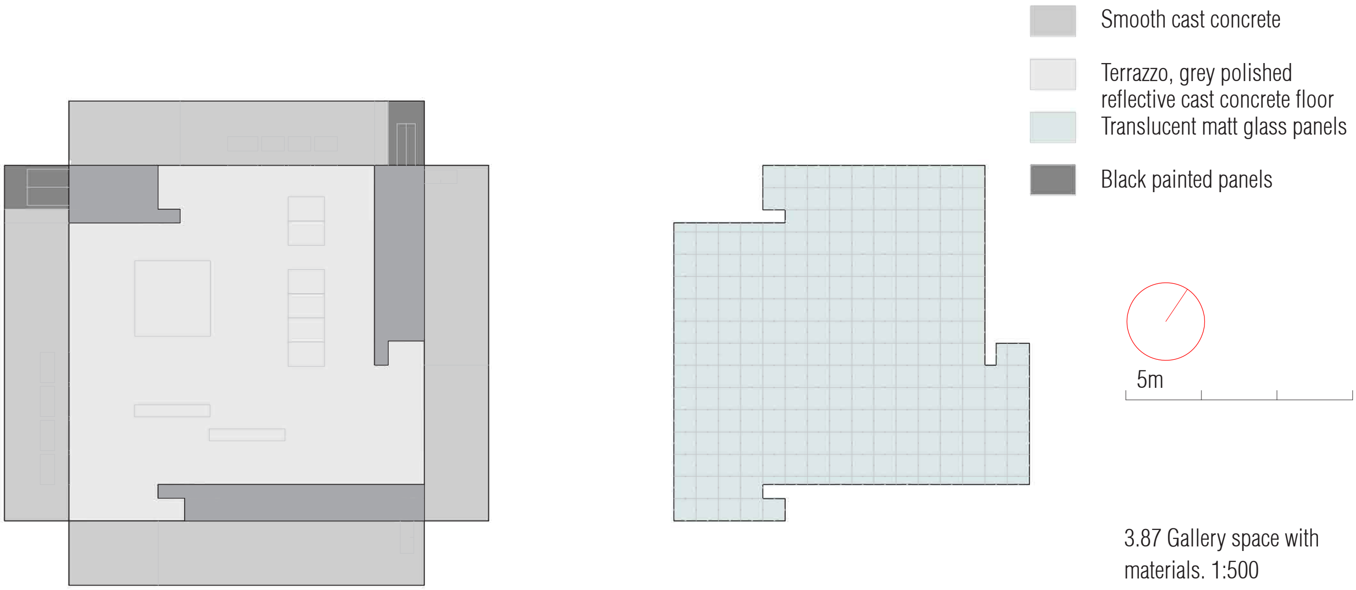
3.84 Image of light plenum
above the gallery space,
Kunsthaus Bregenz.
from: *Sean Grummer.*



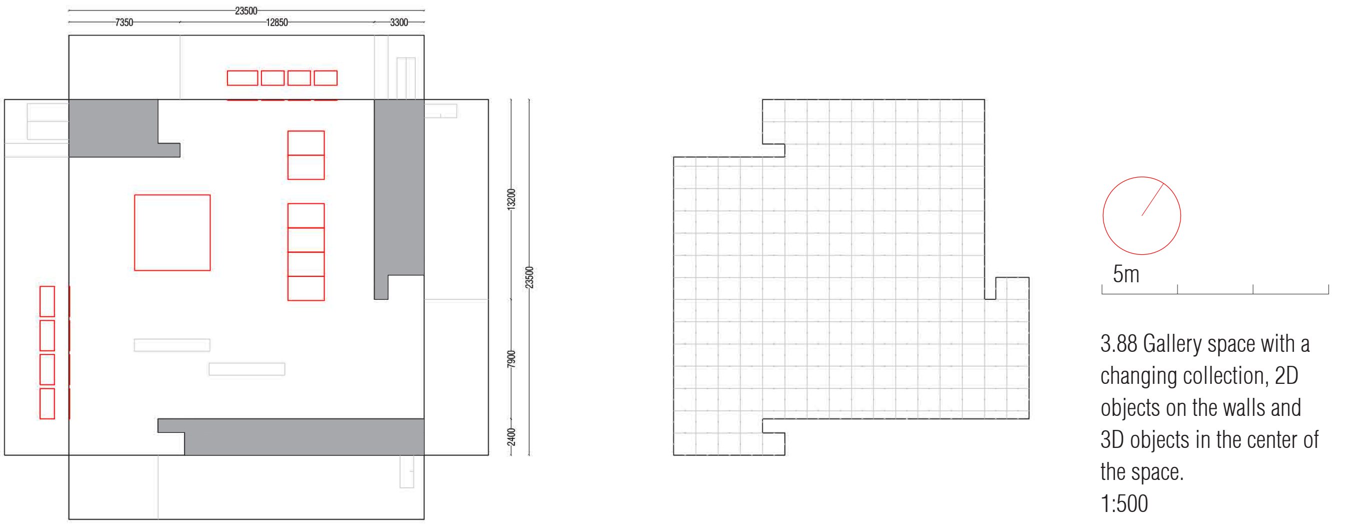
3.85 l. Gallery space with natural daylight openings: The dashed lines are diffuse light coming from the translucent lateral openings in the walls, moving through the translucent ceiling, inbetween the lines is most intense. 1:200

3.86 r. Gallery space with artificial lighting fixtures. Beams of light with a diffuser, directed downwards. The light moves through the translucent ceiling panels. Groundfloor has hanging lamps with a direct focus on the floor. 1:200

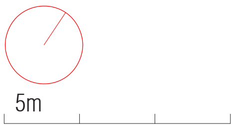




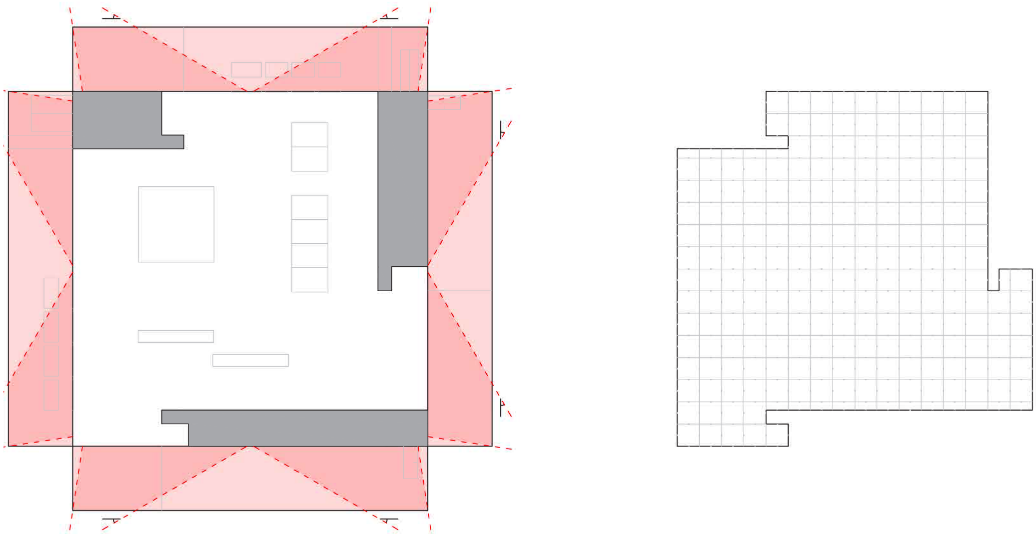
3.87 Gallery space with materials. 1:500

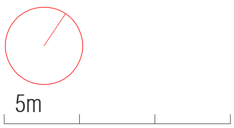


3.88 Gallery space with a changing collection, 2D objects on the walls and 3D objects in the center of the space.
1:500

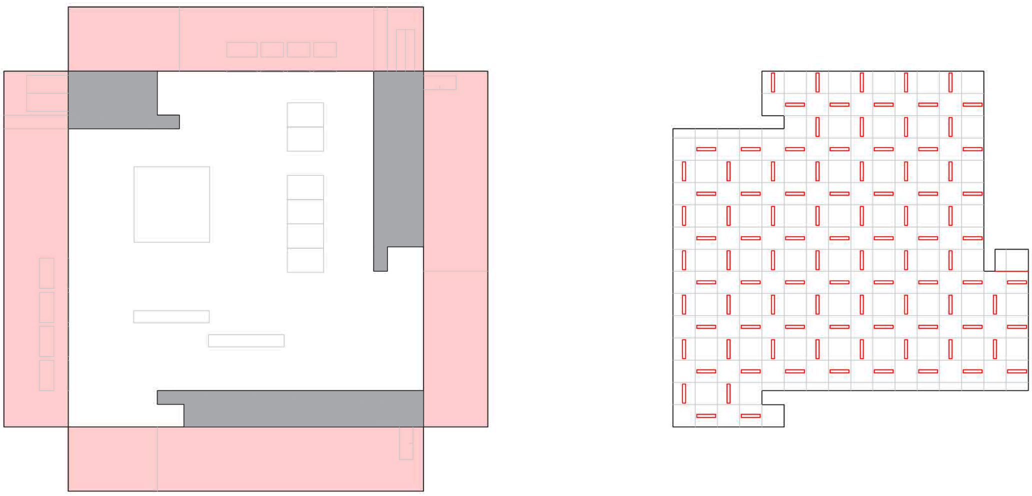


3.89 Gallery space with natural daylight openings: Diffuse daylight is coming from the translucent ceiling. 1:500





3.90 Gallery space with artificial lighting fixtures behind translucent ceiling panels. Beams of light with a diffuser, directed downwards. 1:500



Conclusion

The classification of the daylighting typologies with their properties, characteristics and influence on the exhibition spaces and objects.
Sir John Soane's Museum has a monitor skylight with an additional skylight in the monitor. The gallery space is lit by direct daylight mainly from the northern and western sky. Artificial spotlights are later installed round the perimeter of the monitor to light art on the walls.
Vitra Design Museum has direct daylight from a cross shape element inserted in the vaulted space. Artificial light is integrated in the ceiling with directable spots onto the exhibition objects.
Kimbell Art Museum has a vaulted ceiling with a small daylight slit. The light is reflected and diffused in the space. On either side of the walls of the vault is a slender lunette lateral opening. The natural light is complemented with artificial light, spotlights directed to the exhibition.
Kimbell Piano Pavilion has a glass ceiling with adjustable north opening louvres which can control the light flow of sunlight. The light is diffused by scrims. The wooden roof beams cast a dynamic shifting pattern of shadow upon the walls and enhance the characteristics of natural light. The transparency of the lateral curtain walls allow direct daylight to enter the space. Artificial LED lighting complements the natural daylight. The spotlights are mounted under the wooden beams and direct towards the objects.
De Young Museum has a monitor skylight, a plenum and another skylight above. The light is uniformly distributed and diffuse light enters the space. The artificial spotlights focus direct light on the objects.
Kunsthaus Bregenz has a combination of lateral daylight openings, a monitor skylight and a daylight diffusing ceiling. Daylight enters a plenum through lateral openings with two layers of translucent glass. The ceiling deflects daylight and artificial light from lighting fixtures through translucent panels into the exhibition space. The characteristics of changing daylight affects the appearance of the spaces and exhibitions.
The museums designs have ingenious typologies of skylights with the characteristics of preventing direct daylight from entering the exhibition space and lowering the illuminance. Most of the casestudies have a diffuse lighting with complementary direct artificial lighting.

next page:
3.91 Characteristics, properties, lighting typology museum gallery spaces.

	Materials	type of art 2D, 3D	Daylighting typology	Lighting surface
Sir John Soane's Museum	Plaster walls, wood cabinets and shutters, wood floor	Bronzes, bustes, paintings, etc 2D & 3D	Monitor skylight with skylight	Floor and wall surface
Vitra Design Museum	Plaster walls, plaster ceiling wood floor	Changing collection 2D & 3D	Skylight tube	Floor surface
Kimbell Art Museum	Marble walls, concrete ceiling, wood floor	Changing exhibitions from collection 2D & 3D	Long indirect skylight with reflection	Ceiling and floor surface
Piano Pavillion	Concrete walls, translucent scrims and wood ceiling, wood floor	Changing collection 2D & 3D	Restricted daylight diffusing ceiling. louvres, scrims.	Floor and wall surface
de Young Museum	Plaster walls, wood ceiling, wood floor	Changing collection 2D & 3D	Monitor skylight with skylight. diffuse screen.	Floor and lower wall surface
Kunsthaus Bregenz	Concrete walls, translucent ceiling concrete floor	Changing exhibitions 2D & 3D	Lateral daylight openings, monitor skylight and daylight diffusing ceiling. diffuse glass.	Floor and wall surface

Daylight direct/diffuse	Artificial Light type	surface area gallery	surface area glass	ratio glass surface to gallery surface	
Direct & diffuse	Spots	11.2 m2	14.7	1.3	Sir John Soane's Museum
Direct	Spots	152 m2	61.5	0.4	Vitra Design Museum
Direct & diffuse	Spots	219 m2	23	0.1	Kimbell Art Museum
Direct & diffuse	Spots	580 m2	590	1.0	Piano Pavillion
Direct & diffuse	Spots	169m2	53.1	0.3	de Young Museum
Diffuse	beams, diffuse	438.5m2	140	0.3	Kunsthaus Bregenz

Design

Design of an Architectural Model Museum Gallery Space

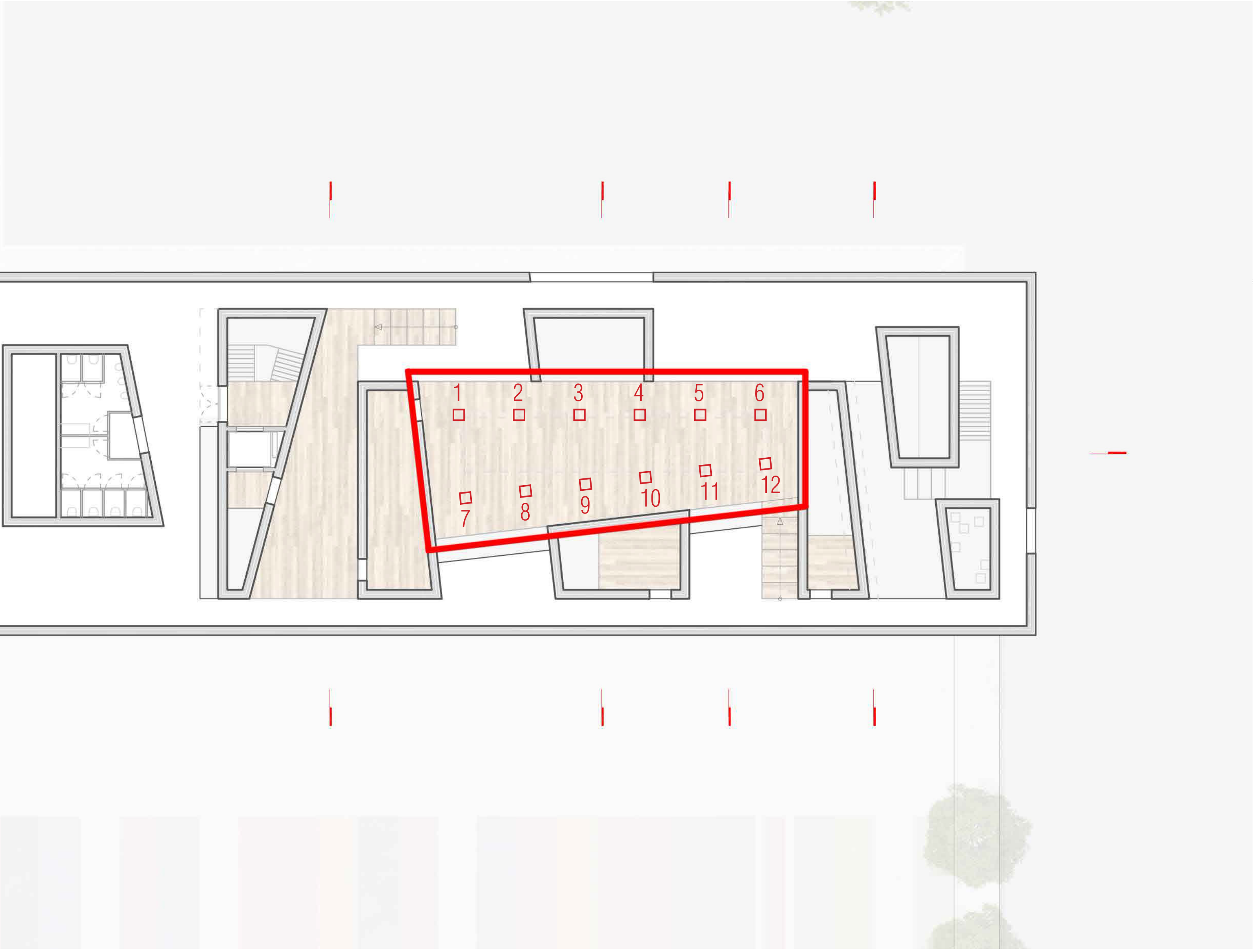
Attitude

The constraints for the design of the gallery space skylight have been studied in the previous chapters; 1. Characteristics of light in museum spaces, 2. Characteristics of light on collections and 3. Museum light design in practice.
The first chapter explaines the characteristics of light in museum spaces. The conditions for an exhibition space are established. The characteristics of natural daylight depend on the balance between the visitor, museum space, museum objects, weather and the sun. The characteristics of artificial light are more stable, reliable and controllable than daylight. The design has to control the intensity, distribution, colour and direction of daylight and artificial light. There is a major role for daylight in a museum design, with many different combinations of daylight and artificial light mentioned under “Typology daylight” and “Typology artificial light” in *chapter 1* to design a space.
The second chapter explains the characteristics of light on collections. The conditions of light on the model collection are established. The characteristics of light on the model are dependent responsiveness, illumination and presentation of the model collection. The design has to control the;
- Responsiveness which depends on the intensity, time and material.
- Illumination which depends on visual acuity, glare, direction, layering and lighting type.
- Presentation which depends on ethics, colour, object and background.

The light is investigated on the basis of the casestudies of chapter three. The research of the examples of renowned architects will be used for the experiment.

From research towards a gallery skylight design for the Architectural Model Museum.
The constraints for the design of the space are based on the boundary conditions of the Architectural design of the Architectural Model Museum. The constraints are also to a great extent determined by the theory from the literature research. The positioning of the collection in the gallery space is based on the concept of the museum casestudies and literature research and will be explained below.

1. Bye House / Wall house
2. Kubuswoningen Helmond
3. Kunsthal Rotterdam
4. House X
5. Museum aan de Stroom(MAS)
6. Concertbuilding Brugge
7. Extension Victoria and Albert Museum
8. Porosity to Fusion
9. Dutch pavilion world exhibition Osaka
10. Rietveld Schröderhuis
11. Central Station Arnhem
12. Starhouse One



Constraints

Characteristics Architectural design
The space that will be optimized is the central space on the upper floor in the the Architectural model Museum design. This large space is best suited for experiments. The long side of the space has a south-southeast orientation just like the orientation of the museum. The gallery space has a tapered form with a length of approximately 21 meters and sides with lengths of 6.4 and 8.7 meters with a floor surface of 155,3 m^2. The minimum height of the space is 3.8 meters and optionally higher depending on the ceiling aperture design. The space is bounded by concrete core volumes, voids connected to the groundfloor and a circulation area in the main upper volume of the museum.
The materials of the museum gallery are a light hard wooden floor, white plaster ceiling, smooth finished light grey concrete walls and internal glass curtain walls.
The space has constraints derived from the architectural design. The solution should not exceed the building envelope. The building façade has a lateral daylight opening with dimensions of 7,3 x 3 meters and a south-southeast orientation. In the winter season when the height of the sun is lower than 25° degrees, the direct light can reach into the gallery space or is blocked by the sunshading. The summer sun has a higher position in the sky and will not have a direct illumination in the gallery space through this lateral daylight opening. There are no other openings in the façade that can cast direct light into the gallery space. The illumination of the gallery space will be primarily influenced by the skylight openings where daylight is the primary source of light. Daylight transmission and artificial light can be adjusted to change the mix of daylight and artificial light within the gallery. Artificial light design of the adjacent spaces and circulation area is submissive to the main gallery space. The gallery space has to be optimized for the impact and effect on the exhibition.

Characteristics Models
The models exhibited in the gallery space are three-dimensional objects representing building designs. The exhibition collection of Piet Sanders has a diversity in appearance with mainly sculptural and experimental concept models. The models have different sizes, materials, textures, colours and a varying scale from 1:20 to 1:100. This is a level of detail and precision the visitor can relate with from close distance. This type of architectural model is interpreted from eye level where the visitor can imagine a real life building. The models are individual objects originated from experimental research.
The central position in the museum fits to the progressive idea of the models and the

4.1 Plan First Floor, Central gallery space with positioning of Models. 1:333

lighting must respond to this. All of the 12 models displayed in the museum gallery are bundled in *Modelling the Model book C*.

Positioning Models
The Architectural design starting point is the viewing experience of the Models, exhibited in many different ways and forms. Models are experienced differently in varying directions to get the best impressions and understanding of the concept. For this reason the museum design facilitates these sight lines all through the building. The casestudies present the three dimensional objects with a distance from the outlines of the exhibition spaces. The objects positioned around the centre of the space and sometimes grouped. Like the concept of the building, the visitor can move freely around the models. The models will be positioned on a frame in line with the grid and directions of the building and gallery space. The height of the models will be presented in such a way that the visitor can experience a realistic view of the building design, this will be approximately 1.10 to 1.40 meters as compared with the objects of the casestudies.

1. Bye House / Wall house, John Hejduk
2. Kubuswoningen Helmond, Piet Blom
3. Kunsthal Rotterdam, Rem Koolhaas
4. House X, Peter Eisenman
5. Museum aan de Stroom(MAS), Neutelings Riedijk Architecten
6. Concertbuilding Brugge, Neutelings Riedijk Architecten
7. Extension Victoria and Albert Museum, Daniel Libeskind
8. Porosity to Fusion, Steven Holl
9. Dutch pavilion world exhibition Osaka, Carlos Weeber
10. Rietveld Schröderhuis, Gerrit Rietveld
11. Central Station Arnhem, Ben van Berkel
12. Starhouse One, Lebbeus Woods

Constraints illumination gallery space
The constraints of light in the museum gallery space is based on the conclusions of the literature research and architectural design;
- The form, dimensions, openings and materials of the gallery space are derived from the architectural design. The skylight is the objective of the design solution.
- Provide a condition where natural daylight is the primary source of light for the display of art. This is dependent on the balance of many variables.
- The average illuminance in existing exhibition rooms ranges from 150 to 250 lux.
- The ability to adjust and control daylight transmission and reduce daylight levels, exclude heatgain, glare and ultraviolet light within the gallery to allow the display of sensitive objects.
- The ability to change and layer daylight and

artificial light within the gallery for an even and constant illumination.
- Reduce daylight into the galleries to a minimum when the museum is closed.

Constraints illumination Models

The constraints of the light on the collection is based on the conclusions of the literature research, architectural design and loan terms of “Het Nieuwe Instituut”;
- The loan terms and conditions of models of HNI (Het Nieuwe Instituut)(61) require a maximum exposure of 50 lux. Daylight illumination levels have to be reduced to 50 lux within the gallery space to allow the display of sensitive objects and maintain the model conditions.
- Direct daylight should be prevented because it has uncontrollable characteristics.
- The presentation and illumination of the exhibition model requires a layering of light, an individual illumination to show the charateristics of the model. The visitor needs more light to detect finer detail. A distinction between object ground and figure to improve three dimensional object appearance. The appearance and balance of three dimensional form, texture colour and detail of the surface are revealed with the reflection of specular and diffuse light.
- For presentation, a correlated colour temperature (CCT) is recommended for a natural appearance of the model.
- For preservation, the light in the gallery is reduced outside opening hours to protect the exhibition from a combination of thermodynamic and photochemical processes that result in a faster degeneration of the models.

Building Technical constraints

The constraints based on the architectural design, literature research, casestudies and loan terms of “Het Nieuwe Instituut” have implications on the building technical development. The Building technical consequences of the design constraints will be appointed below;
- A ceiling which can distribute a diffuse and even illumination
- Controllable system for the lowering of light illumination levels
- Height of the construction to prevent cast shadows and height of the plenum for an even distribution of light.
- Maintenance of the integrated systems.
- Thermal performance of the skylight to establish a constant climatic value in the gallery space.
- Costs of the building solutions
- The makeability and practicality of the design
- Protection of the collection for Ultraviolet light.

Hypothesis

Design Strategy
The design strategy for the gallery skylight design of the Architectural Model Museum will be an investigation on the effect of the casestudies implemented in a model of the gallery space. This will result in conclusions for my own optimized design of a skylight for the gallery space.

Expectations
The models of the casestudies can give an insight in the possibilities of the space, the influence on the exhibition and the contribution in search for design of the Architectural Model Museum space. By testing many skylight options of renown museum designs I hope to find a solution that fits my design and is consistent with the design constraints. The measured values can give an understanding of the light incidence on the exhibition models and gallery space. The images can give understanding of the light distribution off the walls and ceiling surface. The analysis of the models from the casestudies should lead to an understanding of the influence for the gallery space. The architectural design, the technical implementation and lighting design are all of equal importance. The casestudies are a method for finding an optimized solution for the gallery space. This can be one of the casestudy options or a hybrid and combination of multiple solutions which correspond to the constraints of the Architectural design, literature research and loan terms of “Het Nieuwe Instituut”. The conclusions of the results will be transferred into an optimized solution of the skylight with an aesthetic, Building Technical design and balanced lighting design. The presentation of the models is leading in the design.

The standard is:
- the experience of the model
- the conditions of preservation of the model
- the experience of the space
- the models as main feature in the space

Process

Casestudies
The understanding and research of the casestudies is presented in the analysis of chapter 3. The results from this research will be tested and implemented in the scale model of the Architectural Model Museum. The casestudies do not directly translate and require design decisions. Therefore an adjustment of the solutions is needed. The types of lighting and implementation in the museums have to be converted to the gallery space of the Architectural Model Museum.
The "Sir John Soane's Museum" has many different types of skylight. The museum design has lateral side windows, monitor skylights, domes with central skylights plus skylights in different forms, sizes and colours.
"Vitra Design Museum" has corner lighting with different directions, the main skylight has a tube inside the space where direct daylight is reflected into the gallery.
"Kimbell Art Museum" has a lighting system where a light strip with an aluminium element reflects the light onto a concrete ceiling. This light is diffused into the vault and complemented with spotlights.
"Kimbell Art Museum, Piano Pavillion" has a system with a transparent ceiling, sunshading installation, diffusing fabric and spotlights
The "De Young Museum" has an internal translucent monitor skylight with rectangular skylights above.
"Kunsthaus Bregenz" has a diffusing ceiling, illuminated with a combination of daylight and artificial light. The daylight has lateral openings around the plenum.

Design decisions for casestudy models
The lighting type of the casestudies is analysed and the main idea and effect on the space and collection is clear. The same effect on the three dimensional objects is desired in the Architectural Model Museum. Considerations are the different location of the museums and form of the spaces. This integration requires modifications;
- The light concept of variant 3. the "Sir John Soane's Museum": The Picture room is a square space with an attached recess. This in contrast to the Gallery in the Model Museum which has an elongated shape. The recess is showcasing architectural models, this similarity and orientation is advantageous for the integration in the Architectural Model Museum. The small spaces have to be scaled to a large gallery.
- Variant 4. the Vitra Design Museum has a vault shape roof with different dimensions. The walls are rotated to align the tapered form of the gallery space.
- Variant 5. The orientation of the vault of the Kimbell Art Museum is inconsistent with the orientation of the Architectural Model Museum. The vault is rotated and scaled on

one side to follow the tapered form.
- Variant 6. The Kimbell Art Museum - Piano Pavillion has constructive beam elements part of the roof structured this is in contrast with the open Architectural Model Museum gallery space.
- Variant 7. De Young Museum: The monitor skylight and space has different dimensions. This is scaled to correspond to the characteristics.
- Variant 8. Kunsthaus Bregenz: The ratio between the plenum and the height of the space has an effect on the daylight in space. The plenum is scaled in proportion with the gallery.

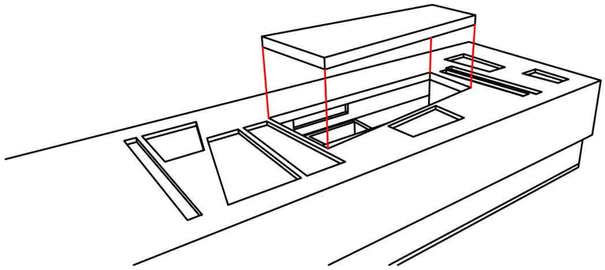
Experiment

The scale models of the casestudies will be placed on a scale 1:20 model of the museum gallery space (figure 4.2). During the experiment the casestudies will be placed in different conditions to analyse the light characteristics of the space. (figure 4.3-4.18)

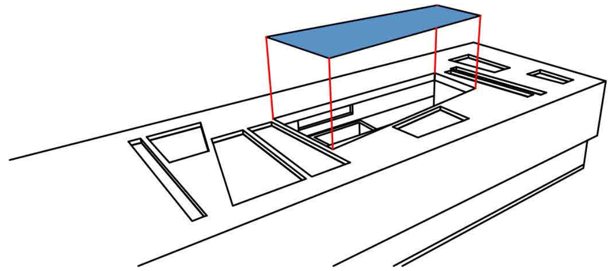
Design

The conclusions from the experiment will be the starting point for the light design of the museum gallery space. This design will be validated to analyse if it meets the requirements resulting from the architectural design and the constraints from literature research, casestudies and loan terms of HNI.

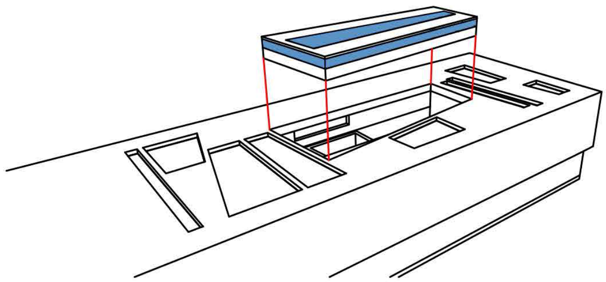
4.2 Variants of casestudies placed on a 1:20 scale model of the gallery space.



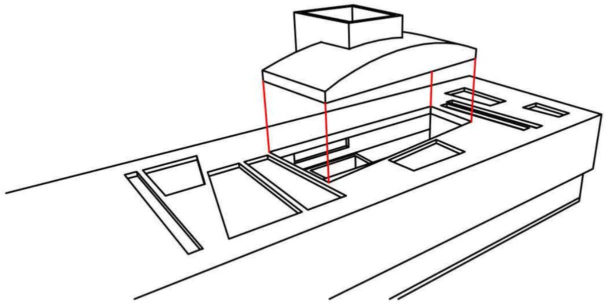
Variant 1. Closed ceiling opening



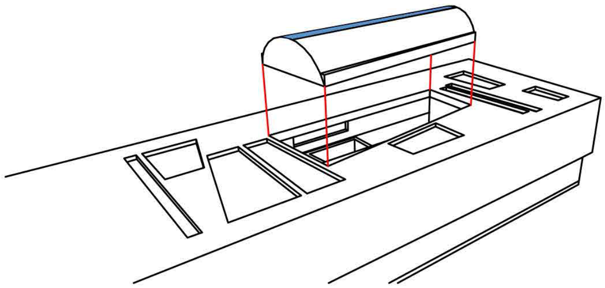
Variant 2. Open ceiling opening



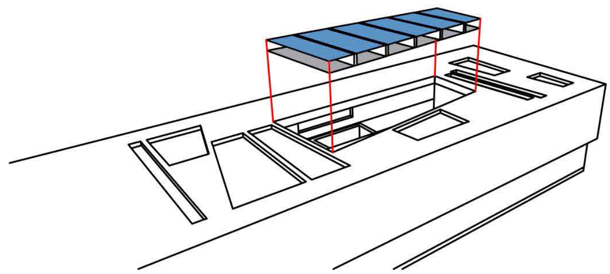
Variant 3. Sir John Soane's Museum interpretation



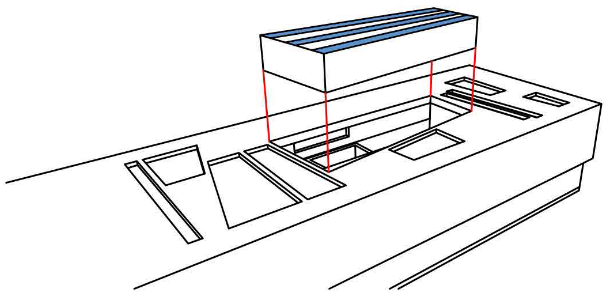
Variant 4. Vitra Design Museum interpretation



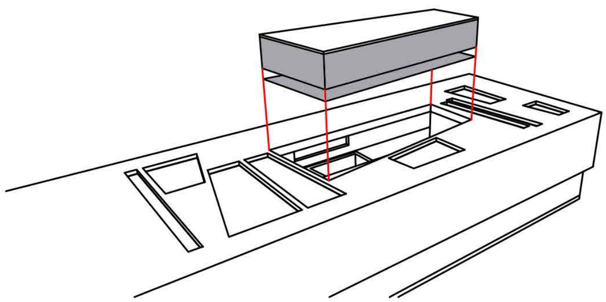
Variant 5. Kimbell Art Museum interpretation



Variant 6. Kimbell Art, Piano Pavilion interpretation



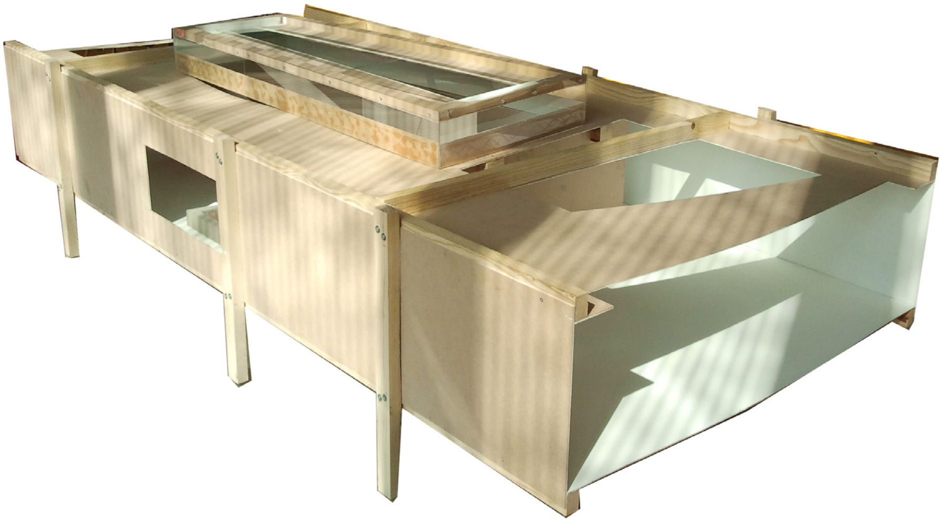
Variant 7. de Young Museum interpretation



Variant 8. Kunsthaus Bregenz interpretation

4.3 - 4.4 Variant 1. Closed ceiling opening model.

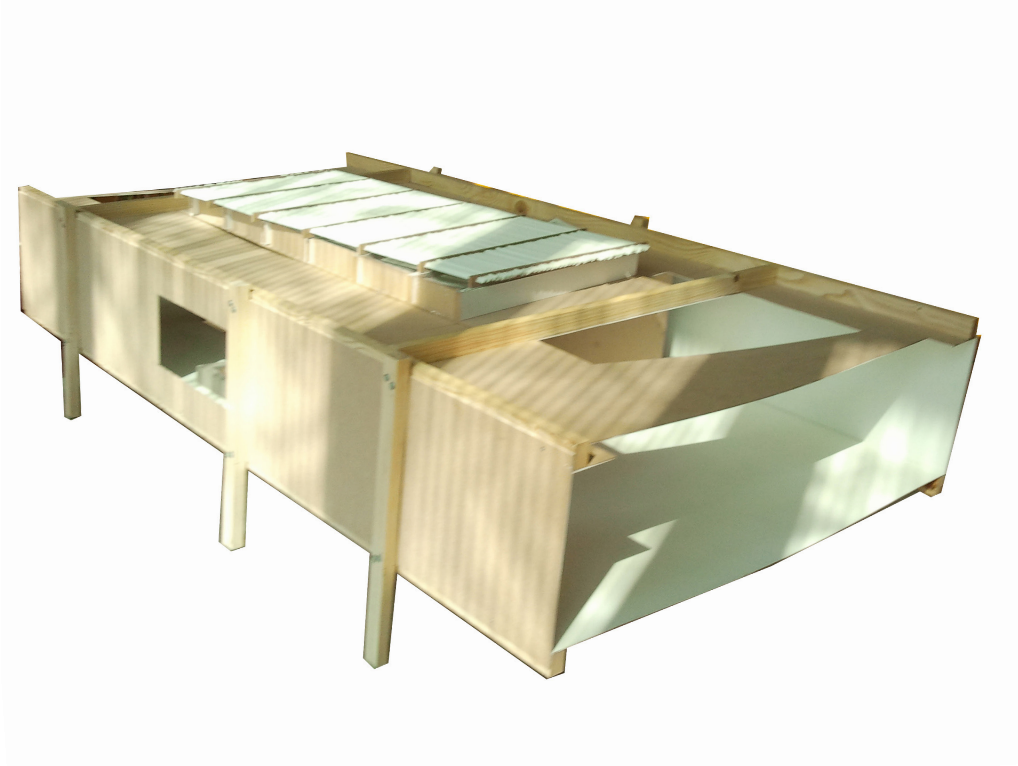
4.5 - 4.6 Variant 2. Open ceiling opening model.



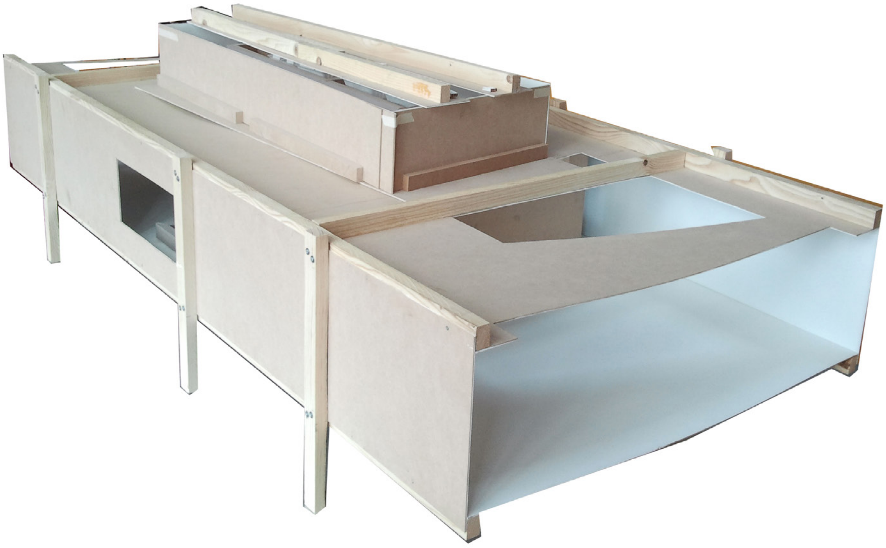
4.7 - 4.8 Variant 3. Sir John Soane's Museum model.

4.9 - 4.10 Variant 4. Vitra
Design Museum model.

4.11 - 4.12 Variant 5.
Kimbell Art Museum
model.



4.13 - 4.14 Variant 6.
Kimbell Art, Piano Pavilion
model.



4.15 - 4.16 Variant 7. de Young Museum model.

4.17 - 4.18 Variant 8.
Kunsthaus Bregenz model.

Method

Materials
The materials used for the experiment setup:
- Scale 1:20 model of the gallery space 2100x1000mm.
- 6 casestudy options, closed ceiling and open ceiling. for daylighting. 1200x600mm.
- Led lighting strips, integrated in model.

measuring instruments:
- 2 Light intensity sensors
- 2 Colour temperature sensors
- Canon photo camera with fisheye lens connected to analysing software.

Location:
- Outside conditions Netherlands, Eindhoven, TU/e, Vertigo parking area.
- TU/e daylight simulator room facility
- Dark space

Experiment model setup
The model setup is a 1:20 scale model with 6 skylight options from the casestudies, 1 closed roof and 1 open roof. The options can be placed on top of the model and have integrated LED lighting. There will be five experiments; Outside in open air with three conditions(setup 1), in the TU/e daylight room facility (setup 2) and in a dark space (setup 3).

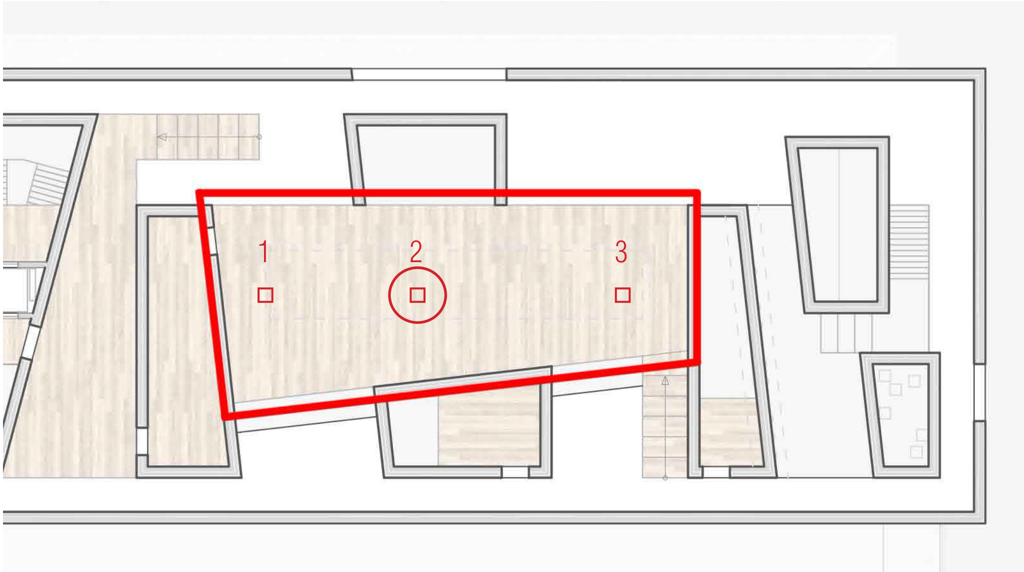
- Setup 1. The model will be placed outside in daylight with the design orientation (figure 4.20). Values will be measured during different skies. Sunny sky at 11.00am, 13.00pm and overcast sky.
- Setup 2. The model will be placed in the TU/e daylight simulator room with a consistent light intensity and evenly distributed illumination (figure 4.21).
- Setup 3. The model will be placed in a dark space. Values of the LED lighting will be measured (figure 4.22).

Experiment sensor setup
The light intensity(lux) and colour temperature (Kelvin) will be measured with 3 sensor positions on the floor of the gallery space and 1 sensor outside the space for the different casestudy options (figure 4.19).

The light intensity will be analysed with a photo camera and analysing software to show the luminous intensity values in cd/m^2 off the surfaces in an image. The light intensity will be measured from a recessed hole in the floor of the gallery, analysing the walls and ceiling of the model (figure 4.19). The software will automate the camera and take a series of pictures with variable shutter speed. The software can calculate the luminous intensity and will give a result of this in an image.

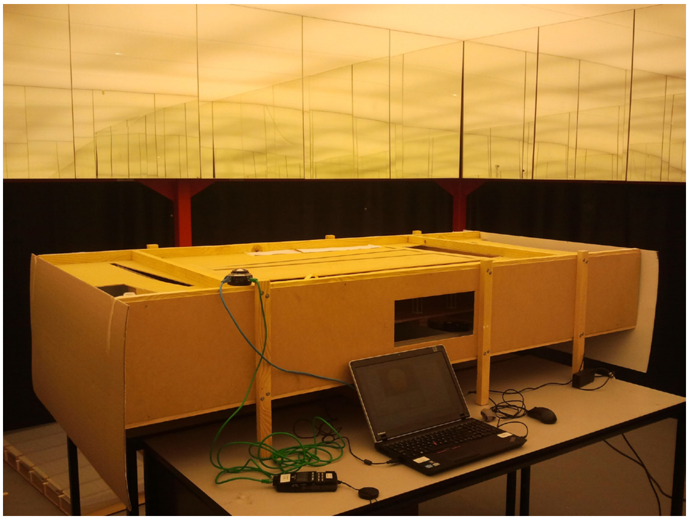
variables of the experiment
- Licht intensity depending on the climatic conditions, this can change any moment in the outside setup.
- Colour temperature is dependent on the climatic conditions, this can change any moment in the outside setup.
- The 8 different variants of 6 casestudies, closed ceiling and open ceiling.

Expectation of results
1. Values luminous exitance in lux on 3 positions for the 7 casestudies with different conditions.
2. Values colour temperature in Kelvin on 3 positions for the 7 casestudies with different conditions.
3. Fisheye images of the gallery space with luminous intensity values in cd/m² off the surfaces for the different conditions.



4.19 Experiment setup, scale model sensors positions 1,2,3 and recessed camera in floor 2.

4.20 Experiment setup, 1:20 scale model outside conditions.



4.21 Experiment setup, 1:20 scale model in daylight simulator.

4.22 Experiment setup, 1:20 scale model in dark space.

Results

The illuminance light intensity in lux and colour temperature in Kelvin for the various options is displayed in *Attachment B, tables 1-4*. The images following in *Attachment B* are and analysis of the fisheye lens images with measurements of luminance levels. This is displayed in a colour index from 0 to 4000 cd/m². The setup is measured in different conditions; direct sunlight 11.00am, 13.00pm, clouded overcast sky, daylight simulator and dark space.

Discussion

- The outside measurements are influenced by illuminance fluctuations and depend on weather conditions. There is sought to compare outside illumination values as close as possible to each other, exact comparisons are almost impossible.
- The first results of the experiment revealed that the influence of the LED lighting was minimal. The effect of the LED lighting in the gallery space is measured in a dark space. These results are added to the research.
- The orientation of the sun influences the creation of shadow surfaces. This changes during the day and can create peak moments of illumination on the gallery surface.
- The colour temperature depends on the materials in the space and properties of the glass. The materials used for the models are are approximate.
- The daylight studio has artificial light and therefore the colour temperature cannot be used for conclusions for a simulation of the daylight sky.
- The fish eye lens with analyzing software is calibrated and tuned to human visibility, values above 4000 cd/ m² may be higher.

Analysis

The results of the experiment are analysed with the tables, images and graphs to show the illuminance, colour temperature and luminance levels in *Attachment B*.

Illuminance value
The tables and graphs for the sensor measurements is shown in *attachment B.* Graph 1 shows the illumination levels of the variants in all different conditions. Graphs 3-6 show the change of illumination in percentages between inside and outside.

- Bright sunlight clear sky 11.00am.
The illumination levels are excessively high to exhibit models with a factor 20x to 1850x too high than 50 lux. The relationship between inside and outside shows the ability to reduce illumination levels. The variants *1.Closed ceiling, 6.Kimbell Piano Pavilion, 7.de Young Museum* and *8.Kunsthaus Bregenz* can quite evenly reduce the outside light below 29%. The variants *2.Open ceiling opening, 3.Sir John Soane's Museum, 4.Vitra Design Museum* and *5. Kimbell Art Museum* have high fluctuations of illumination levels and major peaks. This indicates an uneven distribution and a large variation of daylight intensity in the gallery space. The variations can be attributed to cast shadows or narrow daylight openings.

- Bright sunlight clear sky 13.00pm.
The illumination levels are excessively high to exhibit models with a factor 14x to 1300x too high. The relationship between inside and outside shows the ability to reduce illumination levels. The variants *1.Closed ceiling, 5. Kimbell Art Museum, 6.Kimbell Piano Pavilion, 7.de Young Museum* and *8.Kunsthaus Bregenz* can quite evenly reduce the outside light below 27%. The variant *2.Open ceiling opening* does not reduce any light, *4.Vitra Design Museum* has minor fluctuations of illumination levels and *3.Sir John Soane's Museum* has major fluctuations of illumination levels.

- Clouded overcast sky.
The illumination levels are excessively high to exhibit models with a factor 11x to 310x too high. The relationship between inside and outside shows the ability to reduce illumination levels. The variants *1.Closed ceiling, 5. Kimbell Art Museum, 6.Kimbell Piano Pavilion, 7.de Young Museum* and *8.Kunsthaus Bregenz* can quite evenly reduce the outside light below 25%. The variant *2.Open ceiling opening* has minor fluctuations of illumination levels. *3.Sir John Soane's Museum* and *4.Vitra Design Museum* have high fluctuations of illumination levels.

- Daylight simulator with constant

illumination.
The illumination levels are too high to exhibit models with a factor 3x to 220x. The relationship between inside and outside shows the ability to reduce illumination levels. The variants *1.Closed ceiling, 5. Kimbell Art Museum, 6.Kimbell Piano Pavilion, 7.de Young Museum* and *8.Kunsthaus Bregenz* can quite evenly reduce the outside light below 26%. The variants *2.Open ceiling opening, 3.Sir John Soane's Museum* and *4.Vitra Design Museum* have high fluctuations of illumination levels.

- Dark Space
The intensity of the LED lights cannot be measured with the light intensity sensors. The instrument does not give any results due to the range of the sensor.

Colour temperature value
The tables and graphs for the sensor measurements is shown in *attachment B.* Graph 2 shows the colour temperature levels of the variants in all different conditions. Graphs 7-10 show the change of colour temperature in percentages between inside and outside.

- Bright sunlight clear sky 11.00am.
The colour temperatures of the variants are in between 4040 and 5660K. This is dependent on the type of sky and presence of sunlight. The relationship between inside and outside shows the effect of the materials inside. All the variants, except for the *4.Vitra Design Museum* have an evenly distributed colour temperature value over the gallery space.

- Bright sunlight clear sky 13.00pm.
The colour temperatures of the variants are in between 4160 and 5800K. All the variants, except for the *3.Sir John Soane's Museum* and *4.Vitra Design Museum* have an evenly distributed colour temperature value over the gallery space.

- Clouded overcast sky.
The colour temperatures of the variants are in between 4140 and 6980K. All the variants, except for the *1.Closed ceiling, 3.Sir John Soane's Museum* and *4.Vitra Design Museum* have an evenly distributed colour temperature value over the gallery space.

- Daylight simulator with constant illumination.
These measurements cannot be used because they are from an artificial light source, this is not comparable with the daylight opening solution.

- Dark Space
The colour temperature of the LED lights

can not be measured with the sensors. The instrument does not give any results due to the range of the sensor.

Luminance value
The images from the camera analysis software in *attachement B* show the light distribution off the walls and ceiling surface for the different experiment conditions. The difference between the images is the amount of light emitted from the surfaces.

- Bright sunlight clear sky 11.00am.
When the ceiling is closed or partially closed, the walls have a lower luminance value, this is caused by less light entering the space. The values exceed in all cases the values required from the constraints, with the exception of *1.Closed ceiling*. This variant has a lateral window opening for natural daylight.

- Bright sunlight clear sky 13.00pm.
The values exceed in all cases the values required from the constraints, with the exception of *1.Closed ceiling*. This variant has a lateral window opening for natural daylight. The variants all exceed luminance values of 100 cd/m², this means the incident illuminance is even higher.

- Clouded overcast sky.
The required luminance values are approximated in the variants; *4.Vitra Design Museum, 5.Kimbell Art Museum* and *7.de young Museum*. The values of *1.Closed ceiling* are too low. The other variants exceed the values.

- Daylight simulator with constant illumination.
The required luminance values are approximated in the variants; *6.Kimbell Piano Pavilion, 7.de Young Museum* and *8.Kunsthaus Bregenz*. The values of *1.Closed ceiling, 4.Vitra Design Museum* and *5.Kimbell art museum* are too low. The other variants exceed the values.

- Dark space.
It is not possible to make a statement about LED light based on the limitations of the experiment. The LED light can not be compared with the light in real life because there are too many variables. The extra experiment in the dark space confirms the assumption that the integrated artificial LED lighting has insufficient light sources and a lack of intensity. The implementation of more LED light sources in the model would likely lead to an incresement of gallery illumination.

Conclusion

The analysis of the casestudies with different conditions results in a comparison with the constraints.

Illuminate exhibition space
The variants 1.Closed ceiling, 5.Kimbell Art Museum, 6.Kimbell Piano Pavilion, 7.de Young Museum and *8.Kunsthaus Bregenz* have a significantly lower gallery illuminance value than the outside illuminance, for all the different conditions. These variants also have a constant and even distribution in the gallery space.
- Variant *1.Closed ceiling*, does not have a skylight and does not fit the requirements.
- Variant *5.Kimbell Art Museum* does not fit into the building envelope because of the vault. The ability to adjust and control daylight transmission and reduce daylight levels with different conditions is missing.
- Variant *6.Kimbell Piano Pavilion* does have an even distribution but this is also blocked by the construction which creates cast shadows. Daylight into the galleries should be reduced to a minimum when the museum is closed.
- Variant *7.de Young Museum* does not have the ability to adjust and control daylight transmission and reduce daylight levels with different conditions. Daylight into the galleries should be reduced to a minimum when the museum is closed.
- Variant *8.Kunsthaus Bregenz* does not fit into the building envelope because of the high top volume. The ability to adjust and control daylight transmission and reduce daylight levels with different conditions is missing. Daylight into the galleries should be reduced to a minimum when the museum is closed.

Illuminate collection
- The variants do not comply with the 50 lux maximum exposure of the models.
- Variant *6.Kimbell Piano Pavilion* has direct natural daylight in the exhibition space which is
undesirable but the roof can close outside opening hours.
- The layering of light requires artificial light, there are no conclusions for these tests.

Constraints
The individual variants do not meet the constraints and requirements of the gallery space for the Architectural Model Museum. It is the challenge and objective of the research to find a hybrid form which combines the best characteristics of all variants in a solution that meets the requirements and constraints.

The effect of *8.Kunsthaus Bregenz* is desirable in the gallery space. Three layers of translucent material diffuse the light into the space and create an even and lower illumination in the gallery space. The translucency of the glass can be adjusted to lower the daylight illumination. The light of the casestudy enters the ceiling cavity from the side of the façade, this influences the light distribution. Therefor an opening in the roof would create a more even illuminance. The light of *6.Kimbell Piano Pavilion* can be adjusted with louvres. The amount of daylight in the space is adaptable, prevents huge amounts of direct sunlight and the louvres can be closed outside opening hours.

Based on the constraints and the results, it is possible to make an optimalization for a daylight design for the gallery space of the Architectural Model Museum. The option is a solution for the research question and implements theory and practice in the gallery space design.

How can light be optimally used for the illumination of the museum space and models of the Architectural Model Museum gallery?

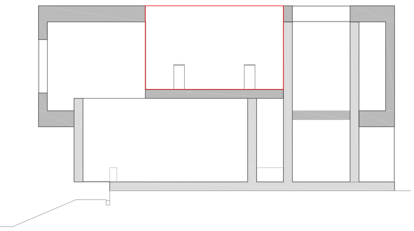
The implementation of the research question is presented in more detail hereafter. This solution is chosen because of the effect on the gallery space and the collection.

Hybrid solution
The skylight design corresponds to the architectural design.
Daylight is the primary source of light in the gallery space and the light enters the space through three layers of translucent glass for a decrease of intensity to 50 lux and uniform distribution of diffuse light. The glass will be covered with a ultraviolet blocking foil.
The skylight construction has a louvre system which can adjust and control daylight transmission and reduce daylight levels, exclude heat gain and glare.
The louvre system reduces daylight in the galleries to a minimum when the museum is closed.
There is a layering of daylight and artificial light within the gallery for an even and constant illumination of the individual characteristics of the model. The appearance and balance of three dimensional form, texture colour and detail of the surface are revealed with the diffuse daylight. The addition of LED spotlights on the boundaries of the gallery space creates a distinction between object ground and figure, to improve the three dimensional object appearance.
A correlated colour temperature (CCT) is recommended for presentation in museums, which provides a natural appearance of the model.

Narrative

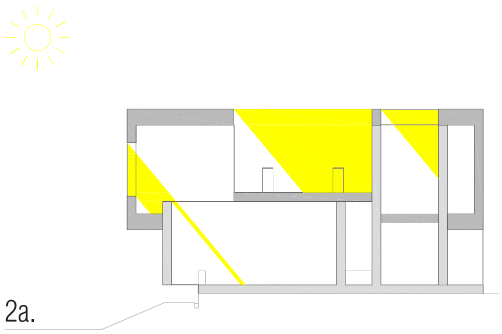
The skylight of the Architectural Model Museum gallery space is a combination of multiple Building Technical solutions. How this will work is presented with the following explanation.

1. The exhibition gallery in the centre of the Architectural Model Museum without any solution.



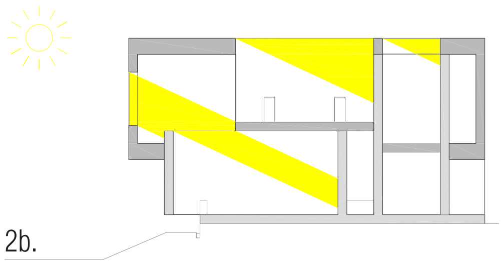
1.

2a. Exhibition space with an open roof in summer situation. The sun illuminates the space and creates a cast shadow, an uneven distribution of light in the museum space and an overexposure to daylight.



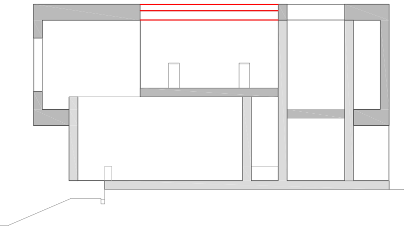
2a.

2b. Exhibition space with an open roof in winter situation. The sun illuminates the space and creates a cast shadow, an uneven distribution of light in the museum space and an overexposure to daylight. The lateral daylight opening in the façade creates a side incidence of light not reaching the gallery.



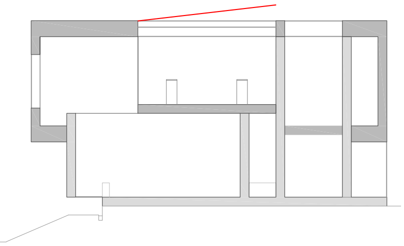
2b.

4.23 - 4.33 Narrative building design.



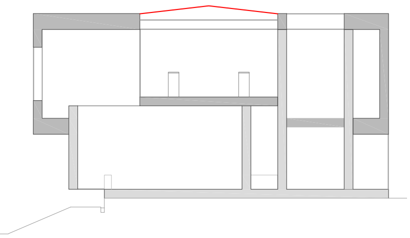
3.

3. Three layers of translucent glass are designed for an even illumination of the gallery space, based on the design of variant *8.Kunsthaus Bregenz* from the casestudies. The glass is covered with a ultraviolet light protection foil film.

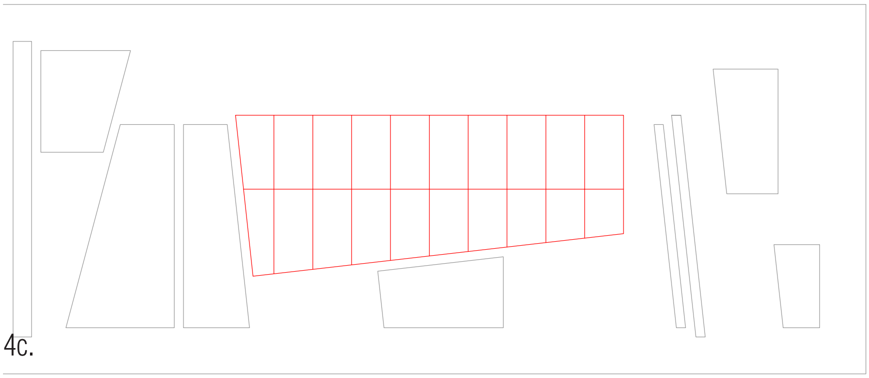


4a.

4. A slope is required for the drainage rainwater. There are various design solutions. Solution 4a has a long slope in one direction, this requires undesirable more height. The solution also doesn't connect to the adjacent skylight. Solution 4b has a slope in two directions, the height of the skylight is reduced and the option connects to the adjacent skylight. Solution 4b is chosen and shown from above in 4c, the plane is divided into windows of similar size. Weight of the window construction is transferred to the edges.

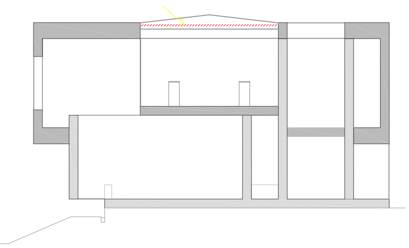


4b.

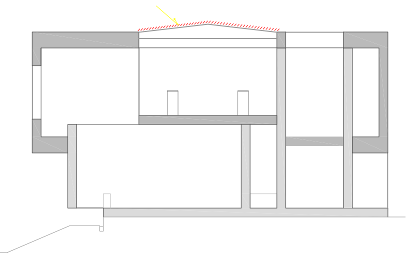


4c.

5. A controllable louvre system is integrated to automate the incidence of light and lowering the illumination levels. The louvre system is based on the design variant *6.Kimbell Piano Pavilion* from the casestudies. Solution 5a has an internal louvre system. The positive effect is the protected internal condition, the negative effects the internal heat gain and limited maintenance space. Solution 5b has an external louvre system. The positive effects are outdoor heat reflection and more maintenance space. The negative effects are the additional height of the construction and the outdoor conditions. The solution of 5b is better for a museum gallery because heat is an important aspect to take into account.

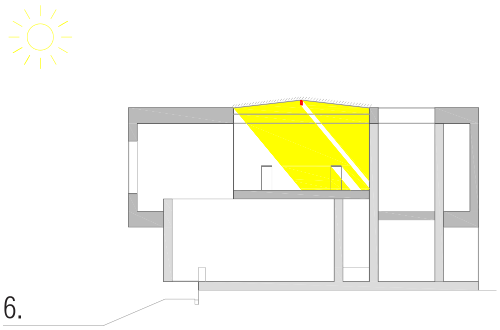


5a.



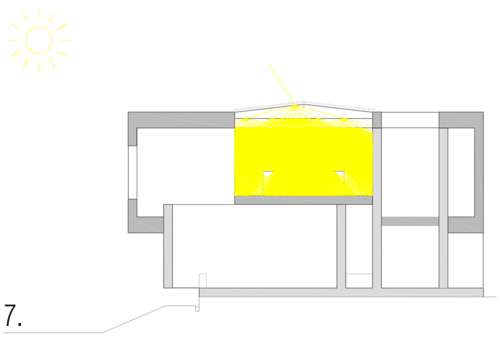
5b.

6. The construction is mentioned before. it is important to lower the height of the construction and installations to reduce the shadows and uneven distribution of light.



6.

7. The three layers of translucent glass provide an even distribution of diffuse light into the exhibition space. The glass is covered with a ultraviolet blocking foil to protect the exhibition objects from light degeneration.



7.

Validation

Measurements have been executed for the validation of the experiment with the design solution model. The intention was to perform all the test including the outdoor experiment but unfortunately the weather conditions of the first experiment were not expected to happen in this period. The measurements in the daylight simulator give a more reliable view of the design solution. The results are compared with the variants of the casestudies.

Illuminance value
The illumination levels are lower than the variants *6.Kimbell Piano Pavilion* and *8.Kunsthaus Bregenz.* The relationship between inside and outside shows the ability to reduce the illumination levels in the gallery space. The design solution can quite evenly reduce the outside light below 19%. The louvres are set in a fixed position during this experiment and with a controllable alternative the illumination levels can be lowered further. The translucency of the material is constant in the experiments, this can be adjusted with gradients of translucent glass to lower the light transmittance.

Colour temperature value
We will not discuss the colour temperature here because the daylight simulator has artificial lighting and does not match the outside conditions.

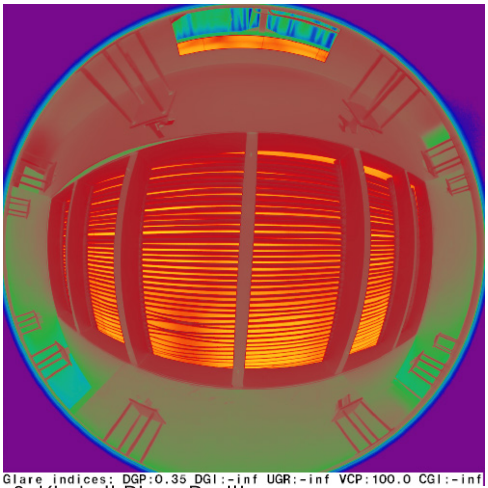
Luminance value
The images from the camera analysis software in *figure 4.34* show the light distribution off the walls and ceiling surface for the different experiment conditions. The difference between the images is the amount of light emitted from the surfaces.
The required luminance value is approximated in the design solution. It is still slightly above the required levels based on the constraints. This can be adjusted by the controllable louvre system.

The results of the design solution are in line with the expectations. The solution model is a hybrid of the variants *6.Kimbell Piano Pavilion* and *8.Kunsthaus Bregenz.* These characteristics are reflected in the results. The measured values come close to the constraints of the light on the collection which is based on the conclusions of the literature research, architectural design and loan terms of “Het Nieuwe Instituut”.

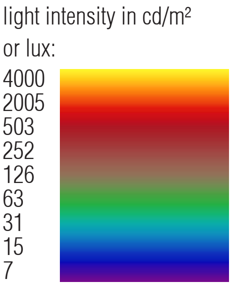
4.34 Experiment results of variants and design solution in daylight simulator with constant illumination.

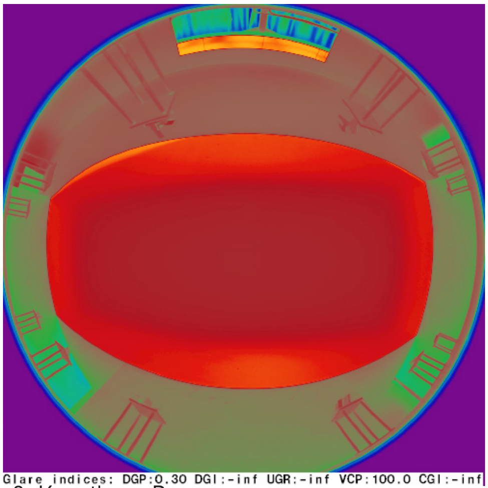
Daylight simulator with constant illumination 8-9-2015

outside 13550 lux 3530 Kelvin

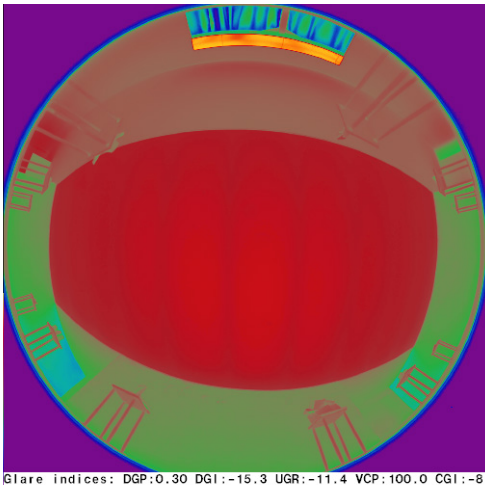


6. Kimbell Piano Pavilion

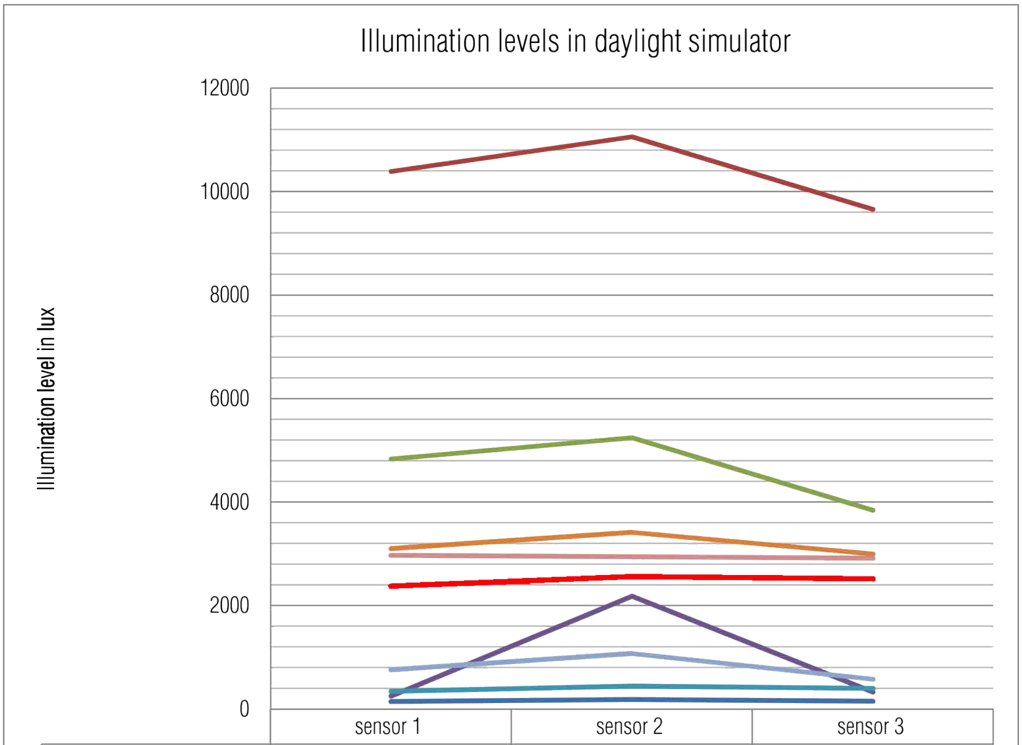




8. Kunsthaus Bregenz

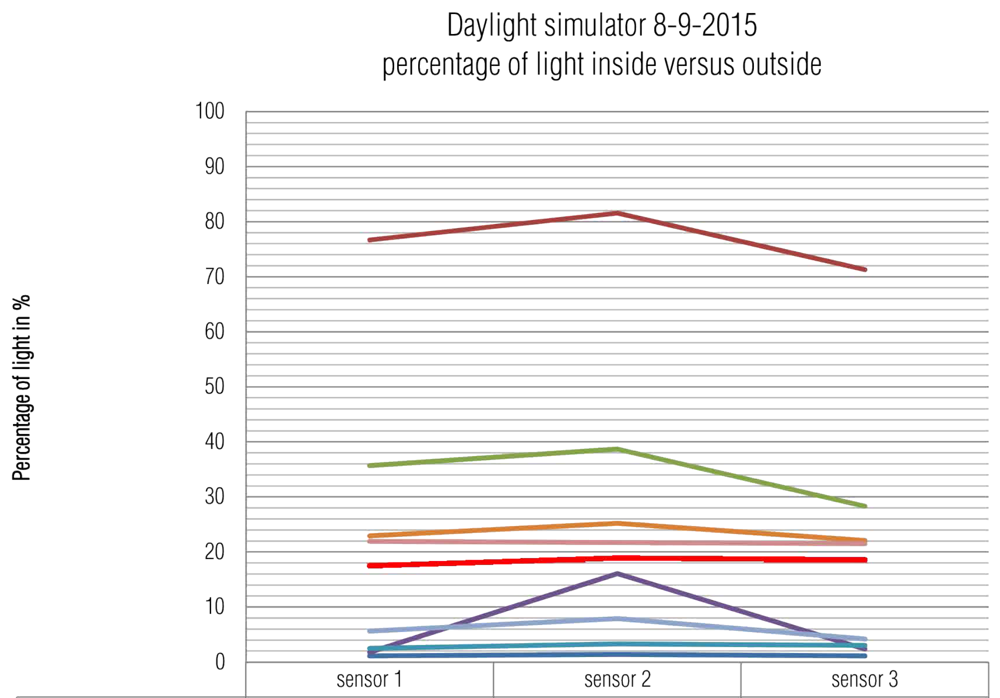


9. Design solution



	sensor 1	sensor 2	sensor 3
1. Closed	145	185	150
2. Open	10390	11060	9660
3. Sir John Soane	4835	5245	3840
4. Vitra Design	250	2180	330
5. Kimbell Art	340	445	400
6. Piano Pavilion	3100	3415	3000
7. de Young	755	1075	575
8. Kunsthaus Bregenz	2970	2940	2915
9. Design solution	2375	2560	2515

4.35 Graph of illumination levels of the variants in the daylight simulator.



	sensor 1	sensor 2	sensor 3
1. Closed	1,1	1,4	1,1
2. Open	76,7	81,6	71,3
3. Soane	35,7	38,7	28,3
4. Vitra	1,8	16,1	2,4
5. Kimbell	2,5	3,3	3
6. Piano Pavilion	22,9	25,2	22,1
7. de Young	5,6	7,9	4,2
8. Kunsthaus Bregenz	21,9	21,7	21,5
9. Design Solution	17,5	18,9	18,6

4.36 Graph of percentage of light change inside versus outside for daylight simulator.

Museum drawings

Urban plan of the Architectural Model Museum in the Museumpark Rotterdam. The Museum has a south-east orientation. The north side of the museum is an open square above the parking garage, the south side is a densely vegetated “Romantic Garden” with trees. The museum has cast concrete core volumes with a glass facade at ground floor level. In and in between the volumes is the exhibition space and museum facilities. The first floor is a closed box with openings for daylight. The height differences visible in the sections, increase the spatial quality and experience of the exhibition objects. It provides more daylight in the exhibition spaces of the lower floor.

4.38 r. Rotterdam
Architectural Model
Museum Museumpark
scale 1:2000

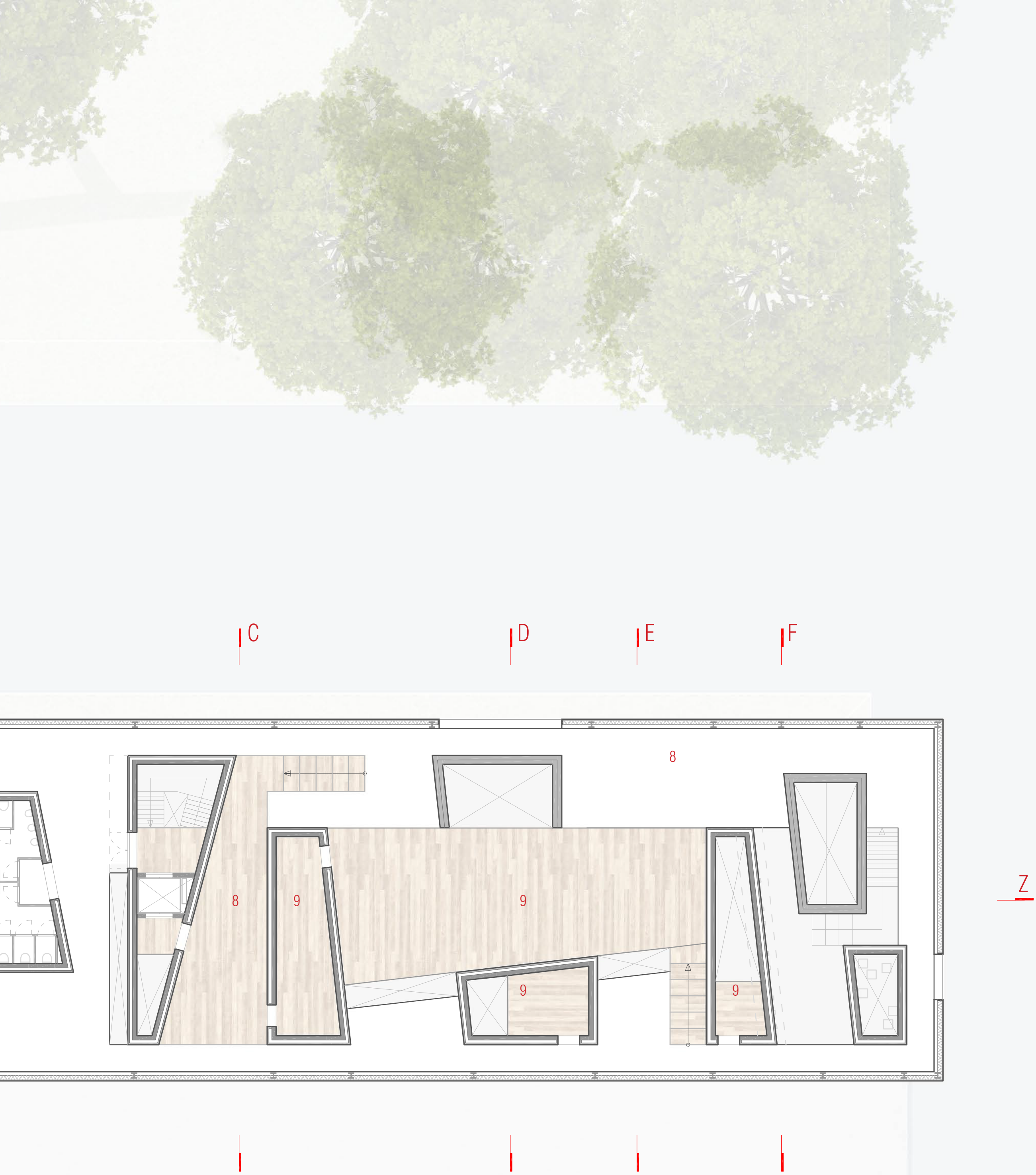
4.37 l. Rotterdam
orientation Museumpark
scale 1:50000


A
B
1
2
1
3
4
5
6
7

1. Office
2. Storage
3. Exit parking garage
4. Load & unload
5. Entrance
6. Bar & kitchen
7. Restaurant
8. Exposition space
9. Exhibition gallery
10. Open depot
11. Research & photo studio
12. Installations

4.39 Plan ground floor
scale 1:333

A
B
10
11
10
8
9
8
9
12
3



1. Office
2. Storage
3. Exit parking garage
4. Load & unload
5. Entrance
6. Bar & kitchen
7. Restaurant
8. Exposition space
9. Exhibition gallery
10. Open depot
11. Research & photo studio
12. Installations

4.40 Plan first floor
scale 1:333


10
11
10
8
9
8
9
12
1
2
1
6
7

1. Office
2. Storage
3. Exit parking garage
4. Load & unload
5. Entrance
6. Bar & kitchen
7. Restaurant
8. Exposition space
9. Exhibition gallery
10. Open depot
11. Research & photo studio
12. Installations

4.41 Longitudinal section Z
scale 1:333

Technical Section

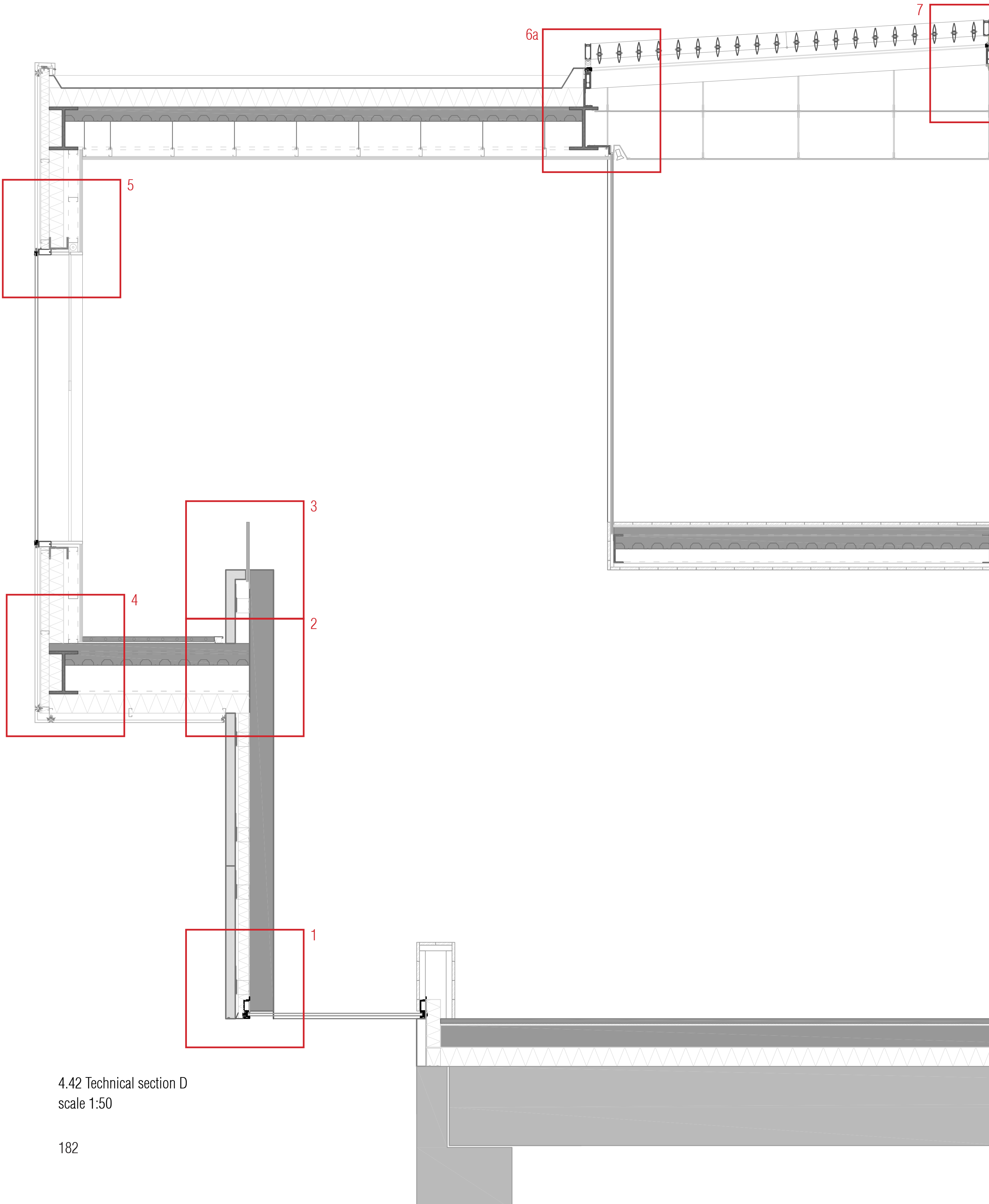
Façade
The ground floor has a glass façade with a Schüco window frames, concrete volumes protrude at the south-east side with an overhang. The core volumes have a cast concrete structure with insulation at the outdoor façade and precast concrete front cover elements. Inside the building, the cavity wall has integrated installations. The upper floor is a box and has a white coated aluminium sheet metal element façade with full story height. The Panels are mounted in the window frames to create an almost seamless transition between glass and metal. The building has a lowered ceiling for construction and installations with a white stuc over plasterboard.

Installations
Visual comfort of light treatment in double or triple layer glass ceiling. Diffuse natural daylight is combined with artificial spotlight for the best exhibition conditions. The roof has transparent and translucent window openings for daylighting. The central gallery space has a multi layer diffusing ceiling with an automated louvre system for perfect light optimalization. The lateral daylight openings have retractable awnings integrated in the façade for sunshading. The thermal heat load of the building is reduced with these daylighting solutions.

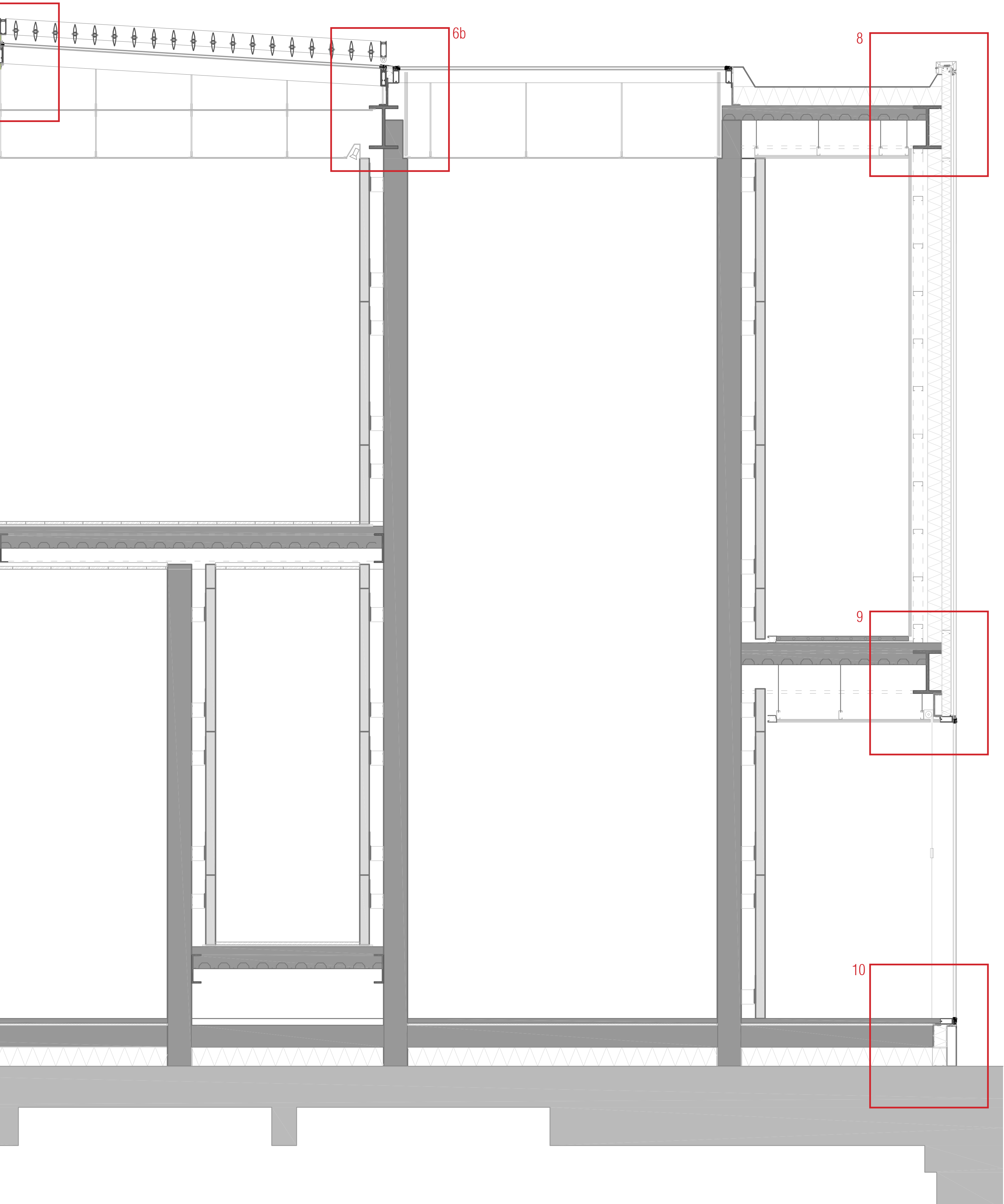
Climate comfort with individual climate regulation of the spaces with floor heating and cooling. Input and output conduits are in the lowered ceilings and hollow cores which are regulated individually. Installations are controlled from the central core of the building. Concrete roof slab results in minor temperature fluctuations in summer conditions because of the thermal mass.

The Air quality is treated central with local air inlets and outlets in the individual spaces for ventilation. Central heat exchanger for energy savings.

Acoustic comfort by sound insulation with a closed box shielding off ambient noise.
An internal sound insulation for optimal spatial acoustics Lowered ceiling with sound absorption ensures prevention and repression of high noise levels and maintaining optimal acoustics.



4.42 Technical section D
scale 1:50


6b
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9
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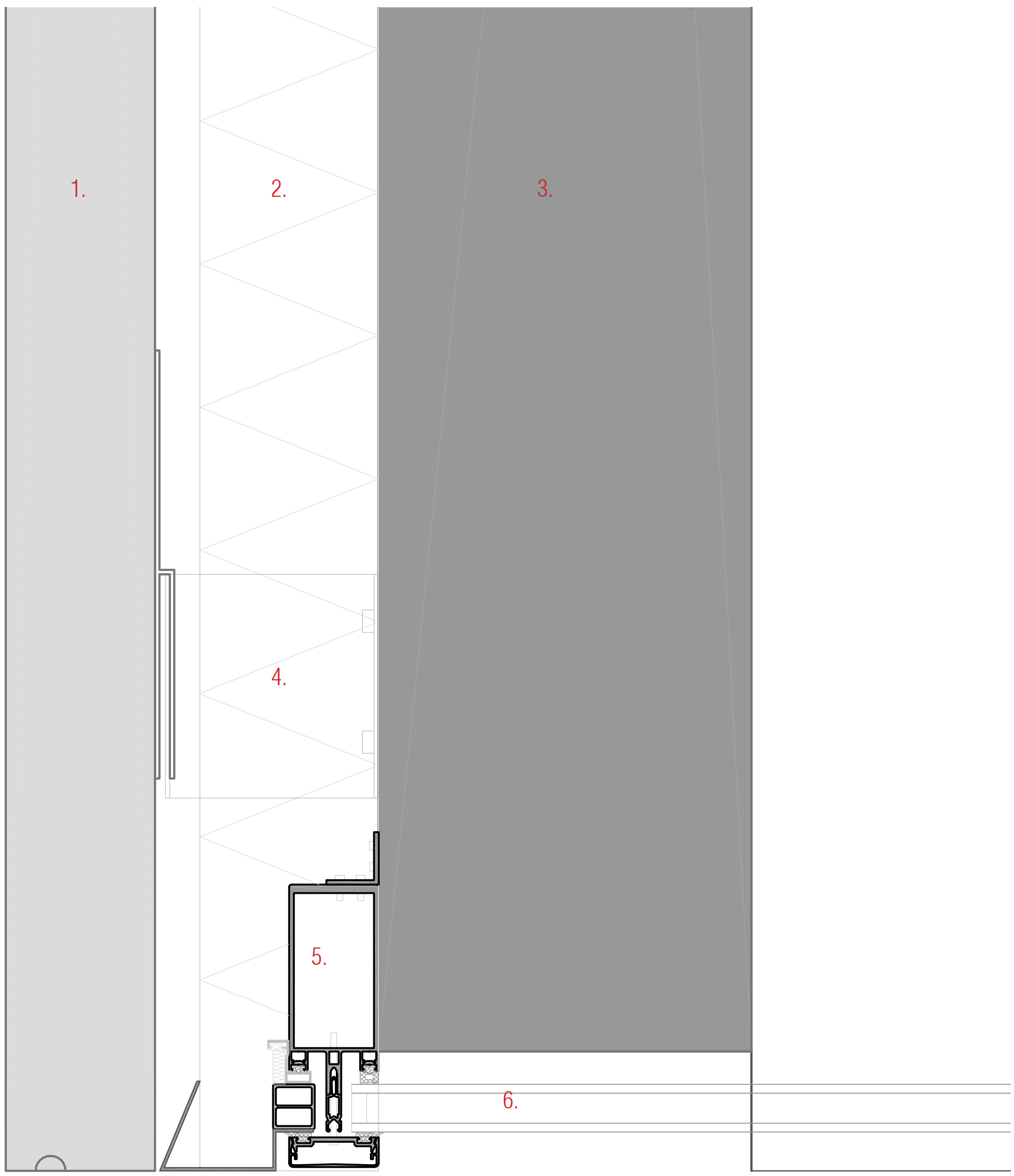
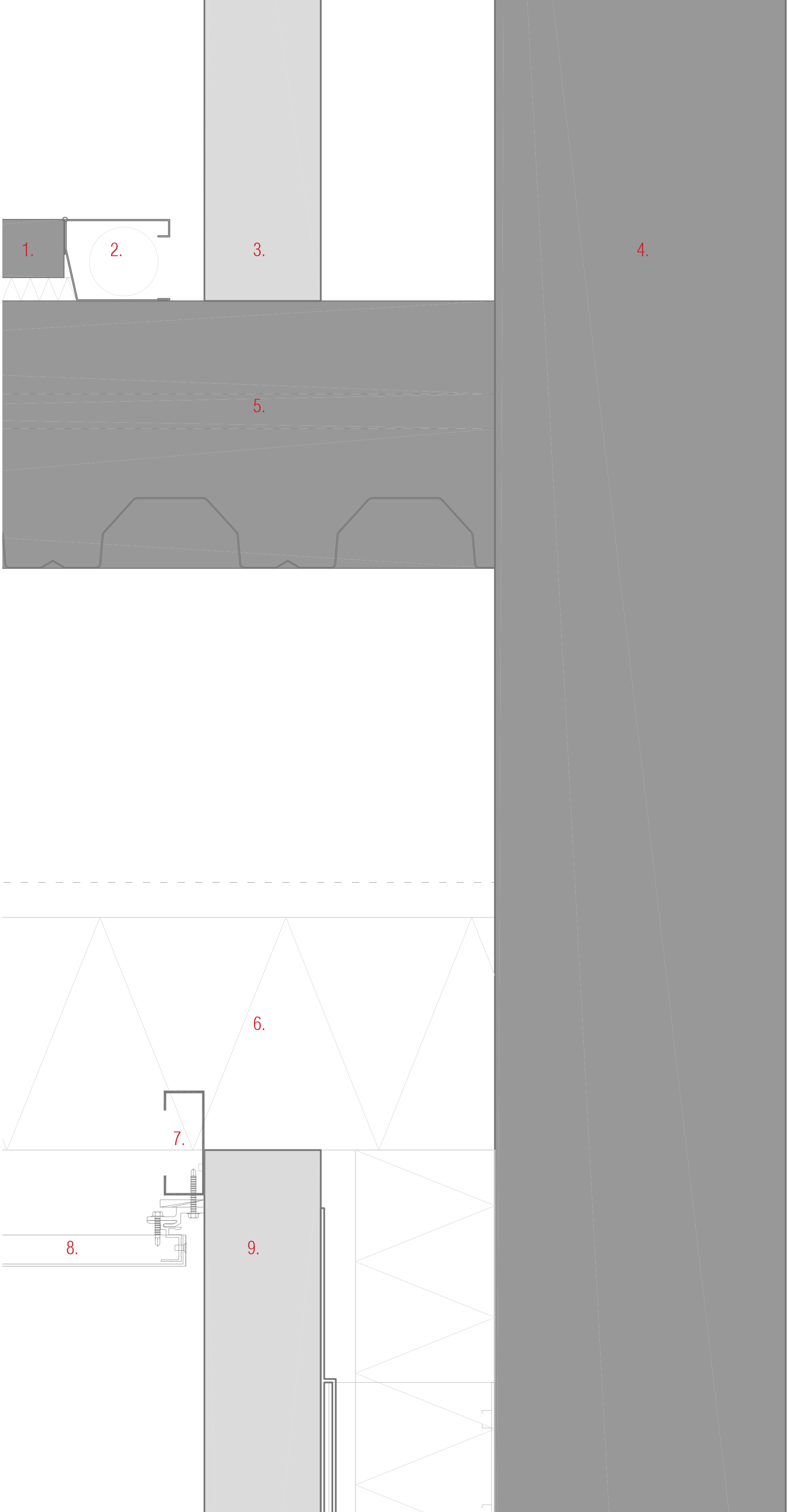


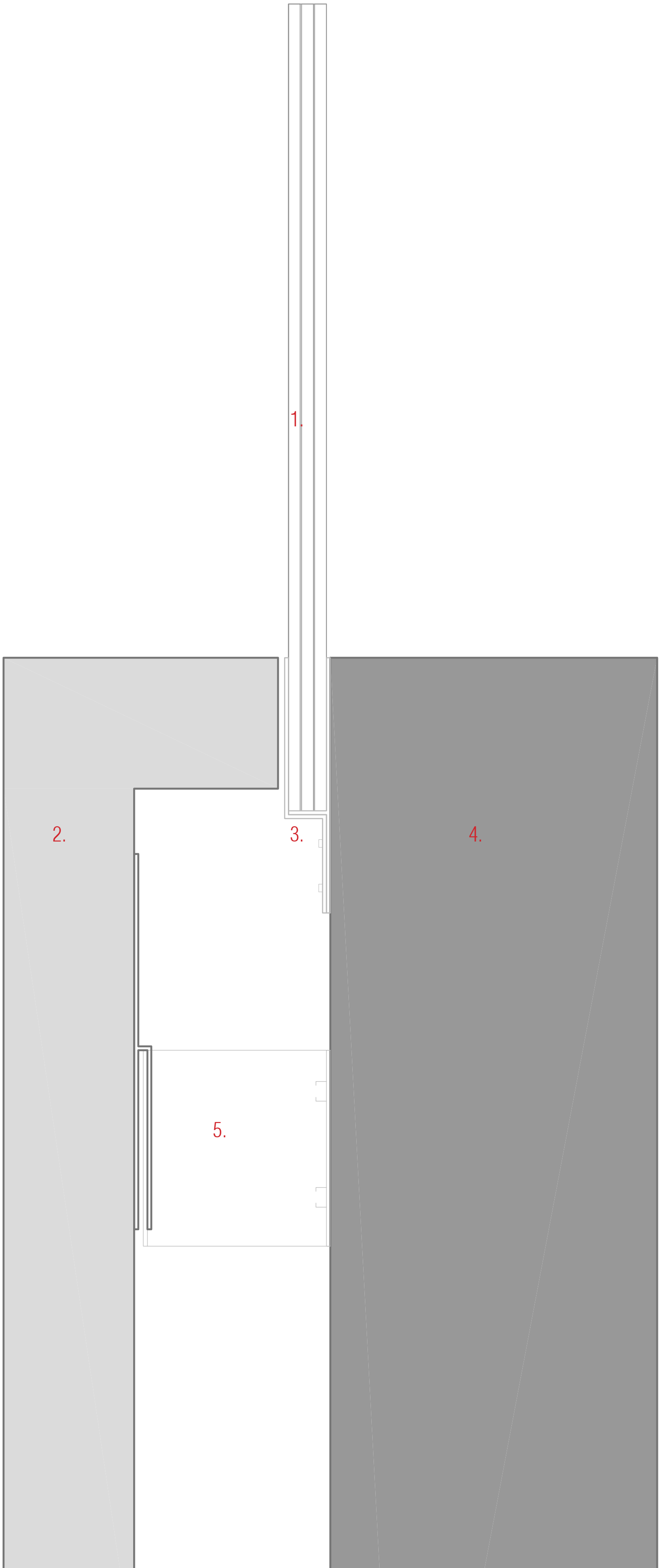
1. Precast concrete element 100x3200x1500
2. Insulation EPS 120 mm
3. Cast reinforced concrete 250 mm
4. H-steel mounting element
5. Schüco FW60plus window frames with HR++ glazing
6. HR++ glazing with UV-filter foils

4.43 Vertical detail 1
scale 1:5



1. Concrete top floor with floor heating
2. Floor light element
3. Precast concrete element 100x770x1500
4. Cast reinforced concrete 250 mm
5. Steel HODY trapezium floor with concrete deck
6. Insulation EPS 200 mm
7. Metalstud substructure
8. Aluminum sheeting facade element with white coating 2x30x6800x1500
9. Precast concrete element 100x3200x1500

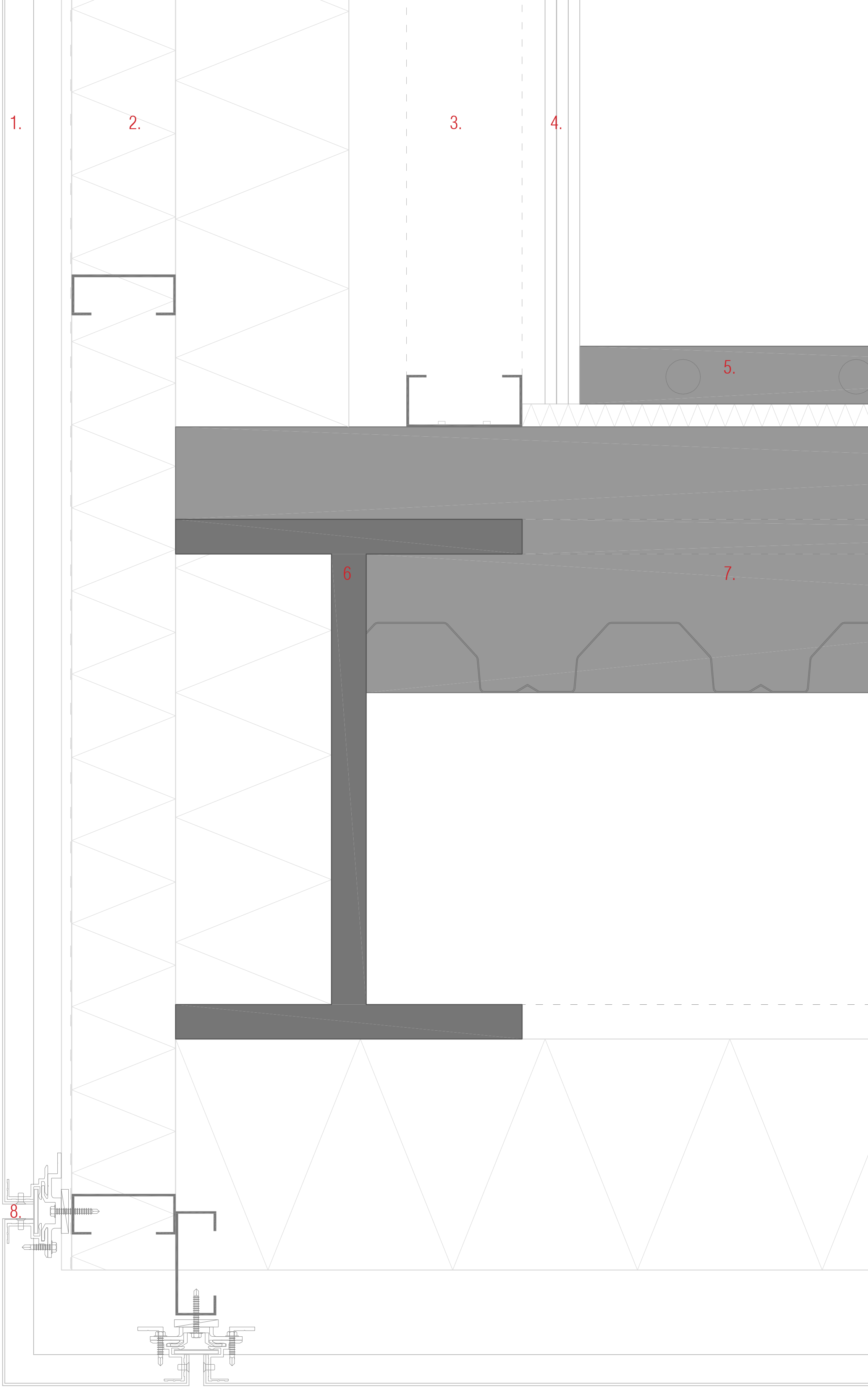
4.44 V ertical detail 2
scale 1:5



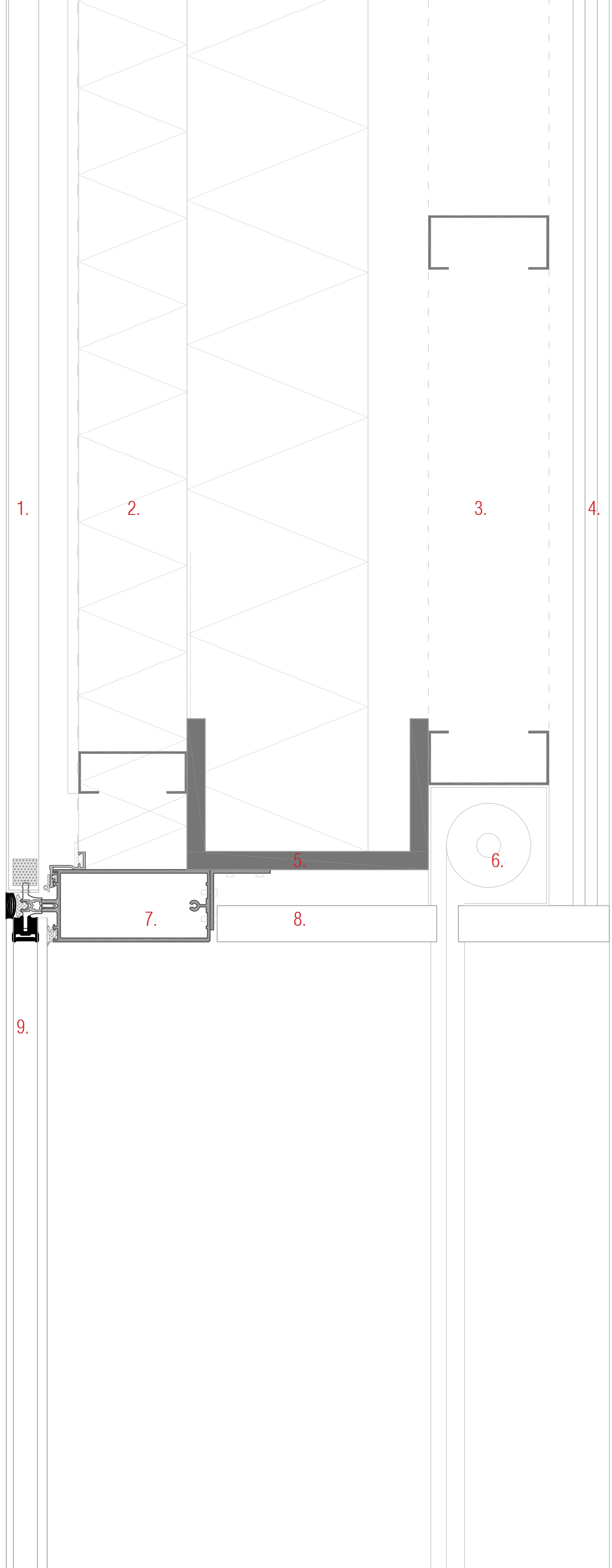
1. Triple layer laminated safety glass
2. Precast concrete element 100x770x310x1500
3. Window frame clamp system inside glass walls
4. Cast reinforced concrete 250 mm
5. H-steel mounting element for precast concrete elements

4.45 Vertical detail 3
scale 1:5

1. Aluminum sheeting facade element with white coating 2x30x6800x1500
2. Insulation EPS 90+150 mm in metal substructure
3. Metalstud structure
4. plasterboard with stuc
5. Concrete top floor with floor heating
6. I-steel construction beam HEM 450
7. Steel HODY trapezium with concrete deck floor
8. Mounting system for façade panels



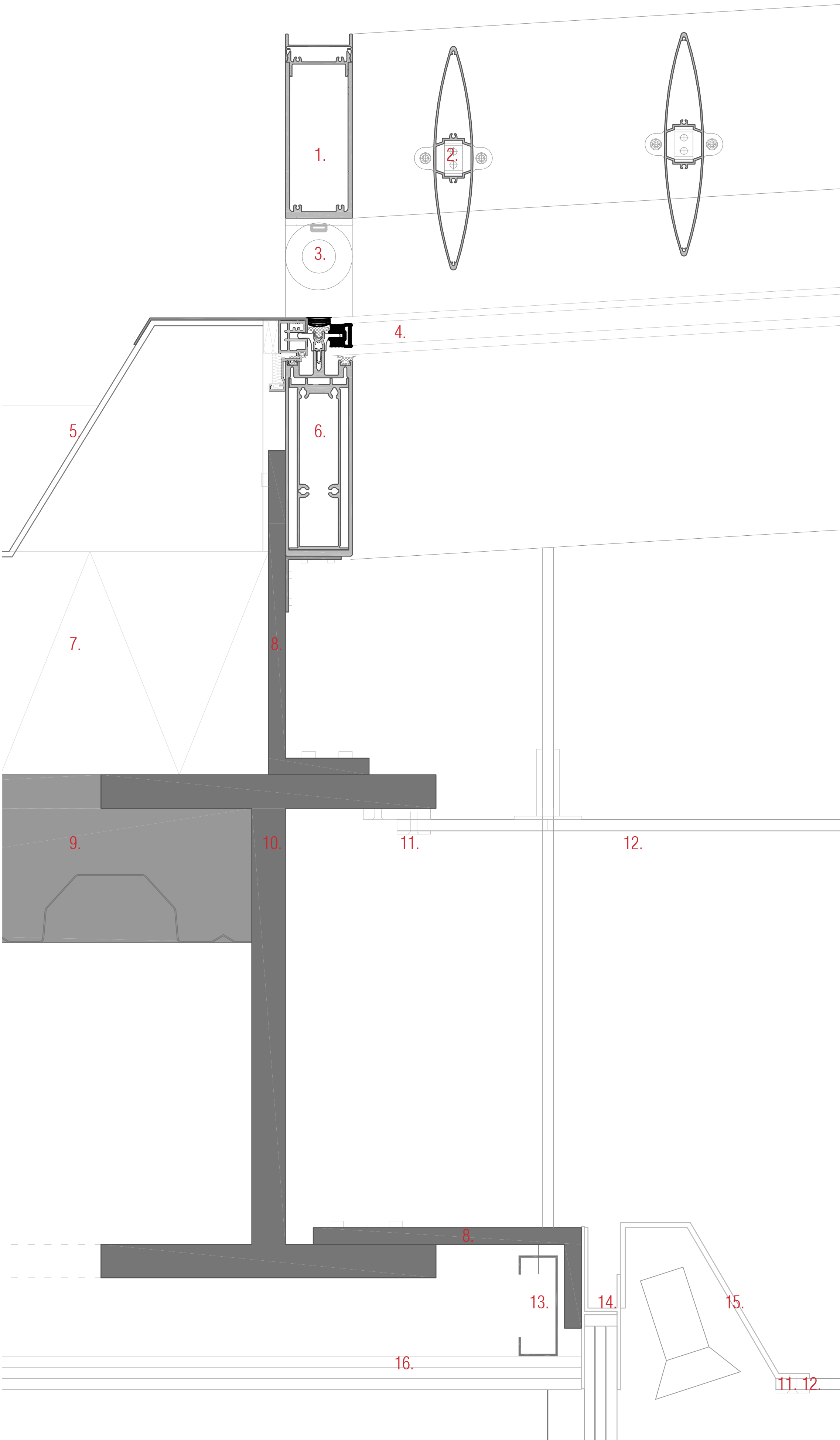
4.46 Vertical detail 4
scale 1:5



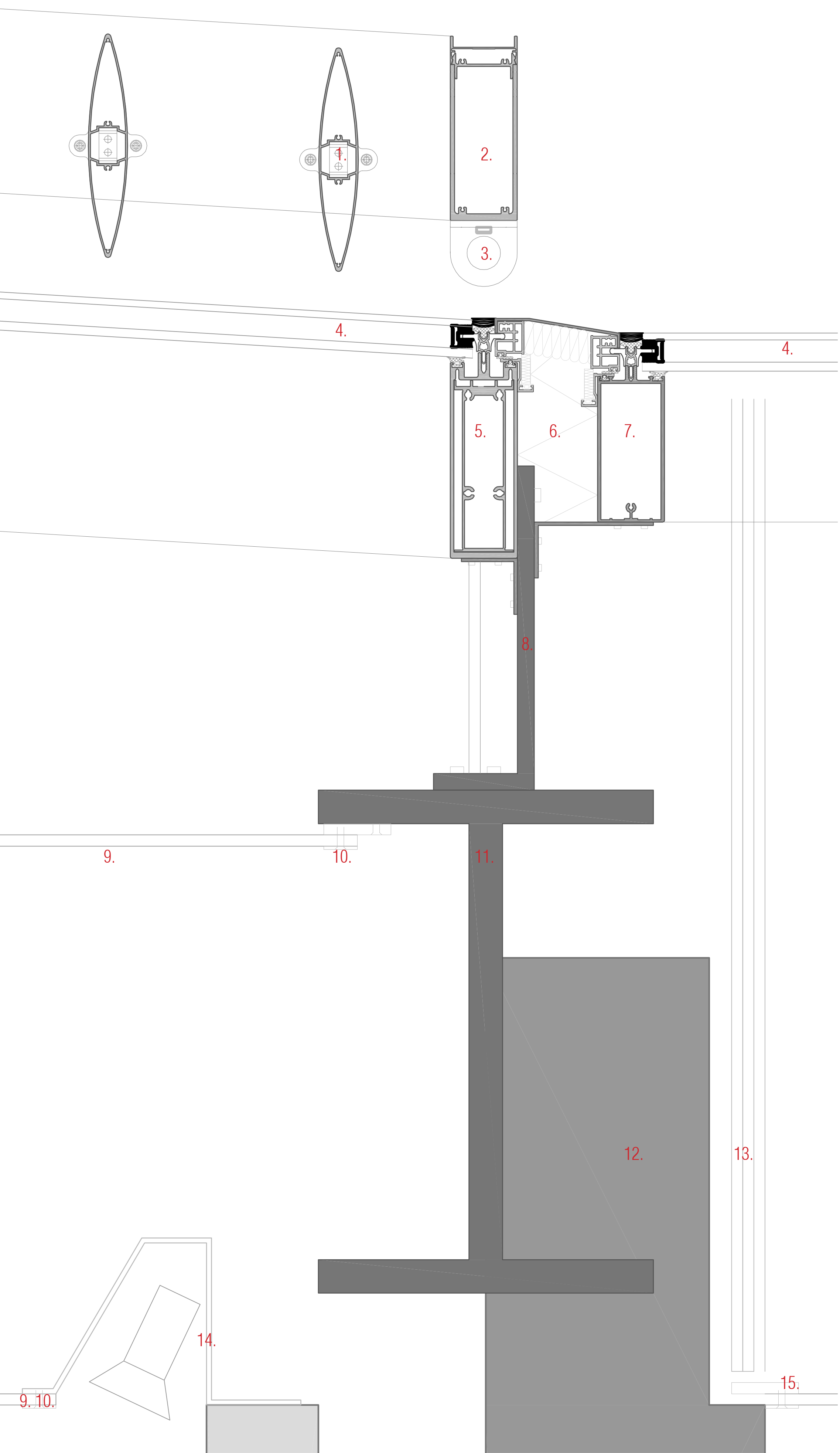
1. Aluminum sheeting facade element with white coating 2x30x1850x1500
2. Insulation EPS 90+150 mm in metal substructure
3. Metalstud structure
4. Plasterboard with stuc
5. U-steel construction beam
6. Integrated sunscreen rolling system element
7. Schüco FW60plus window frames
8. Wood cladding window opening
9. HR++ glazing with UV-filter foils

4.47 Vertical detail 5
scale 1:5

1. Schüco louvre frame with integrated active rotation system
2. Schüco aluminum large louvre blades ALB active system 205 mm
3. Retractable louvre maintenance system
4. HR++ diffuse glazing with UV-filter foils
5. White EPDM roof covering
6. Schüco FW60plus window frames with reinforced structure
7. Insulation EPS 200 mm
8. L-steel construction element 290x90x15 mm
9. Steel HODY trapezium with concrete deck
10. I-steel construction beam HEM 450
11. Adjustable mounting system for glass ceiling
12. Diffuse glazing planels 1000x1000mm
13. Metalstud structure
14. Window frame clamp system for indoor glass walls
15. Aluminum recess element with artifical spotlight fixtures
16. Lowered ceiling with plasterboard and stuc



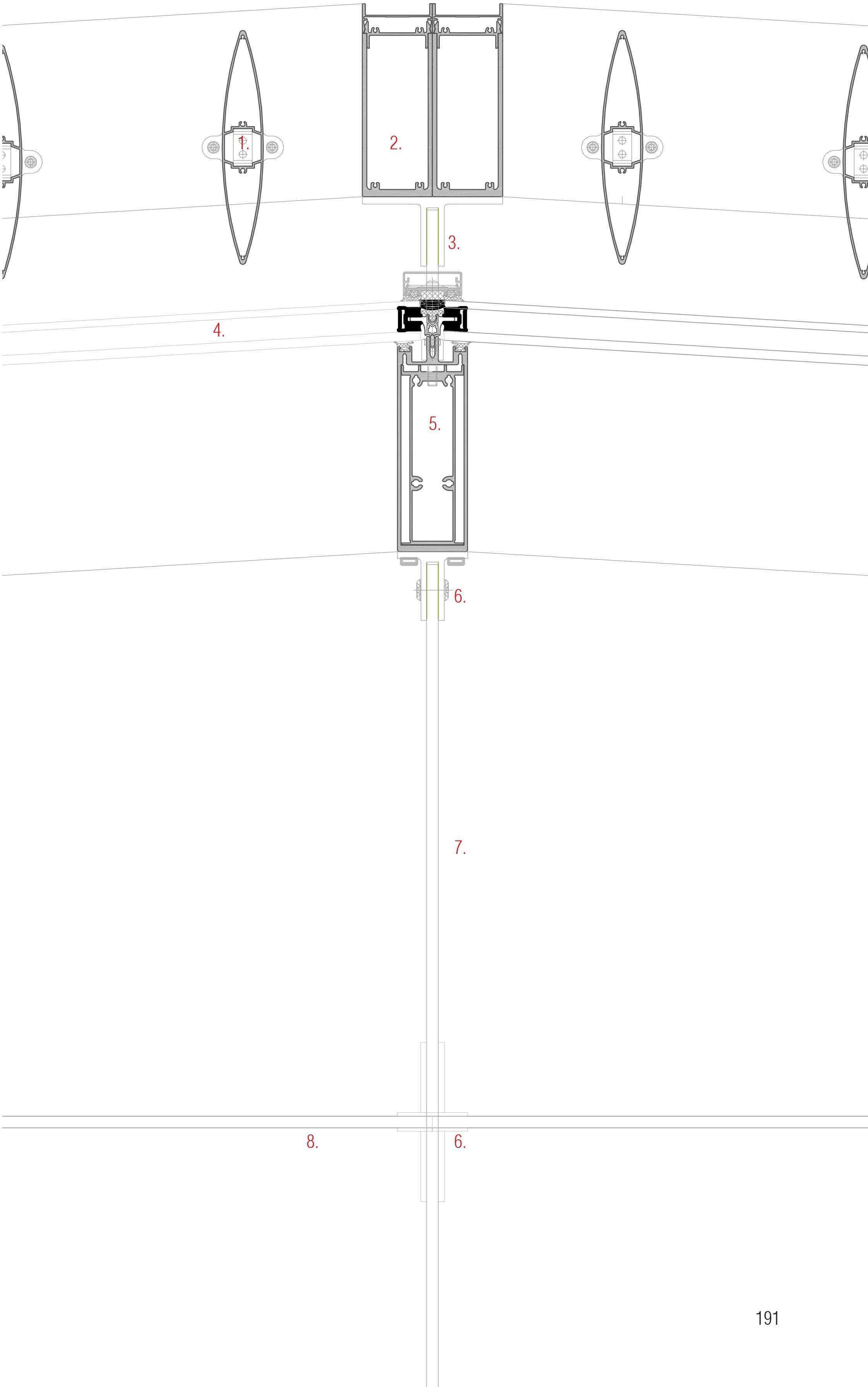
4.48 Vertical detail 6a
scale 1:5



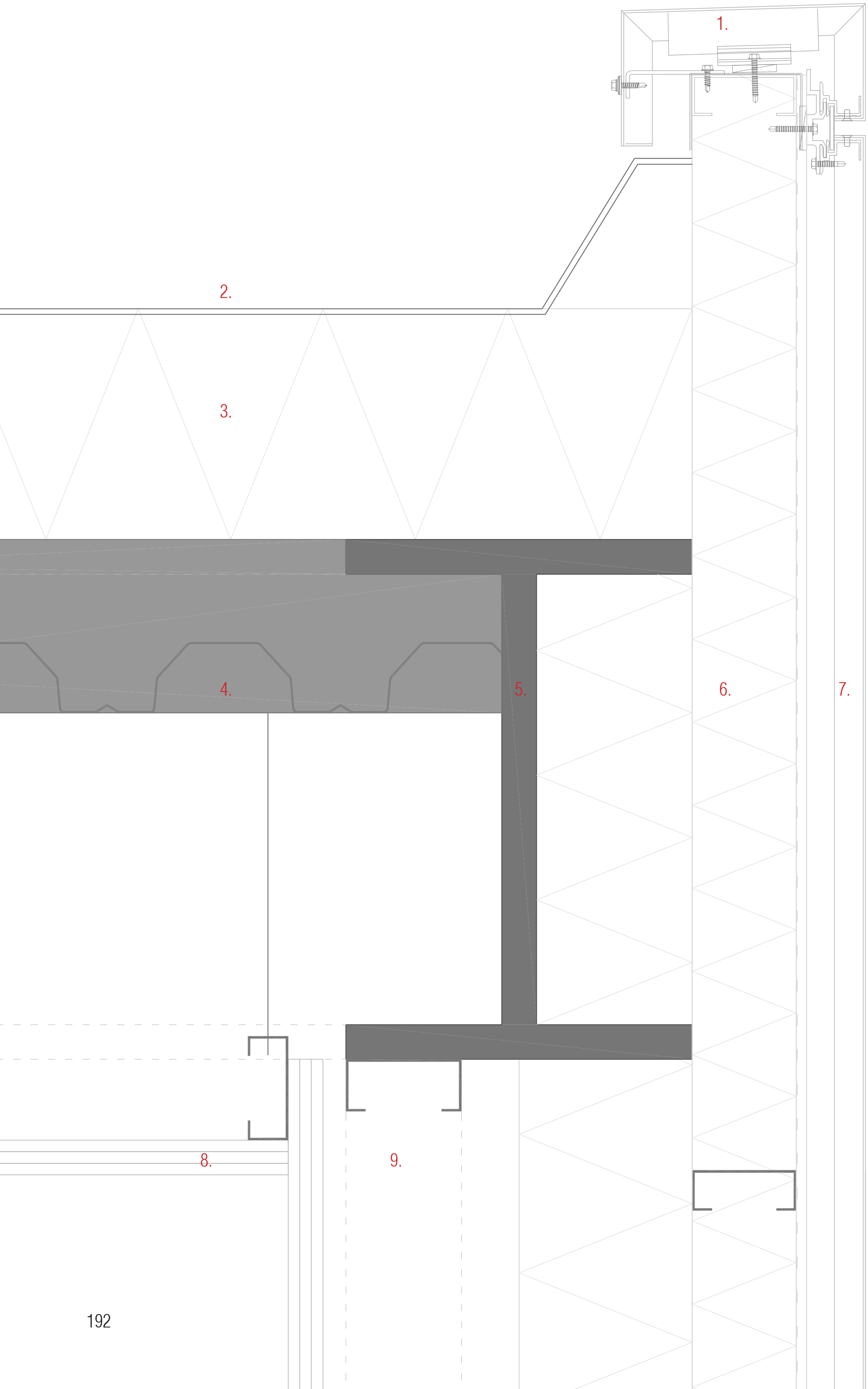
1. Schüco aluminum large louvre blades ALB active system 205 mm
2. Schüco louvre frame with integrated active rotation system
3. Retractable louvre maintenance system
4. HR++ diffuse glazing with UV-filter foils
5. Schüco FW60plus window frames with reinforced structure
6. Insulation
7. Schüco FW60plus window frames
8. L-steel construction element 290x90x15 mm
9. Diffuse glazing planels 1000x1000mm
10. Adjustable mounting system for glass ceiling
11. I-steel construction beam HEM 450
12. Cast reinforced concrete 250 mm
13. Plasterboard boarding
14. Aluminum recess element with artifical spotlight fixtures
15. Diffuse glazing ceiling

4.49 Vertical detail 6b
scale 1:5

1. Schüco aluminum large louvre blades ALB active system 205 mm
2. Schüco louvre frame with integrated active rotation system, retractable for maintenance
3. Support and guide rail for retractable louvre maintenance system
4. HR++ diffuse glazing with UV-filter foils
5. Schüco FW60plus window frames with reinforced structure
6. Adjustable mounting system for glass ceiling, screw-thread pins suspended from construction
7. Cavity with diffuse artificial light inbetween mounting system
8. Diffuse glazing planels 1000x1000mm



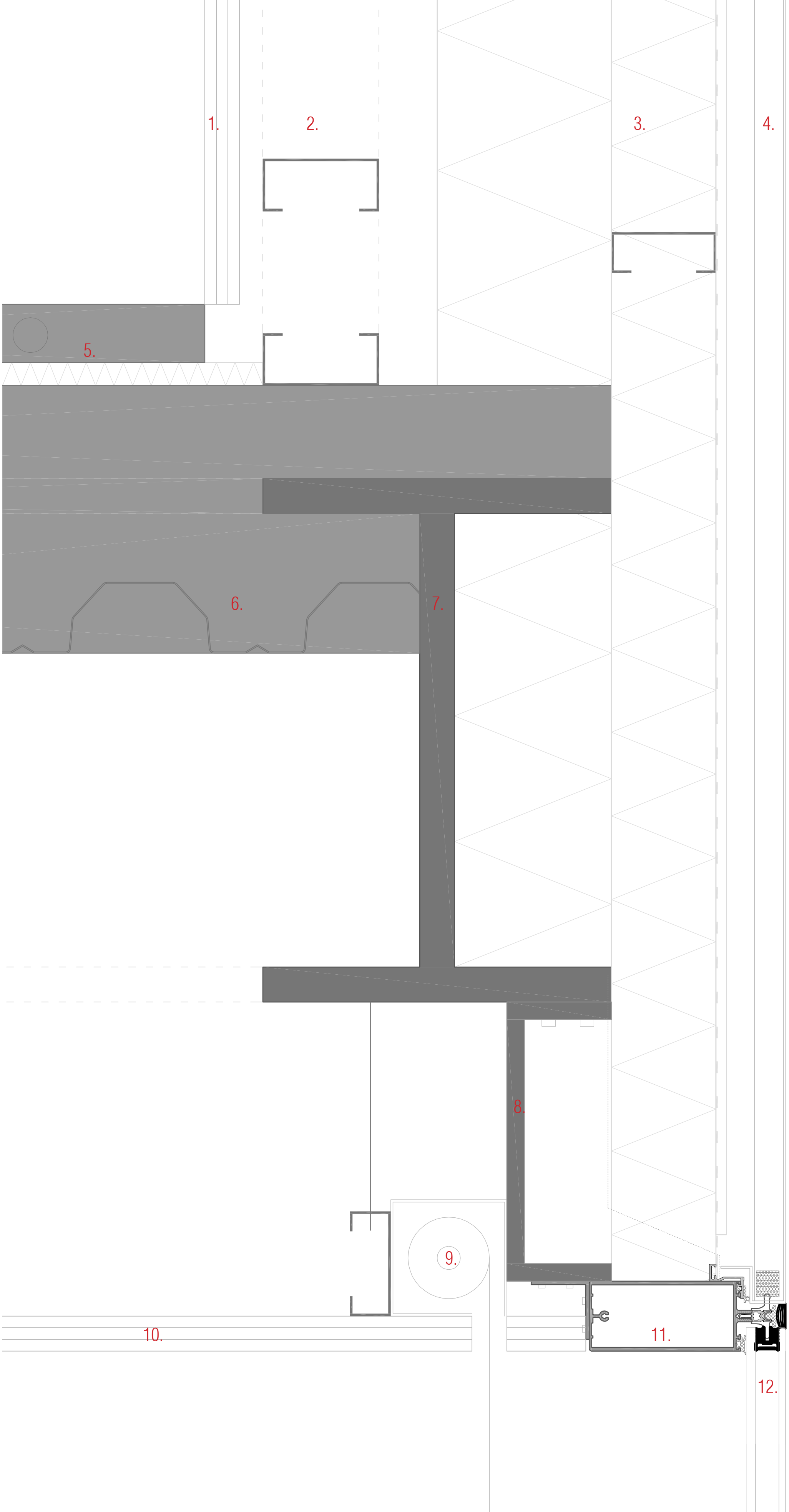
4.50 Vertical detail 7
scale 1:5



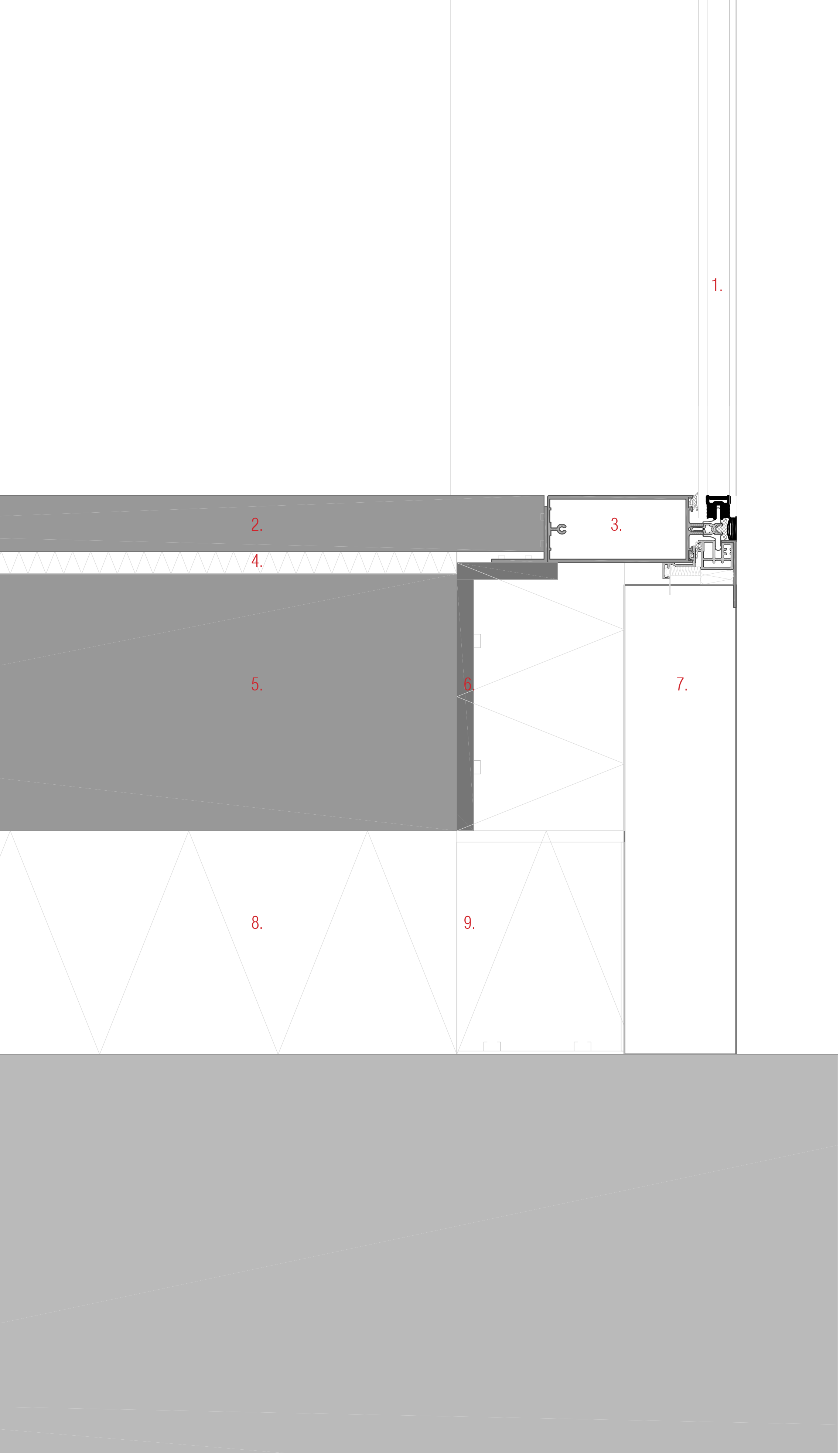
1. Aluminum sheeting roof edge with white coating 2x120x105x1500
2. White EPDM roof covering
3. Insulation EPS 200mm
4. steel HODY trapezium with concrete deck
5. I-steel construction beam HEM 450
6. Insulation EPS 150+90 mm in metal substructure
7. Aluminum sheeting facade element with white coating 2x30x6800x1500
8. Lowered ceiling with plasterboard and stuc
9. Metalstud structure with plasterboard and stuc

4.51 Vertical detail 8
scale 1:5

1. plasterboard with stuc
2. Metalstud structure
3. Insulation EPS 150+90 mm in metal substructure
4. Aluminum sheeting facade element with white coating 2x30x6800x1500
5. Concrete top floor with floor heating
6. steel HODY trapezium with concrete deck
7. I-steel construction beam HEM 450
8. U-steel construction element
9. Integrated sunscreen rolling system element
10. Lowered ceiling with plasterboard and stuc
11. Schüco FW60plus window frames
12. HR++ glazing with UV-filter foils



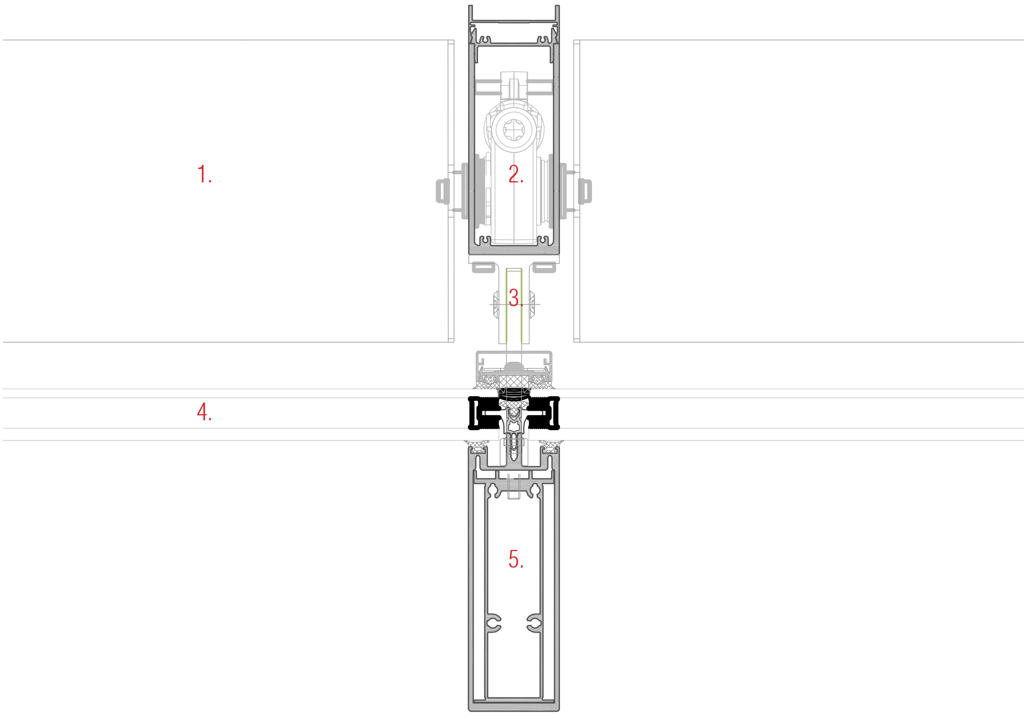
4.52 Vertical detail 9
scale 1:5



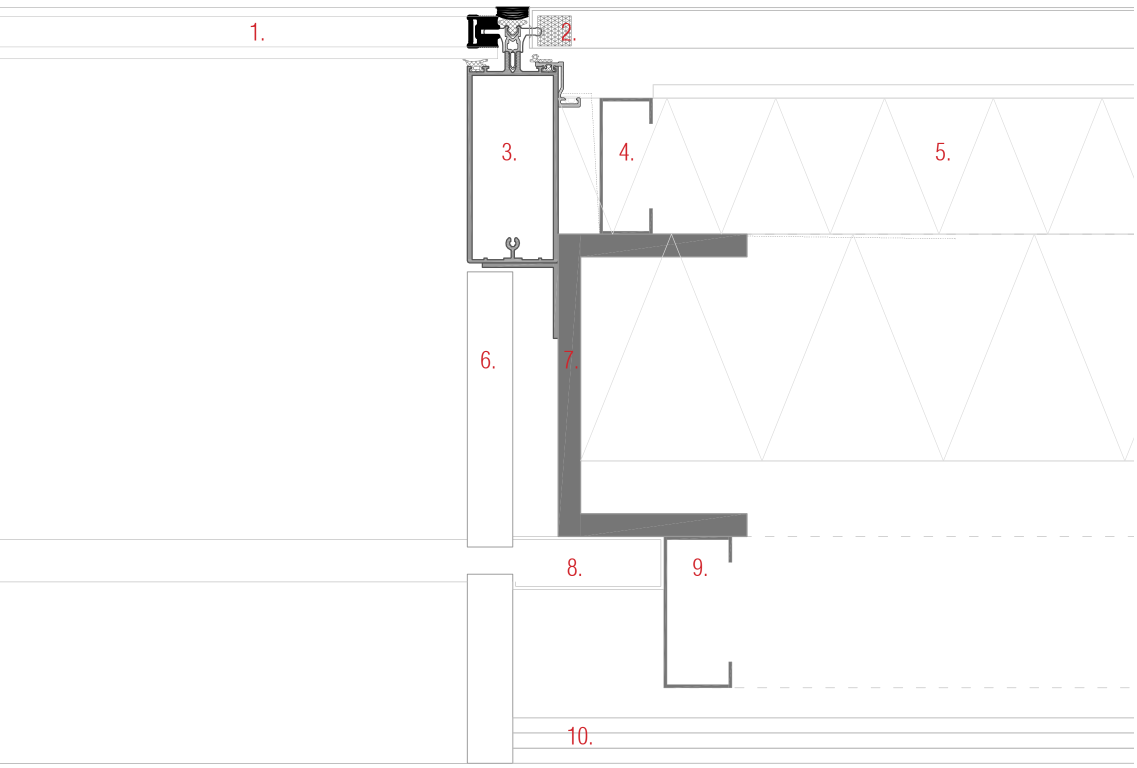
1. HR++ glazing with UV-filter foils
2. Concrete top floor with floor heating
3. Schüco FW60plus window frames
4. hard-insulation
5. Cast reinforced concrete 230 mm
6. L-steel mounting element
7. Precast concrete element 100x420x1500
8. Insulation EPS 200 mm
9. H-steel mounting element for precast concrete elements

4.53 Vertical detail 10
scale 1:5

1. Schüco aluminum large louvre blades ALB active system 205 mm
2. Schüco louvre frame with integrated active rotation system, retractable for maintenance
3. Support and guide rail for retractable louvre maintenance system
4. HR++ diffuse glazing with UV-filter foils
5. Schüco FW60plus window frames with reinforced structure

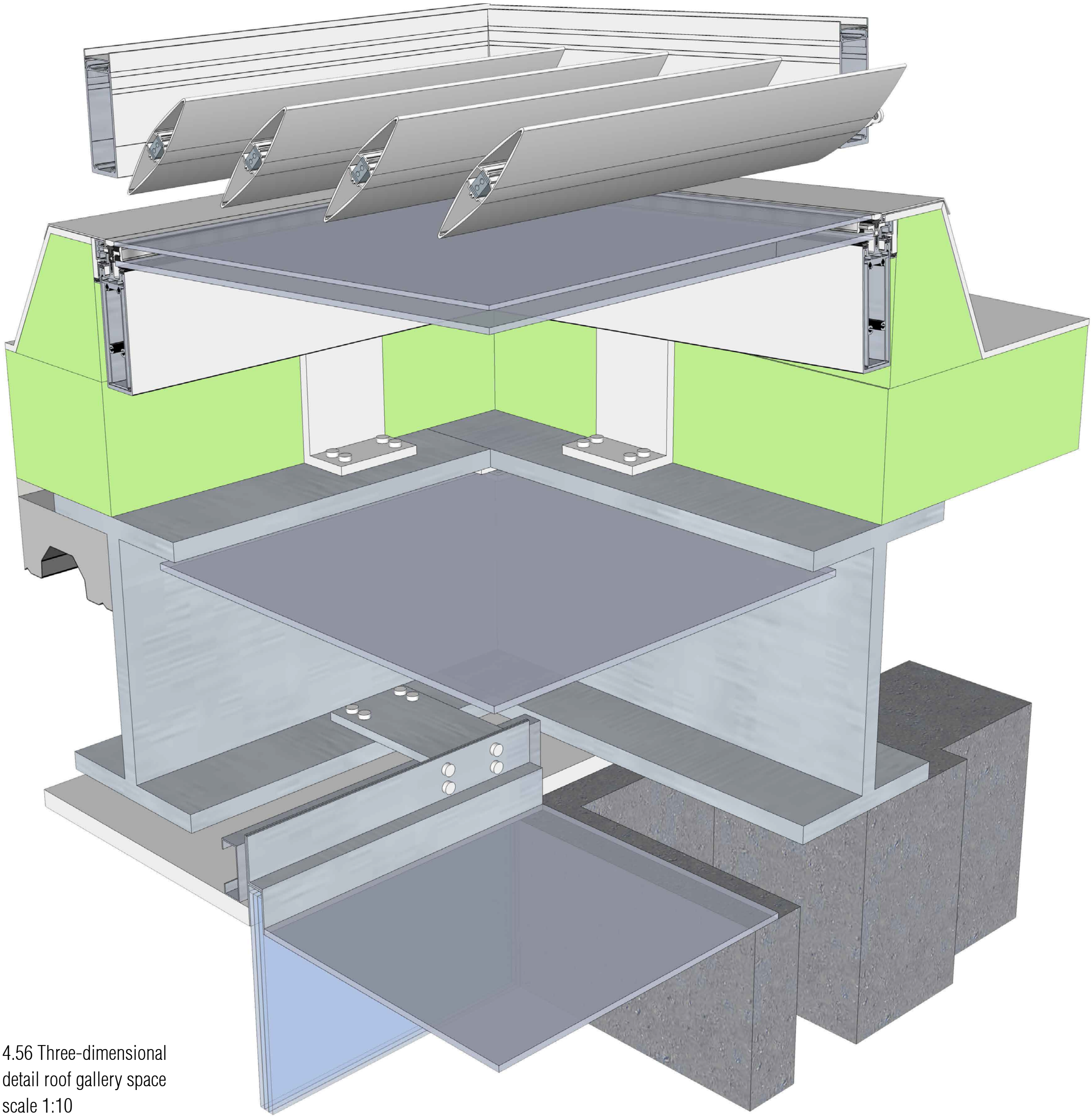


4.54 Vertical detail 11 longitudinal section gallery space
scale 1:5

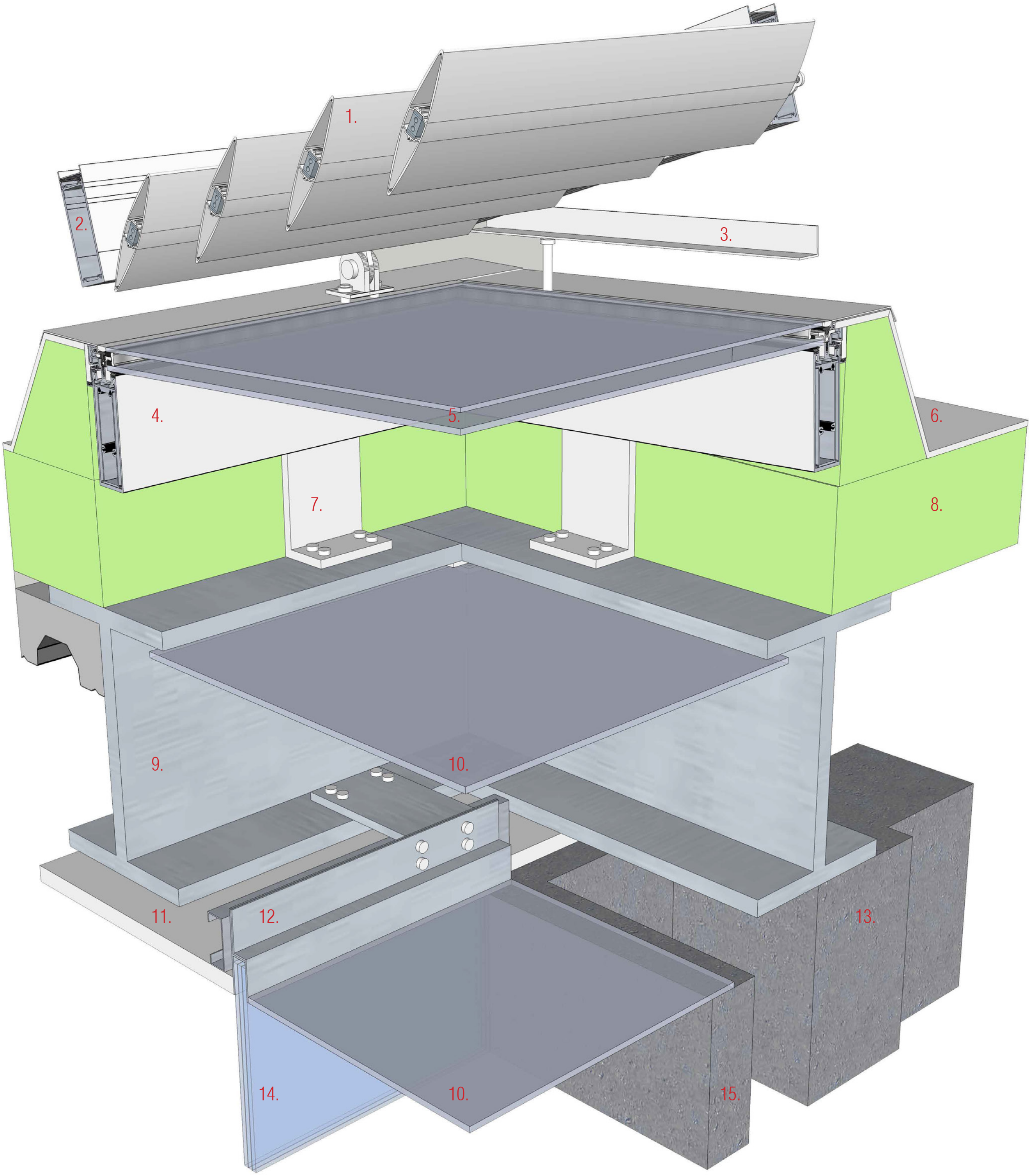


1. HR++ glazing with UV-filter foils
2. Aluminum sheeting facade element with white coating 2x30x1850x1500
3. Schüco FW60plus window frames
4. Metalstud structure
5. Insulation EPS 90+150 mm in metal substructure
6. Wood cladding window opening
7. U-steel construction beam
8. Integrated sunscreen rolling system element
9. Metalstud structure
10. plasterboard with stuc

4.55 Horizontal detail 12
window opening first floor
scale 1:5



4.56 Three-dimensional detail roof gallery space scale 1:10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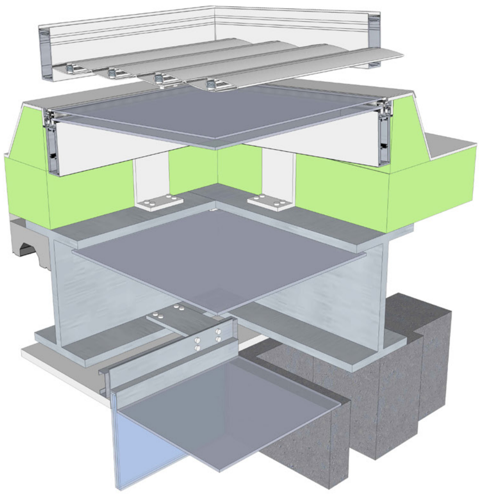
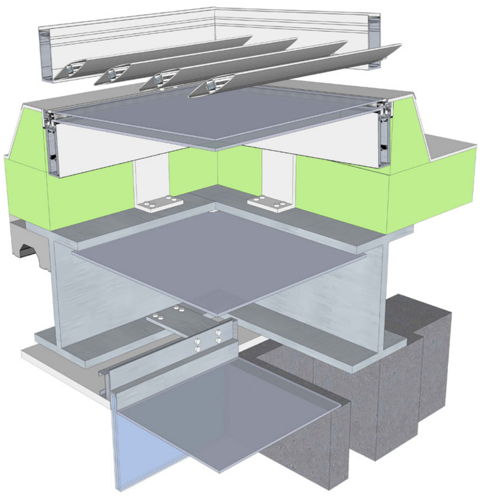
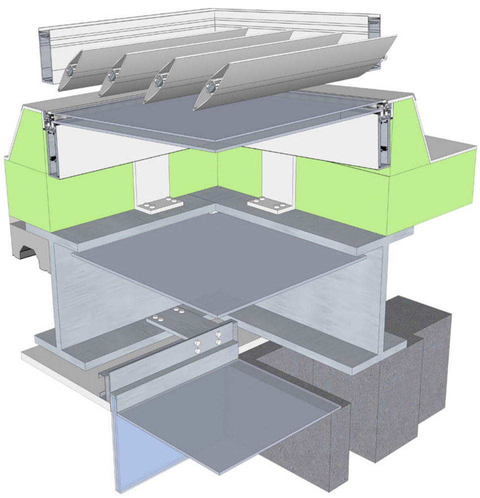
4.58 - 4.60 r. Three-dimensional detail maintenance roof gallery space.







1. Schüco aluminum large louvre blades ALB active system 205 mm
2. Schüco louvre frame with integrated active rotation system
3. Support and guide rail for retractable louvre maintenance system
4. Schüco FW60plus window frames with reinforced structure
5. HR++ glazing with UV-filter foils
6. White EPDM roof covering sheets
7. L-steel construction mounting element
8. Insulation layer EPS 200 mm
9. I-steel construction beam HEM 450
10. Diffuse glazing planels 1000x1000mm
11. plasterboard with stuc suspended from ceiling
12. Window frame clamp system
13. Cast reinforced concrete 250 mm
14. Triple layer laminated safety glass
15. Precast concrete element 100x3200x1500

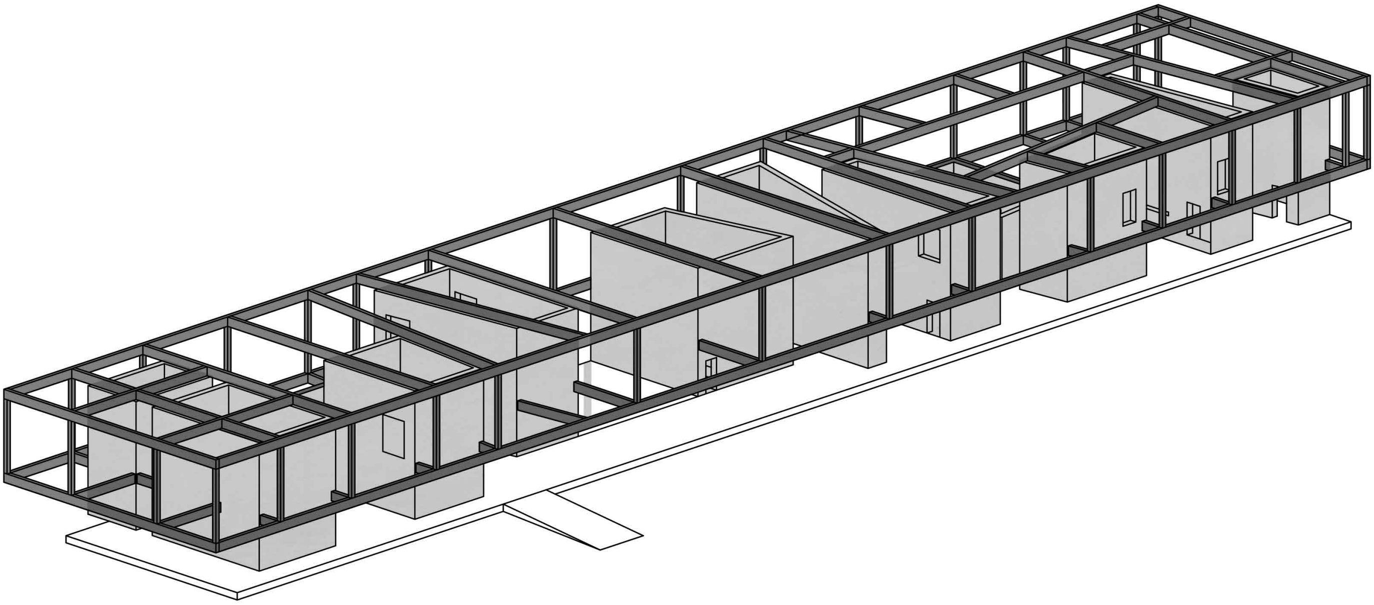
4.57 l. Three-dimensional detail maintenance roof gallery space
scale 1:10

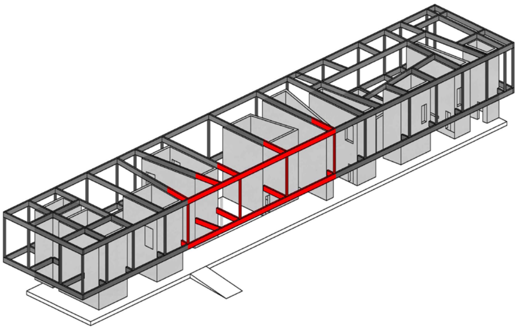
Three-dimensional details

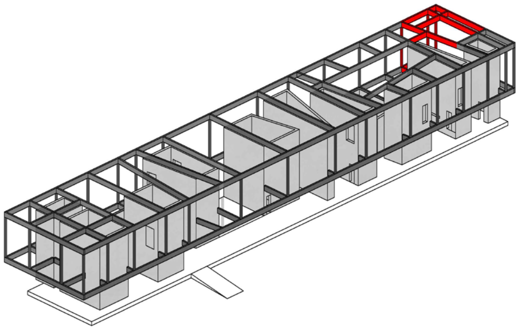
Louvre system
The first layer is a louvre system te adjust the amount of sunlight entering the gallery space. The louvres can be closed to block all direct sunlight or opened admitting the daylight. The louvre system element can rotate to the side for maintenance.

Diffusing layers
The gallery space has four layers of diffusing glass to provide an even distribution of light on the models. The first two layers have a thermal insulating function and UV-blocking film. The lower two layers of glass can diffuse the light into the gallery space without obstacles of construction elements.

Materials
The gallery space has a glass diffusing ceiling for an even distribution. A triple layer safety glass wall for the relation with the park and lateral daylight. The museum has a concrete core structure with steel I-shape HEM 450 roof beams. The window frame is an aluminium Schüco FW60plus window frame with a reinforced structure for the span of the gallery space.







Museum Drawings

Construction

main structure of the building are concrete center cores on the grid of the existing parking garage beneath. The cores have fixed steel beams on the first floor to support the top volume. The roof is a bearing steelstructure connected to the concrete cores.

The load of steel structure is calculated at the critical points to get the boundary values. All connections are fixed. The NEN Eurocode 1 is used for Loads on structures. The loads of the floors of a Museum building are category C, spaces where people meet. The load of the roof are category H, non accessible roofs only for repair and maintenance. This is calculated with uniform member loads

q_{floor} = total floor load
= variable floor load + permanent floor load
= 5 kN/m^2 + 8 kN/m^2 = 13 kN/m^2

q_{roof} = total roof load
= imposed roof load + permanent roof load
= 1 kN/m^2 + 4 kN/m^2 = 5 kN/m^2

$q_{floor, line}$ = 50,5 kN/m
$q_{roof, line}$ = 131,3 kN/m

serviceability limit state, deflection is
δ_{max} = 0,024 mm
The beams to be applied at the critical points are HEM 450

4.61 Structure scheme
conrete cores with steel structure.
scale 1:500

4.62 I. Structure scheme
critical point 1

4.63 Structure scheme
critical point 2

Conclusion

Reflection

Preceding the in depth Building Technology research was the graduation project ReCollection. The group research started with investigating the life, journey and architecture of Sir John Soane. His architectural choices gave a new perspective on the possibilities of lighting in museum spaces. The objective for the Architecture graduation project was a museum design for a specific collection. This resulted in the design of an Architectural Model Museum in the Museumpark of Rotterdam.

The Building Technology research is an investigation for an optimal daylight solution for the central gallery space. An adequate Building Physical knowledge was required to understand the basic characteristics of light. This has led to a better understanding of what information is required in lighting design. The research was necessary for the set-up of the contents for the first two sub-questions; *Characteristics of Light in Museum Spaces* and *Characteristics of Light on Collections.* Most difficult was to organize the enormous amount of general information and to filter the appropriate information. My educational background in Building Physics was limited and therefor I had to get an understanding of the theory.

The greater part of these two research questions is Building Physical knowledge. One could ask if this fits in the master Building Technology. However, it provides insight into the possibilities and constraints of light design and is necessary for making a thorough design solution for the central gallery space. Building Technology focuses on all of the aspect of Architecture Building and Planning.

The casestudies in the chapter *Museum Light Design in Practice,* frame the research and provide six design options. The analysis of the options with a 1:20 scale model of the gallery space was a challenge to make it as realistic as possible. The interpretation of the casestudies to fit with the central gallery space required a adjustment of the designs, approximating materials and artificial light. The result of the research has led to an optimal design solution which is validated in the scale model. A skylight roof construction with Building Technical solutions for a better performance and optimalization of the museum space.

Glossary

Key words

modelling
model
methodology
light
skylight
daylight
artificial light
materiality
exhibition
objects
space
gallery
diffuse
direct
practice
renown architecs

Sir John Soane
Frank O. Gehry
Louis Kahn
Renzo Piano Building Workshop
Jacques Herzog
Pierre de Meuron
Herzog & de Meuron
Peter Zumthor

Sir John Soane's Museum
Vitra Design Museum
Kmibell Art Museum
Piano Pavilion
de Young Museum
Kunsthaus Bregenz

List of Sources

Picture Sources

Introduction B

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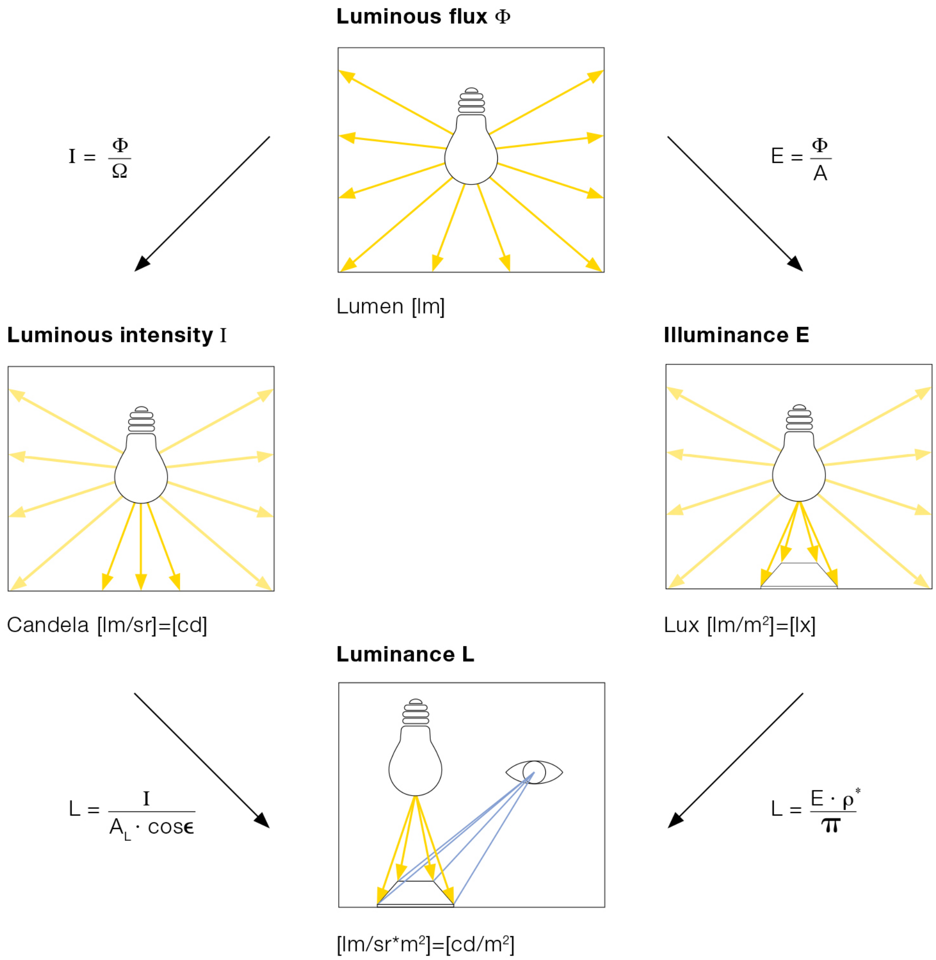


Ω = solid angle into which luminous flux is emitted
A = area hit by luminous flux
$A_L \cdot \cos\epsilon$ = visible areas of light source
ρ = reflectance of area
π = 3.14
* = for diffuse surface areas

A.2 Basic parameters used in lighting. Luminous flux, Luminous intensity, Illuminance, Luminance

Attachment A

Light Design

This research will go into the specific light design for an Architectural Model Museum with a gallery space and an architectural model collection. This is an introduction to the general characteristics of light which will be of influence on the space and objects. The next parts are natural daylight, artificial light, light on surfaces and artificial light. To understand the design options of light, the possibilities of the control have to be explained. The design of light can be divided into four subjects:

What is light design?
- Intensity
- Distribution
- Colour
- Movement

Intensity
Light has an intensity, lighting science generally talks about the amount of light in pieces, these are called *Lumens*. This is the *Luminous flux*, the quantity of light from a light source. The light density is the amount of lumens per area. Lighting science is concerned how the pieces of light affect the human vision. A unit of light energy is measured, how it affects the sensitivity of the human eye.
The *Illuminance* is the measurement of lumens onto a surface. Illuminance is expressed in *Lux* or *Lumen per square meter.*

Illuminance (E_v) = *lux* (lx) = *lumen* (lm)/m²

The *Luminance or Exitance* is the lumens off of a surface. The Luminance is expressed in *Candela per square meter*, it is a unit for light density (cd/m²).

Luminance (L_v) = *candela* (cd)/m²

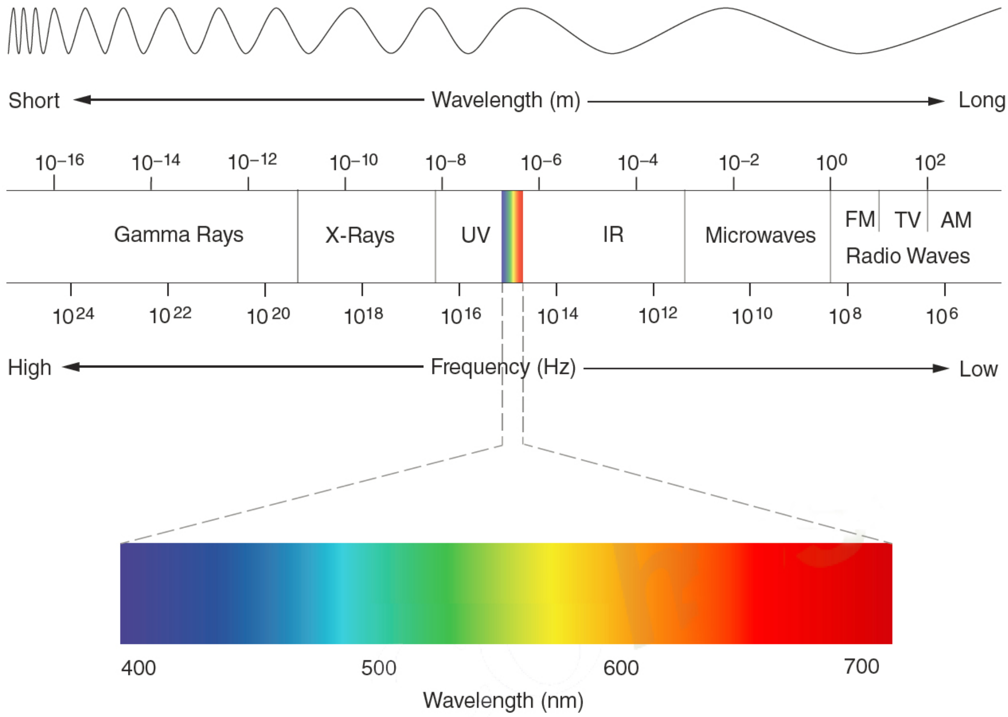
The *Luminous Intensity* in *Candela* is equal to *Lumen per Steradian* of spherical area. A steradian is larger when the sphere around the lightsource grows, because light spreads out spherically from it's origin. The steradian solid angle grows larger but the luminous flux passing through stays the same. The specific direction of light has a density of lumens.

Luminous Intensity (I_v) = *candela* (cd) = *lumens* (lm) / *steradian* (sr)

and,

lux (lx) = *candela* (cd) · *steradian* (sr)/m²

in *The Architecture of Light* (2008),(70) the light levels in design are discussed. The intensity of light can be different, from low dimmed light for intimate spaces to bright light exposure for a more public environment.



A.3 Electromagnetic spectrum.

Surface Colour	Reflectance factor %
White	70 - 85
Light gray	45 - 65
Medium gray	25 - 40
Dark gray	10 - 20
Black	<5
Yellow	65 - 75
Yellowish brown	30 - 50
Dark brown	10 - 25
Light green	30 - 55
Dark green	10 - 25
Pink	45 - 60
Light red	25 - 35
Dark red	10 - 20
Light blue	30 - 55
Dark blue	10 - 25

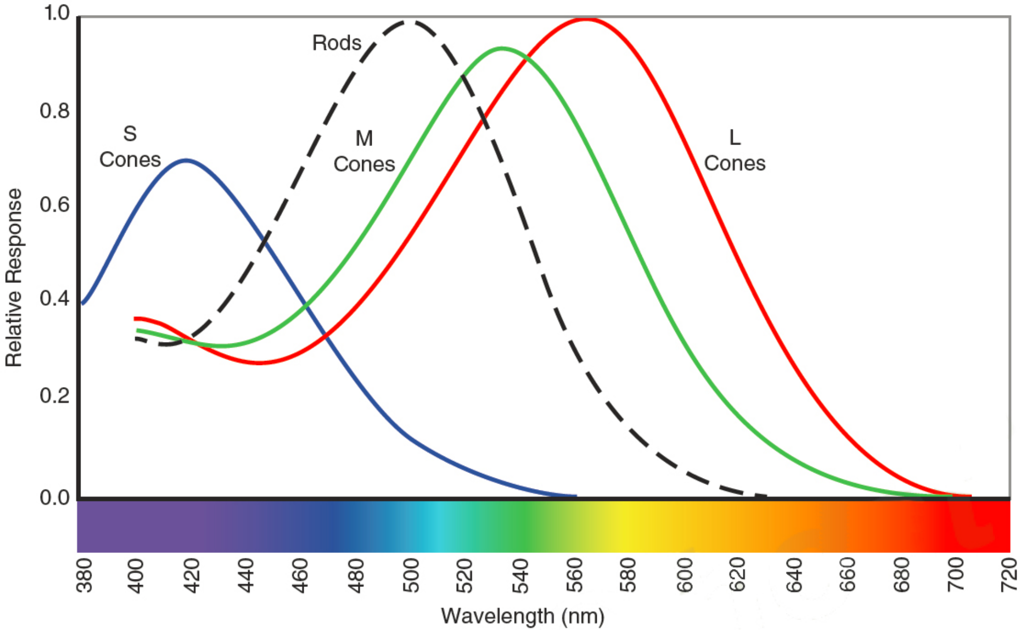
Surface Material	Reflectance factor %
Mirrored and optical coated glass	80 - 99
Metalized and optical coated plastic	75 - 97
Aluminum, processed anodized and coated	75 - 95
Lacquer, brilliant white	87 - 88
Aluminum, high-gloss anodized	75 - 87
Aluminum, mat anodized	75 - 84
White glass	75 - 80
Marble, white	60 - 70
Stainless steel	60 - 65
Concrete, light	30 - 40
Concrete, dark	15 - 25
Sandstone, light	30 - 40
Sandstone, dark	15 - 25
Granite	15 - 25
Brick, light	20 - 30
Brick, dark	10 - 15
Mortar, light	35 - 50
Wood, light	30 - 50
Wood, dark	10 - 25

Ground Surface	Reflectance factor %
Meadow, lawn	approx. 5
Snow, fresh	approx. 70
Snow, old	approx. 50
Fields	approx. 25
Concrete	approx. 50
Gravel	approx. 20
Grit	approx. 10

A.4 Reflectance factors for different colours, materials and surfaces

When the light is too bright, glare may occur and this can cause blinding. *Direct glare* occurs when the light come directly from a light source. There is *reflected glare* through a reflection of a brightly illuminated object into the eye. The third type is disability glare when the light source is brighter then the objects surrounding it.
Without the minimal amount of light, the room appears gloomy and dark The colour vision of the human eye starts to be affected when the illuminance is lower then 75 lux.

Distribution
Light is a visible part of the electromagnetic spectrum, it is energy and travels in waves. (figure 0.2) The rods in the eye can adapt to sense brightness, in darkness they become more sensitive. The light has wavelenghts from 380 to 770 nanometer, this is also related to the color and will be explained later. The light comes from a light source, this can be natural daylight or artificial light, both have their characteristics which will also be explained later. The light from a source eventually reaches a surface.
The *Exitance* is the lumens leaving a surface considering the reflectiveness of the surface it has no unit of measurement. It is the illuminance onto a surface mutiplied by the reflectance in percentages. The reflectance factor for different colours, materials and surfaces is illustrated in (figure 0.3).
The distribution of light results in brightness and contrast on a surface. In *Designing with Light* (2014) (71) is explained; “Room brightness is a combination of the intensity of the light and the reflecting, diffusing, transmitting and absorbing properties of the surface in the room.“
Reflection of a surface has three types, *specular* where the angle of incidence is the same as the angle of reflection, *semi-specular* surfaces that reflect a part of the light and scatter the other part, the *matte* surface is diffusing all of the light and sends the light in all directions. Almost all materials become a secondairy light source by the reflection of the light, this is inter-reflection. This light reduces shadows and contrast and increases the overall brightness of the space. Not all the light is reflected, part of the light is *absorbed* by the surface. Materials with a lighter colour reflect more light then dark, low reflectance surfaces
Refraction occurs when light is passes through a material. The angle of incidence and the refraction angle determine the refraction of the light.
Diffusion is the scattering of light, the light is refracted in all possible directions.
Transmission is light going through a material. The material can be *transparent*, it is clear and the eye can see through. A



A.5 Rod and cone sensitivity curves

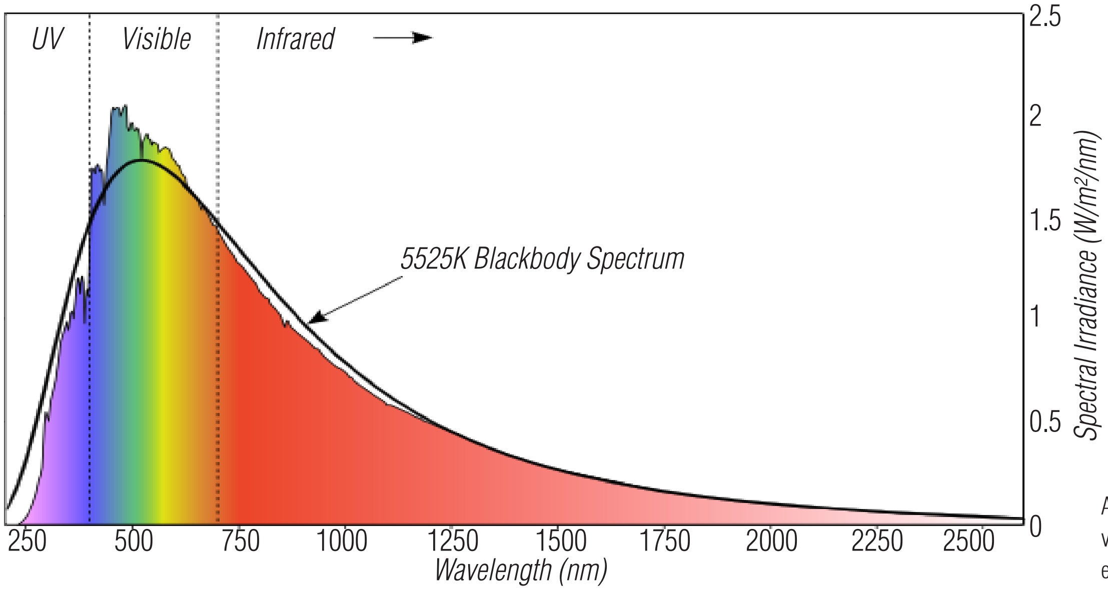
translucent material is transmitting light, the light is scattered and the objects are blurred. Through an *opaque* material does not pass light, it blocks the light.

Colour

Light has a colour, it is a name for an experience of the mind. the human eye can detect the wavelength range between 380 and 780 nm. Every wavelength will give another predictable colour experience. This is from short-wave violet with a high frequency and energy to long-wave red light with a low frequency and energy. The interpretation and experience of colour can vary per person, the translation is subjective. "This model of colour vision leads to the understanding that the sensation of colour is merely the brains translation of the retina's detection of different quantities of different wavelengths of light." The *Architecture of Light* (2008) adds "This has important ramifications in that we can artificially create any colour experience we want through an engineered combination of many different wavelengths of light."(72)
In close range of visible light in the electromagnetic spectrum is the ultraviolet (UV) and infrared (IR) rays on the lower and upper border. (figure 0.3) The eye has three types of cone receptors for colour and therefor out visual system is trichromatic. The cones are sensitive to short, medium and long wavelengths and can combine information together to sense and see the full spectrum. (figure 0.5) Colour and colour temperature can influence the mood. Warm colours evoke a relax state of mind while cool colours evoke productivity and colours with a high saturation evoke interest.
The colour temperature indicates the warmth or coolness of white light. It is derived from the heating of an incandescent source. Incandescent materials emit different colours of light at a specified temperature. The standard for discussing the colours is a blackbody radiator. *Designing with light* (2004) describes; "A blackbody is an object or material that perfectly absorbs all electromagnetic energy that strikes it."(73) The energy is not radiated equally at all wavelengths by the blackbody. "As the temperature increases, and thus the amount of radiated energy increases, the peak wavelengths of visible light emitted shifts from red (long wavelength and low energy) to blue (short wavelength and high energy)"(74) The spectral distribution curve (SPD) shows the light source radiant power at each wavelength, based on the theoretical spectrum of a blackbody. The blackbody is the refrence standard when discussing colour temperature. Light of other sources then incandescent is compared to a blackbody to determine the correlated colour temperature(CCT).

Light	Luminance (cd/m²)
Minimal perceptible level	0.000001
Darkest sky	0.0004
Night sky	0.001
Typical night sky in big city	3
Sky at sunrise or sunset	25
Zenith at sunset	100
Average cloudy sky	2000
Full moon	2500
Blue sky	4000
Overcast sky	6000
Average clear sky	7000 - 8000
white illuminated cloud	10000
Sun at horizon	600000
Sun at noon	1600 000 000

0.6 Luminance levels of the sky in (cd/m²). There is a considerable range in values, the numbers are typical.



A.7 Solar spectrum. UV, visible light to the human eye and infrared light.

Light Colour	Colour temperature (K)
Red	1800
Candle Flame	1900
Sun at sunrise and sunset	2000
Very warm	2200
Warm	2700
Incandescent lamp	2850
Quartz lamp	3200
Neutral (white florescent)	3500
Cool (white florescent)	4100
Daylight fluorescent	5000
Cold, sun direct at noon	5000 - 5400
Sun and clear sky at noon	5500 - 6000
Daylight fluorescent	6000
Daylight	6500
Overcast sky	6000 - 7500
Very cold	7500
Overcast sky (average)	8000
Winter North sky	10000
Icy cold	12000
Average blue sky	13700

A.8 Colour temperature and characteristics.

Daylighting

Intensity
The illuminance of daylight has many variable factors. The brightness of the incoming daylight depends on the time of day, time of year, weather conditions like direct sunlight, precipitation and overcast, the shading of surrounding objects like buildings and vegetation, reflections of glass and mirrors, high air pollution levels of particulate matter mainly in large cities and more conditions. Daylight as a source is very intense, daylight design is a study of controlling the light. The sensitivity of the human eye in sky brightness varies greatly, this depends on the atmospheric conditions. Various lumination levels of daylight, where the sky is considered as a surface, are illustrated in (figure 0.6). The *Daylight Factor* (DF) is the spatial distribution of natural light, it is a percentage of the outside illuminance compared to the inside illuminance of a space and has no precise level. The Daylight Factor is inadequate in dynamic changes in sky conditions per location.
A new units of measurements according to *Assessment of Daylight Performance in Buildings* (2015) is the *Usefull Daylight Illuminance* or Usefull Daylight Index (UDI). “Natural illumination of a work surface involves continuous variations and consequently significant differences, both from the spatial and temporal points of view, just as the levels of illumination differ greatly when evaluated near a fenestrated front or with respect to the most distant point, as happens from one instant to the next as a result of a change in external weather conditions.”(75)
The system provides data over 12 months about the usefull daylight illumination and excessive levels of natural light. It is defined that the illumination levels in a space that rage from 100 - 2500 lux interval are usefull. Outside these broders the light is defined as insufficient or exceeded.
According to *Lightbook* (2001) (76), the illuminance of the midday sun with a clear sky is on a winter day is about 10000 lux and a summer day has over 100.000 lux. When there is an overcast sky the winter values are 2000 lux to 20000 lux in summer. There are recommendations and regulations by European standards (EN 12464) of 500 lux nominal illuminance value in indoor daylight oriented workplaces. This can be partly supplemented by artificial light.

Colour
The daylight sky has a blue colour, in the short-wave blue end range of the spectrum this is because the light entering the earth atmosphere is scattered. We percieve this natural daylight as white and *Lighting Design* (2006) (77) states “It seems that our visual system can assess the spectral properties

of the incoming rays and compensate for this effect on the appearance of objects."
The perception of the sky can, depending on the weather conditions, be more white, grey or blue when there is an overcast or cloudless sky. The colour changes over the course of the day. The sunrise and sunset have a red coloured appearance in the long-wave range "because the light must travel a longer distance through the denser strata of the atmosphere closer to the surface of the earth."(78) The solar spectrum is wider then the light visible to the human eye, this is illustrated in (figure 0.7).
Daylight has a positive effect on the human physical and psychological well-being. Most of the sensory information is percieved with the eyes. *Lighting Design* (2006) states: "Light enables spatial perception and orientation, it is light that lets us recognize and distinguish colours."(79) Colour has a positive effect on the emotional state, it heightens concentration levels and optimism, it raises an attractive and comfortable feeling. The spectrum frequencies of natural sunlight blend to a white light and there is no substitute for these qualities. The spectral composition of light moves all day from blue to red and is rich in the short-wave part of the visual spectrum. The colour temperatures found in daylight are illustrated in (figure 0.8). The sun itself has a colour temperature of 5800K.

Distribution
Natural daylight is dynamic and changes depending on the season and time, the solar position and sky conditions. It is emitted from all sides of the hemisphere and illuminates the surrounding.
There are two different ways of solar radiation, direct and diffuse radiation. Direct radiation are rays directly from the sun, diffuse radiation is from a blue sky or through a cloud cover. An interior space should have a sufficient number of daylight openings for natural lighting. The planning rules of 30°/45° are not a requirement according to *Lighting Design* (2006) (80) but more of a guideline. It is a basic design strategy based on the lineary spreading of light. 30° is in relation with the available light in the sky and the 45° is the lateral light behind a window. When projecting the 30°/45° to a vertical window, the space that is adequately lit can be drawn. When projecting to a skylight, the area above the 30° angle will be adequately lit. The width of the area lit is the height of the room added to the with of the skylight.
The variation of daylight affects the well-being of people, the rhythm of light and dark influences the performance and human health. In *Daylighting and Integrated Lighting Design* (2015) is stated that "exposure to bright light at the appropriate time of day and for appropriate durationhas been shown

to alleviate sleep disorders and daylight is usefull resource to provide the bright light exposure, timing, and duration required."(81) The daylight supports alertness and productivity but with it's cycle also the sleep - awake habituation. It is not sufficient to only include the specified amount of daylight in a building. The design requires reducement of glare, providing a usefull amount of diffuse daylight, and preferably a high quality view outside. The presumption of experts for many years was an ergonomically correct light, this resulted in monotone illumination without contrast and reflection. The standards exist but it is not the only purpose of lighting design today.

The negative side effects of daylight on the human body are sunburn when being exposed to the sun without protection and this can result in skincancer. Precautionary measures should be taken to prevent this from happening. Materials suffer from exposure to certain wavelengths of light this is called photodegradation and will be described later in the following chapter about light on the collection.

The different daylight techniques for illumination of a space are: Sidelighting, toplighting and corelighting. *Assessment of Daylight Performance in Buildings* (2015) (82) describes the *sidelighting* as a system of architectural solutions with vertical openings in the façade for natural lighting. The window size, window positioning, depth of the room and orientation of the opening are important for the amount of daylight. More equal distribution of light in the space can be met with different strategies. Overbrightness, overheating and glare can be prevented with shading options.

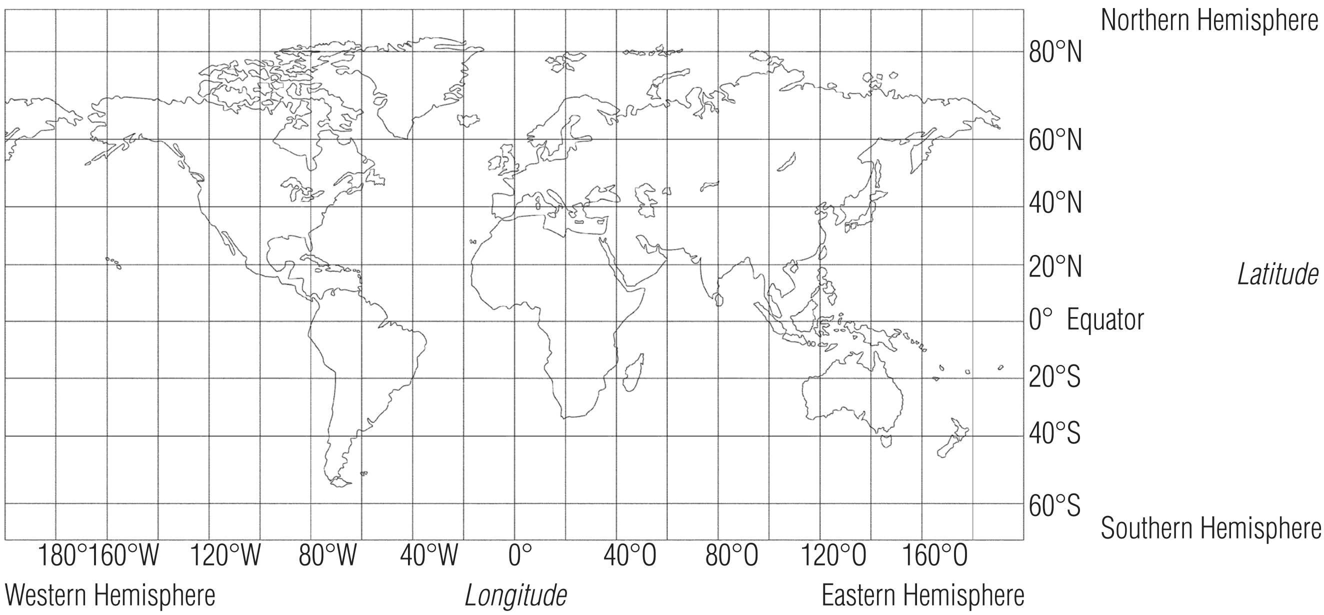
The *toplighting* is a strategy to allow natural light deep into to the space with skylights or roof monitors. The space is largely illuminated by the best available and brightest part of the sky. The size of the toplight in relation to the space is important for the perception of the user. With control and shading systems the overheating and glare can be prevented.

The last is *corelighting*, it is a technique that uses optical ducts, atria and inner courtyards. This method is often a combination of side- and top-lighting. To get a suficcient amount of light into the spaces, the relation of height and depth should be similar. Cetainly not exceed twice the height of the daylight opening. This technique has a very bright central space in relation to the surrounding spaces. The central space can be controlled with shading options.

Shading systems are available in many variations both internal and external.

Their function can differ from sunshading, overheating, and directing light to preventing

System	Position	System performances: Glare protection	External view	Defl ected light	Homogeneous distribution	Energy saving	Manual/automatic operation
Prismatic panels	Vertical windows and skylights	D	X	D	D	D	D
Prismatic panels	Vertical windows	V	V	X	V	V	V
Louvre and blade systems	Skylights	D	X	X	V	X	X
Anidolic zenithal systems and anidolic ceilings	Skylights and glass roofing	V	V	X	V	V	X
Lightshelf	Vertical windows and skylights	D	V	X	D	V	V
Systems and windows for directing sunlight	Vertical windows and skylights	D	V	X	V	V	V
	Direct lighting systems						
Guided diffusion systems	Transparent windows	V	V	D	D	D	X
Louvres and Venetian blinds	Vertical windows	V	D	V	V	V	V
Lightshelf	Vertical windows	D	V	–	V	V	D
Glazing and holographic optical element (HOE) systems	Vertical windows	D	D	D	D	D	X
Skylights with laser-cut panels	Vertical windows	D	–	D	V	V	D
Lightshelf	Vertical windows and skylights	D	D	D	D	D	V
Venetian blinds with anidolic systems	Vertical windows	V	D	D	V	D	D
Lightshelf	Vertical windows	D	V	D	D	D	X
Integrated anidolic systems	Vertical windows	X	V	V	V	V	X
Anidolic ceilings	Transparent façades	–	V	V	V	V	X
Fish system	Vertical windows	V	D	V	V	V	X
Glazing and HOE systems	Transparent façades in glazed courtyards	–	V	V	V	V	X
	Indirect lighting systems						
Laser-cut panels	Vertical windows and skylights	X	V	V	V	V	X
Prismatic panels	Vertical windows and skylights	D	D	D	V	D	D
Glazing and HOE systems for skylights	Skylights	D	V	V	D	V	X



A.9 Review of the main shading systems. Shielding systems for daylighting. V is Yes, X is No, D is depends

A.10 Latitude and longitude lines to determine the coordinates of the position on the earth.

excessive glare. They shield the sun and provide a desired amount of daylight. The different options and characteristics for shadingsystems are shown in (figure 0.9). The lightshelf, louvre, prismatic panels, laser cut panels, light guiding shades, sun-directing glass, glazing and shading systems that employ HOE materials(film coating), zenithal anidolic systems and anidolic ceilings are futher explained in *Assessment of Daylight Performance in Buildings* (2015).(83)

Movement

The location on earth is determinative for the orbit of the sun and the altitude of insolation. Therefore the horizontal latitude *(local latitude)* and vertical longitude *(local longitude)* of the location must be determined. (figure 0.10) Maps and website tools are available to obtain the position.
The altitude of the sun changes depending on the location, time of year and time of day. This is a cycle that is repeated throughout the seasons. *Lightbook* (2001) states; “The extreme values are particularly important for making general statements about lighting conditions.”(84) The position of the sun at solar noon is the highest on June 21 and the lowest on December 21. On the northern hemisphere, these are the summer and winter solstices. On March 21 and September 23, the sun rises in the east and sets due west, the vernal and autumnal equinoxes. (figure 0.11) The direct insolation shows the changing position of the sun, where the length of the shadow of every object changes during the seasons. At the equinox solar noon, on March 21 and September 23, where the sun is perpendicular above the equator, the position of the sun is:

21 Mar. & 23 Sept. = 90° - (local latitude)

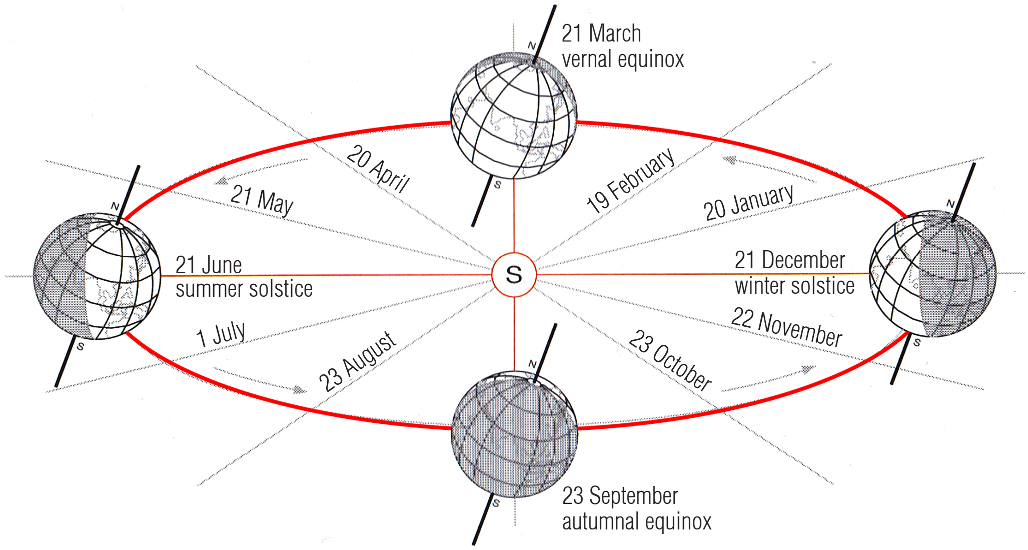
The axis of the earth is tilted in relation to the plane of the earth’s orbit around the sun by 23.5°, this effects the calculation. The highest altitude of the sun at solar noon is on June 21:

21 June. = 90° + 23.5° - (local latitude)

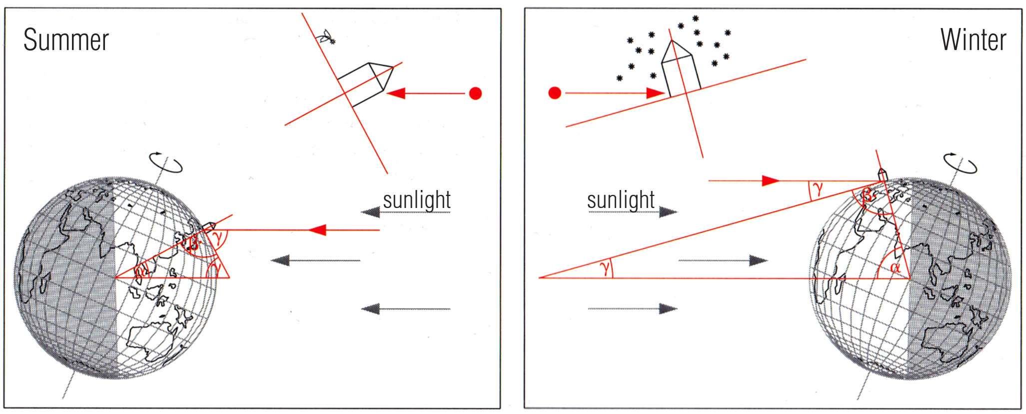
The lowest altitude of the sun at solar noon is on December 21:

21 Dec. = 90° - 23.5° - (local latitude)

This is illustrated in (figure 0.12 & 0.13). The parallel sunlight reaches the location at an angle γ. These rays form a right angle β with the *(local latitude).* The incline of the earth’s axis towards the orbit of the earth around the sun is α. This is the direction of the sun rays at an angle of 23.5°. This results in the following for the summer :



A.11 The position of the Earth in orbit around the sun throughout the northern hemisphere seasons. The length of the day and highest position of the sun vary, the solstice and equinox have extreme values.



A.12 & A.13 The incline of the Earth's axis affects the length of the shadow of every object on earth and the solar radiation.
Left the summer and right the winter season on the northern hemisphere. The southern hemisphere has reversed seasons.

$$\alpha + \beta + \gamma = 180°$$
$$\alpha = \textit{(local latitude)} + 23.5°$$
$$\beta = 90°$$
$$\gamma = 180° - \alpha - 90°$$

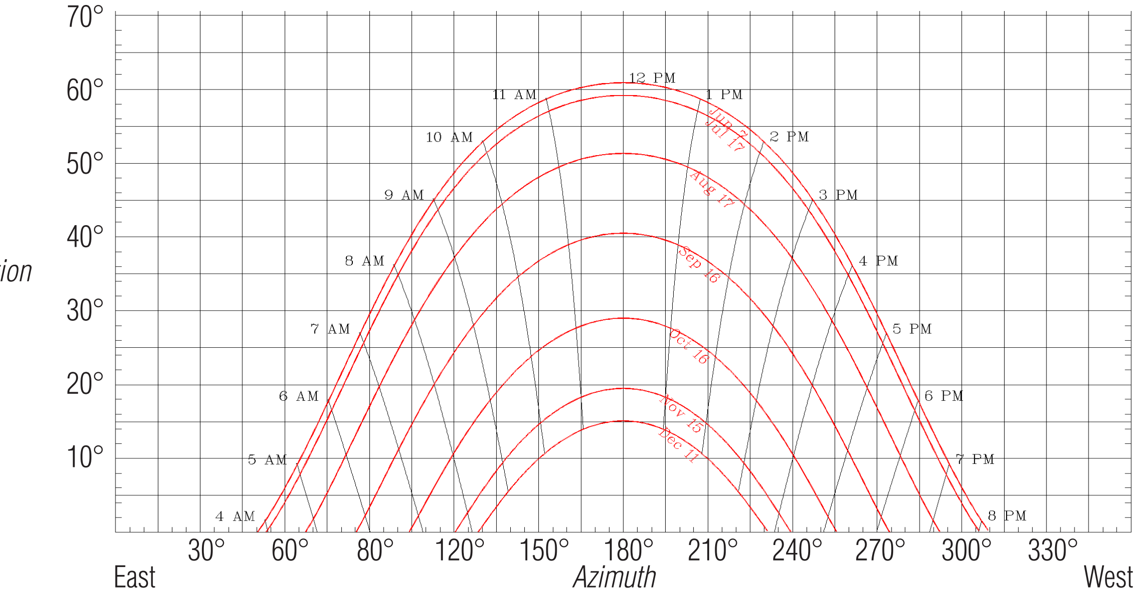
And the situation in the winter:

$$\alpha + \beta + \gamma = 180°$$
$$\alpha = \textit{(local latitude)} - 23.5°$$
$$\beta = 90°$$
$$\gamma = 180° - \alpha - 90°$$

The calculations are explained in *Lightbook, the practice of lighting design*. (2001) (85)
The altitude of the sun on a specific location during the day demands more complicated calculations and will not be discussed in this book. Online websites offer tools to calculate this by entering the location:
www.timeanddate.com(86)
solardat.uoregon.edu(87)
The results vary by location on the northern, southern, eastern or western hemisphere(figure 0.14) and can be combined in a sun position diagram. The graph shows the course of the sun through the seasons. (figure 0.15) The position of the sun in the sky is given by the azimuth, the horizontal component from east to west, and the height, the angle between the sun and the horizon.
It can be used to draw the insolation of a building into the floorplan and section views.
Provide insight into the technical building properties required in the façade and interior.

Location	Latitude	Longitude	21 June	21 Mar. / 23 Sept.	21 Dec.
Murmansk	68.96° N	33.08° E	44°	21°	no sun
Amsterdam	52.37° N	4.90° E	61°	38°	14°
Rotterdam	51.92° N	4.48° E	61°	38°	15°
London	51.50° N	0.12° W	62°	38.5°	15°
Eindhoven	51.44° N	5.48° E	62°	39°	15°
Paris	48.86° N	2.35° E	64°	40.5°	17°
Milan	45.47° N	9.19° E	68°	44.5°	21°
New York	40.71° N	74.01° W	72°	48.5°	25°
Beijing	39.90° N	116.41° E	73.5°	50°	26.5°
Los Angeles	34.05° N	118.24° W	80°	56.5°	33°
Dakar	14.76° N	17.37° W	98.5°	75°	51.5°
The Equator	0.00°	0.00°	113.5°	90°	66.5°
Cape Town	33.92° S	18.42° E	80°	56.5°	33°
Melbourne	37.81° S	144.96° E	29°	29°	76°
Ushuaia	54.82° S	68.27° E	12°	35°	58°

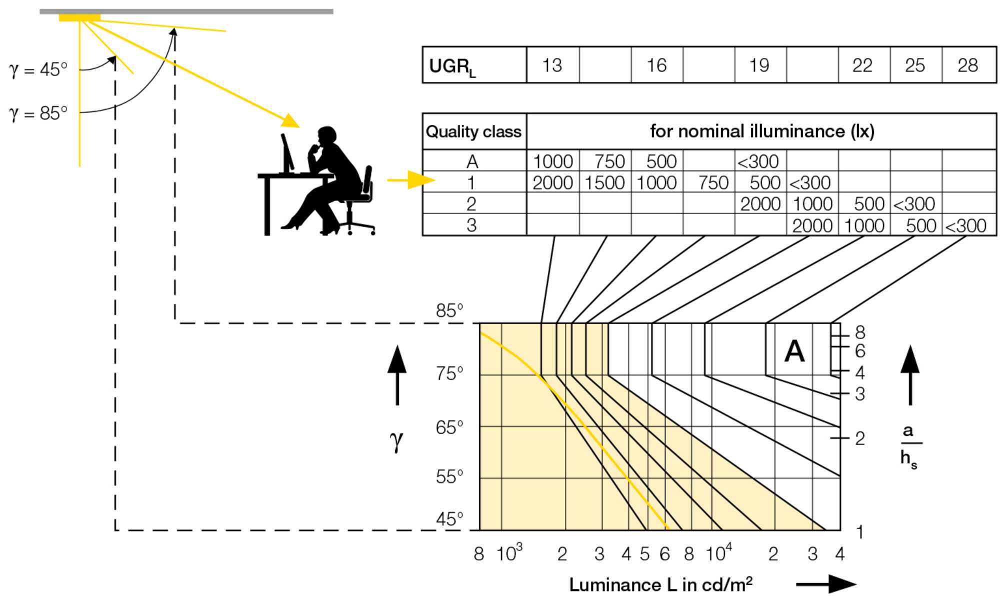
A.14 Altitude of the sun at different cities at solar noon.



A.15 Sun position graph for location Rotterdam, the Netherlands 51.92° northern latitude. The graphics show the course of the sun from east to west with it's extreme values, various elevations throughout the day and year

		$\bar{E}_m$	UGR_L	U_0	R_a
Traffic zones and general areas inside buildings					
Circulation areas within buildings	Circulation areas and corridors	100	28	0.40	40
	Stairs, escalators, moving walkways	100	25	0.40	40
	Elevators, lifts	100	25	0.40	40
	Loading ramps/bays	150	25	0.40	40
Rest, sanitation and first aid rooms	Canteens, pantries	200	22	0.40	80
	Rest rooms	100	22	0.40	80
	Cloakrooms, washrooms, bathrooms, toilets	200	25	0.40	80
Offices	Filing, copying, etc.	300	19	0.40	80
	Writing, typing, reading, data processing	500	19	0.60	80
	Conference and meeting rooms	500	19	0.60	80
	Reception desks	300	22	0.60	80
	Archives	200	25	0.40	80
General areas of public assembly	Entrance halls	100	22	0.40	80
	Cloakrooms	200	25	0.40	80
	Lounges	200	22	0.40	80
	Ticket offices	300	22	0.60	80
Restaurants and hotels	Kitchens	500	22	0.60	80
	dining room	–	–	–	80
	Self-service restaurants	200	22	0.40	80
	Corridors	100	25	0.40	80
Museums	Exhibits, insensitive to light	according to requirements			
	Light-sensitive exhibits				

A.16 European Standard values for lighting of indoor public and workplaces. “Lighting of indoor workplaces”, EN 12464-1 (June 2011)
$\bar{E}_m$ = (average) maintained illuminance
UGR_L = UGR limits for rating direct glare
U_0 = Uniformity ratio between the lowest (E_{min}) and the mean illuminance level ($\bar{E}$) in the area to be evaluated
R_a = lower limit for the colour rendering index



A.17 Unified Glare Rating method levels and corresponding illumination levels.

Artificial lighting

Intensity
The minimum acceptable illuminance requirements for the visual task area is defined in European standards, "*Guide to DIN EN 12464-1 Lighting of work places, Indoor work places*"(88) by the Committee for European Standardisation (CEN). The guidelines recommend the same characteristics outside the working area but this is not obligatory. Museum spaces belong to the "places of public assembly"(figure 0.16) and are an exception to the regulations. Exhibits insensitive to light and light-sensitive exhibits can be designed according to requirements of the exhibition. This is discussed further on in "Light in museum spaces." The standard requires a minimal illuminance level of 30 lux on ceilings and 50 lux on walls. Offices, class rooms and hospitals have the minimal value of 50 lux for ceilings and 75 lux on walls. An significant increase of these values should be be achieved for a minimal experience of the space. The Unified Glare Rating method (UGR) is used to evaluate the glare of indoor spaces. It is an indication of the direct glare percieved in a space illuminated by artificial lighting. The UGR values for individual luminaires are available in corresponding photometric data sheets of the manufacturer. The formula takes the UGR levels for all the luminaires according to the International Commission on Illumination (CIE 117 Discomfort Glare in Interior Lighting) and the brightness of walls and ceilings and gives the maximum permissible value (figure 0.17). The illuminances can be adjusted by increments of

20 - 30 - 50 - 75 - 150 - 200 - 300 - 500 - 750 - 1000 - 1500 - 2000 - 3000 - 5000 lx

When the visual conditions deviate from the normal conditions. The idea was previously to make the lighting in rooms as constant as possible but according to *Lightbook* (2001) "the aim is now to imitate the qualities of daylight in artificial light."(89) The illuminance and colour temperature have to change during the day for a pleasant atmosphere to work and stay.

Distribution
Artificial light, in contrary with natural light is invented and controlled by humans. New developments have lead to improved results in energy consumption, efficiency, heat reduction, noise reduction, luminous efficacy, directional lighting, reliability, low maintenance, longevity, UV reduction, toxic substance reduction, startup time, voltage, range of colours and more. The development of the luminaire results in higher quality, more reliable and consistent lights. An overview of different main types of light techniques

Light Production type	Light conversion efficiency	Average lifespan (hours)	Power Consumption	Efficiacy (lm/W)	Colour Temp. (Kelvin)	Faithfull Colours (CRI)	Flicker	UV Radiation	Lead content	Mercury	Infrared radiation
Thermal radiation Thermal light sources											
Incandescent	*5 - 10%*	*1 - 2K*	*Very high*	*12*	*2700 - 10000K*	*90-100*	*Yes*	*Yes*	*Yes*	*No*	*Yes*
Halogen incandescent	*5 - 10%*	*2 - 4K*	*Very high*	*18*	*3000 - 3200K*	*90-100*	*Yes*	*Yes*	*Yes*	*No*	*Yes*
Gas discharge Discharge lamps *- Low intensity discharge (LID)*											
Fluorescent	*25%*	*7 - 15K*	*High*	*80*	*2700 - 6000K*	*>80*	*Yes*	*Yes*	*No*	*Yes*	*-*
- High intensity discharge (HID)											
Metal Halide	*25%*	*6 - 20K*	*High*	*65 - 115*	*3000 - 20000K*	*>60*	*Yes*	*Yes*	*Selective Yes*	*Yes*	*-*
High pressure sodium (HPS)	*30%*	*<24K*	*High*	*50 - 90*	*1900 - 2200K*	*>60*	*Yes*	*Yes*	*Yes*	*Yes*	*-*
Low Pressure Sodium (LPS)	*30%*	*<16K*	*High*	*50 - 90*	*2200K*	*40 - 60*	*No*	*Yes*	*-*	*No*	*-*
Mercury vapour	*15%*	*<16K*	*High*	*30 - 65*	*2200K*	*40 - 50*	*Yes*	*Yes*	*-*	*Yes*	*-*
Electroluminescence Semiconductor light sources											
Light emitting diodes	*90%*	*50K*	*Low*	*65 - 160*	*2700 - 10000K*	*65 - 95*	*No*	*No*	*No*	*No*	*No*

	colour temperature	*Appearance*	*Association*
Warm white	>3300K	reddish	warm
Intermediate white	3300 - 5300K	white	neutral
Cool white	<5300K	bluish	cool

A.18 General light source comparison om main types Thermal radiation, Gas discharge, Electroluminescence. With subtypes Incandescent, Halogen, LID Fluorescent, HID Matal halide, HID HPS, HID LPS, HID Mercury vapour and LED.

A.19 Colour temperature, appearance and association.

are the thermal light sources with thermal radiation, discharge lamps with gas discharge and semiconductor light sources with electroluminescence (figure 0.18)
Part of the thermal light sources is the traditional *incandescent lamp,* described by the "*American Lighting Association*."(90)
It works by the principle of glowing heated metal in a bulb, they produce a warm, yellow-white light that is emitted in all directions.
A lot of energy is lost by heat in the infrared spectrum. Improvements are the reflectorized incandescent, other filament with Tungsten, and gas added like Xenon and *Halogen*.
The small amount of gas creates a chemical reaction that evaporates the material back to the filament. The incandescent lamp mostly produces heat and is succeeded by other techniques.
The discharge lamp has two types. The first is the *low intensity discharge lamp*. It is a light source that produces light by a complex chemical proces. The enery is discharged into a gas which emits radiation, the ultraviolet radiation is converted to visible light by a phosphor coating. This process produces a wide spectrum of energy efficient light with minimal heat gain but the drawback is the toxic mercury. It includes the *fluorescent lamp* and *compact fluorescent light* (CFL).
The second is the *high-intensity discharge (HID)* lamp. It produces light by an electrical discharge between two electrodes through a plasma, or ionized gas causing metallic additives to vaporize. The lamps are highly energy efficient. The metal halide lamp, *high-pressure sodium (HPS)* lamp, *low-pressure sodium (LPS)* lamp and *mercury vapour* lamp belong to this category.
One of the semiconductor light sources is the *light emitting diode (LED).* It is a chemical chip, an encased solid material which is named solid-state technology. It produces light when energy goes through a negatively charged semiconductor, the electrons combine and create a photon which is a unit of light. The technique of LED light is constantly improving and is prefered for it's low energy consumption and long lifespan.
There are two methods to produce white light, the RGB LED with three diodes combined and the phosphor coated LED in order to shift the color into the white spectrum.
The shape of the light source can be a point, line or plane. *Designing with light* (2014) (91) states; "Another way of approaching a lighting design is by considering the visual impact of luminaires as an element of the interior design." Point sources are small with concentrated light. The reflection of the light source itself on the surface is small and shadows have sharp edges. A line source can be a linear source or a combination of point sources. The shadows can have a transition.

A plane source is an area of diffuse light, this softens or prevents shadows.

Colour

The quality of light is given on a scale of 0 (horrible) to 100 (perfect) by the Color Rendering Index (CRI). (figure 0.18) shows the CRI for different types of artificial light. The CRI of natural daylight is generally defines with a perfect 100. This is also identified as Ra or Ra8.

The colour of light describes the appearance and association.(figure 0.19) The colour of artificial light relates to the light emitted from a metal object heated.

Because of the way our eyes and brains work, the artificial recreation of light is possible by combining different wavelengths of light. The brightness of the light is sensed by the rods in our eyes, the peak sensitivity is send to our brains

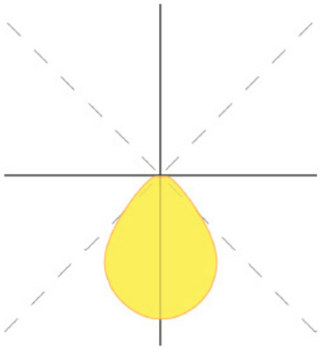
White light is sensed by the cones in our eyes, it is a combination of the small, medium and high wavelengths. With our psychiology of vision it is possible to recreate a white colour with artificial light, by adding the three wavelenghts to a combination that our eyes see as white. The drawback of this method is the very poor colour rendering of surfaces. The brain works in such a way, that it believes the colour rendering of the artificial light source. This will lead to two colours that can be rendered and the other colours will be greyscale. When choosing an artificial light according to *The architecture of light* (2008) the designer should determine, "The completeness of the spectrum of a light source or Color Rendering Index, and the balance of spectrum of light source or colour temperature." (92) Designers can pick colours from a colour reference system, the first system in 1931 is a colour trangle from the International Commission on illumination (CIE) (x,y). In 1976 CIE developed (u', v'), it is usefull for describing the perceptibility of colour differences.

Characteristics

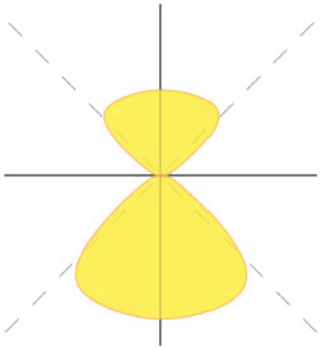
The luminaire can be clearly distinguished by different specifications. The categories of *Lightbook* (2001) (93) are a combination of the location, type of mounting, type of lamp and the accessories (figure 0.20). It is devided by the positioning of the luminaire including the ceiling, floor, wall, a standard or table. The *luminaire* is distinguished according to mounting type; the recessed, semi-recessed, surface mounted, standard and pendant downlights.The fixture can be equiped with a point or linear light source. The main use of most *ceiling luminaires* with a direct downward direction is the general illumination of spaces. The downlight can also radiate asymmetrical to a wall, indirectly via the ceiling or a combination of direct and indirect light. They can be equiped with many types of light sources with properties according to the requirements. Most downlights have integrated elements to enhance the desired properties. According to *Lighting Design Basics* (2004) the "trim choise can dramatically effect the light quality generated by the downlight."(94) There are many options of baffles, lamellae, reflectors, antiglares, filters, bulkheads, wallwashers, adjustable accents and lens trims to enhance the light quality in spaces. *Floor luminaires* are increasingly used in indoor spaces, they often produce a narrow beaming light. It is contrary to natural light which comes from above and delivers a unique light quality. The upward direction can enhance the perception of height en verticality but blinding, unavoidable in close proximity, must be prevented. W*all luminaires* have a lower mounting height then ceiling luminaires and distribute a warmer more intimate atmosphere light. The luminaires have fixtures that can both illuminate floor and ceiling. Coves or screened wall luminaires can create a washed effect, enhance the geometry of the space and bring textures of the wall to life. The *standard luminaire* is a flexible light which offers a range of various fixtures standing on the floor. The uplight creates an indirect light via an illuminated ceiling, luminaires with a translucent shade create islands of light and direct light can be used for reading and working tasks. A smaller version of the standard luminaire is the *table luminaire*, the direction and distance of the light can often be adjusted.

The direction of the distribution from the lighting source can be upward or downward. The distribution can be direct, semi-direct, direct/indirect, semi-indirect and diffuse. Illustrated in (figure 0.22)

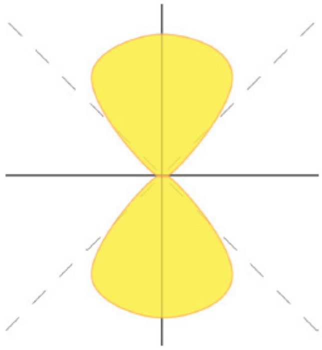
Location	*Type of installation*	*Type of light*	*Lamp*	*Lighting accessories*
Ceiling Luminaires	Recessed	Downlight	QT TC HIT	Louvre / Lamellae Bulkhead Glass
		Linear rectangle	TC / T	Louvre / Lamellae / Bulkhead
		Secondary	TC / T / HIT	Shielding of the lamp
	Semi - Recessed	Downlight	QT / TC / HIT	Without / With aura
		Linear rectangle	TC / T	Louvre / Lamellae / Bulkhead
		Secondary	TC / T / HIT	Shielding of the lamp
	Surface - Mounted	Downlight	QT / T / HIT	Without / With aura
		Linear rectangle	TC / T	Louvre / Lamellae / Bulkhead
		Secondary	TC / T / HIT	Shielding of the lamp
	Pendant	Downlight	QT / T / HIT	
		With shade or housing	QT / T / HIT	Translucent
		Linear only directly radiating	TC / T	
		Linear directly-indirectly radiating		
		Linear only indirectly radiating		
Floor Luminaires	Recessed	Direct symmetrical	QT / TC / HIT	
		Direct asymmetrical	QT / TC / HIT	
		Diffusely radiating	TC / T / LED	
		Signal light	LED / Fiberglass technology	
	Semi - Recessed	Diffusely radiating	TC / LED	
		Signal light	LED	
		Shaded, only radiating onto floor	QT / TC / HIT	
	Surface - Mounted	Floor floodlight	TC / HIT	
		Diffusely radiating	TC / LED	
		Signal light	LED	
Wall Luminaires	Recessed	Ceiling floodlights	QT / TC / T / HIT	
		Floor floodlights, night light	QT / TC / T / HIT	
		Diffused light	QT / TC	Hit frosted pane
	Surface mounted	Ceiling floodlights	QT / TC / T / HIT	
		Floor floodlights nightlight	QT / TC / HIT	
		Diffused light	QT / TC	Hit frosted pane without / with aura
		Direct / Indirect radiating against ceiling and floor screened	QT / TC /HIT	Also combinations
		Radiating only against the wall	QT	
Standard Luminaires	Fixed or swivelling	Directly radiating	QT / TC	
		Indirectly radiating	QT / TC / HIT	
		Directly-indirectly radiating	QT / TC / HIT	Or in combination
		Diffusely radiating	QT / TC	
Table Luminaires	Fixed	Directly radiating	A / QT / TC / T	
		Directly-indirectly radiating	QT / TC	
		Diffusely radiating	A / QT / TC	
	Swivelling movable	Directly radiating	A / QT / TC	



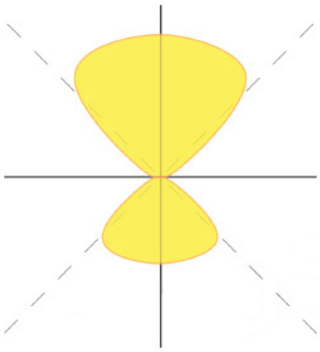
Direct distribution
Describes light leaving a fixture and entering the illuminated space without first bouncing off of any architectural elements such as the ceiling or walls.



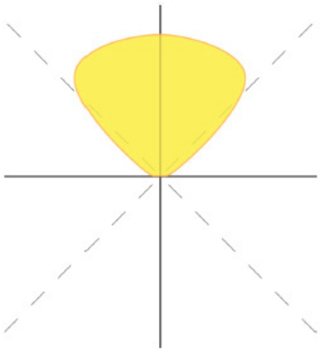
Semi-direct distribution
A light distribution pattern in which 60 percent or more of the light is directed downward and 40 percent or less is directed upward.



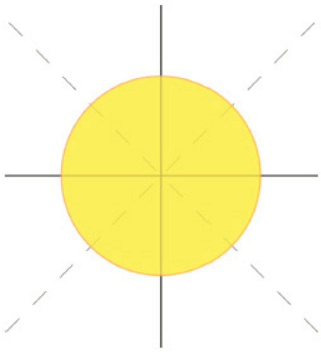
Direct-indirect distribution
A light distribution pattern or luminaire in which the light is directed downward and upward.



Semi-indirect distribution
A light distribution pattern in which 40 percent or less of the light is directed downward and 60 percent or more is directed upward.



Indirect distribution
A light distribution pattern in which all of the light is directed upward to bounce off of the ceiling.



Diffuse distribution
A light distribution pattern in which light is dispersed in all directions.

A.22 The type of distribution can be direct, semi-direct, direct/indirect, semi-indirect and diffuse

A.20 l. Luminaires categorized by manner and place of installation and specification. Abbreviations in figure 0.20

A.21 r. Abbreviations Lamp designation system (LBS).

Lamp designation system (LBS). Standardised system for designation of electrical lamps for general lighting:

A	All purpose lamp	Incandescent
QT	incandescent Quartz glass Tubular lamp	Halogen lamp
TC	incandescent Tubular Compact lamp	Compact fluorescent lamp
T	Low pressure dischange mercury Tubular lamp	Fluorescent lamp
HIT	High pressure discharge Iodide Metal halide lamp	High pressure lamp
LED	Light Emitting Diode	LED lamp

Light on surface

Intensity & colour

Light becomes visible when it strikes a surface. As described in the previous part of "Light Design," the *Illuminance* is the measurement of lumens onto a surface, the *Luminance* is the lumens off of a surface and the *Exitance* is the lumens leaving a surface considering the reflectiveness of the surface. This does not explains the manner in which a surface works with light. The radiation of light can be influenced by the colour and texture of the material and the surface. The colour of a surface influences the amount of light that is absorbed and the amount of light that is reflected. The texture is ralated to the reflection of direct light, diffuse light or an intermediate characteristic. These are the characteristics of a material that determine the brightness of the material and the light.

Distribution

The appearance of a surface is different with diffuse licht, direct sunlight or artificial light. When the light hits a surface it can be absorbed, filtered, reflected or refracted. This is described in the literature of *Lightbook* (2001) (95) and "*Zumtobel Lichthandbuch*."(96) These terms are all linked together. When all the light of the spectrum reaches a surface, all but the colour of the surface is absorbed and the colour of the surface is reflected. A black surface absorbs most light and a white surface reflects most light (figure 0.4). Reflection is the change of direction of the light when it hits a surface with a differing refractive index, it can be completely or partially relfected. The translucency of materials varies, they all have a different transmittance from transparent to translucent and non-transparent. Light can refract through a surface when it has a transmittance body, the refractive index changes the direction of the light at the transition between two media. A filter can transmit light by certain wavelengths of the spectrum or send light in a different direction. As explained before, there is soft diffuse light and directional focussed light in the basic spectrum of light texture. The texture of lightsources is described in *The architecture of light* (2008).(97) Diffuse light illuminates evenly in every direction at all angles, consequently the reflecting surface scatters the light in all directions. Diffuse light can fill shadows and reduce textural imperfections and contrast of surfaces. A diffuse light sourcse can be made even more diffuse with a difusing material around it using frosted glass and acrylic. A space with merely diffuse light can become monotonous and visually unattractive. Directional light comes from a light source that pushes the light in one direction. The light is focussed and the brightest light is mainly in the center,

it delivers a specific direction of light. The direct light adds visual interest and casts accent by lighting objects and surfaces. The spectrum of light textures provides four levels; very directional light, directional light, diffuse light and very diffuse light. Natural light is a construction material,
Assessment of Daylight Performance in Buildings (2015) explains a term in a publication magazine Licht und Lampe of Joachim Teichmuller, he used the term Licht-Architektur. "The definition Architecture of Light is the one best suited to describe the substantial role that natural light plays in fixing, informing and bringing alive the architecture of the constructed space."(98)

Shade

Shadows have a distinctive contrast between light and dark that enriches the texture of the matrial. In the proces of the illuminance, shadows are created on the surface. *Lightbook* (2001) states: "Three types of shadows may be distinguished; shade, half-shade and cast shadow."(99) The shadows on the surfaces are formed by light and percieved by the eye as gradations from brightness to semi-darkness and complete darkness. A shadow is the absence of light due to blocked rays of light by objects. This can differ from surrounding environment, to wall openings, furniture, light fixtures and accessories. The power of the shadow depends on the presence of light. Bright and directional light produces harsh shadows while soft and diffuse light brightens the shadow. The proximity of the lightsource affects the shape of the shadow. A surface can cast shadow over itself by a coarse texture material that blocks light. The shadow can contribute to the atmosphere in the space.

Analysing light

Simulations

The way in which the light enters the space can be approximated with simulations. *Lightbook* (2001)(100) offers some basic options and approximations. A sketch or drawing is a helpful but also difficult tool to visualize a light design. It is a very conceptual representation and demands imagination of the viewer. The light is often shown with cones, beam paths or ellipses to illustrate the varying illuminances and directions. These drawings can be assisted by photos of reference projects to give an impression of the space. Graphs can be used to calculate and represent the illuminations for the spaces, it is more used for confirmation than for the visualisation. Results from the input are numeric, illuminance and greyscale output. Computer generations with render programs can give an realistic representation of the spaces in a three-dimensional image. The input is important for exact representation. Examples of software that can be used are Ecotect and Dialux. These tools give numerical and graphical estimations with isolux lines considering the direct sun and sky radiation, daily and annual path of the sun, geographic location and artificial light. The use and features are explained in *Assessment of Daylight Performance in Buildings* (2015).(101) The output is a realistic render with all the approximated light characteristics of the actual space.

Velux has a Daylight Visualiser with analysing and render options, a simple tool with various options. Other illuminance visualisation software is: AGI32 (Windows), Visual (Windows), Let There Be Light (Mac), Radiance (Linux). And daylight simulation software plugin for Ecotect, Rhinoceros and Sketchup is Daysim Daylight simulator.

The last method of simulating is a physical model. This can be a full scale mock-up to test the setup in practice or a smaller scale version of the space. Daylight can e scaled in models when all the dimensions are scale to detail. Artificial light in spaces is more difficult because the illumination does not match.

Bright sunlight clear sky 11.00am 20-8-2015

position	1		2		3	
	lux	K	lux	K	lux	K
1. Closed						
inside	705	4040	1435	4140	1380	4180
outside	68500	5565	68300	5560	67550	5600
2. Open						
inside	60500	5660	64400	5500	65200	5370
outside	63000	5600	63150	5625	64000	5590
3. Sir John Soane museum						
inside	33200	5180	52600	5130	57800	5500
outside	72680	5670	72830	5710	68300	5730
4. Vitra design museum						
inside	1350	4120	11300	5385	1920	4240
outside	60200	5850	64000	5790	63200	5855
5. Kimbell art museum						
inside	1350	4510	2030	4630	2440	4700
outside	70580	5720	64300	5820	66600	5760
6. Kimbell Piano Pavilion						
inside	6870	5480	8560	5540	8200	5480
outside	69350	5720	69200	5720	71800	5710
7. de Young museum						
inside	4640	4930	6990	5010	4950	4740
outside	67000	5790	67340	5785	65800	5780
8. Kunsthaus Bregenz						
inside	14960	5160	17920	4830	18230	4750
outside	58900	5900	64250	5800	64350	5800

B.1 Experiment results of variants in direct sunlight clear sky 11.00am 20 august 2015

Attachment B

Bright Sunlight 13.00pm 19-8-2015

position	1		2		3	
	lux	K	lux	K	lux	K
1. Closed						
inside	990	4260	1500	4230	1115	4260
2. Open						
inside	92550	5670	92270	5640	92100	5610
3. Sir John Soane museum						
inside	57300	5380	65400	5260	37800	5800
4. Vitra design museum						
inside	2900	4160	6300	5140	2700	4250
5. Kimbell art museum						
inside	2220	4690	2740	4730	2340	4750
6. Kimbell Piano Pavilion						
inside	12200	5540	10900	5710	10300	5720
7. de Young museum						
inside	10480	4790	9320	4770	7150	4720
8. Kunsthaus Bregenz						
inside	23300	4880	25000	4930	24900	4820
outside	94000	5750				

B.2 Experiment results of variants in direct sunlight clear sky 13.00pm 19 august 2015

Clouded overcast sky 14.00pm 19-8-2015

position	1		2		3	
	lux	K	lux	K	lux	K
1. Closed						
inside	540	4500	700	4300	715	4140
2. Open						
inside	14200	6930	15500	7000	14800	7000
3. Sir John Soane museum						
inside	8300	6560	8390	6740	6360	6860
4. Vitra design museum						
inside	820	4800	5300	6100	940	5400
5. Kimbell art museum						
inside	620	5310	760	5340	800	5440
6. Kimbell Piano Pavilion						
inside	3980	6980	4610	7020	4040	7120
7. de Young museum						
inside	1280	5650	1580	5770	1220	5630
8. Kunsthaus Bregenz						
inside	4800	6110	4800	6060	4870	6190
outside	20000	7140				

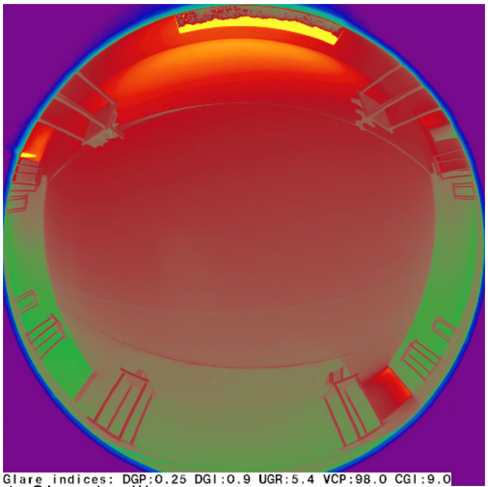
B.3 Experiment results of variants in clouded overcast sky 14.00pm 19 august 2015

Daylight simulator with constant illumination 20-8-2015

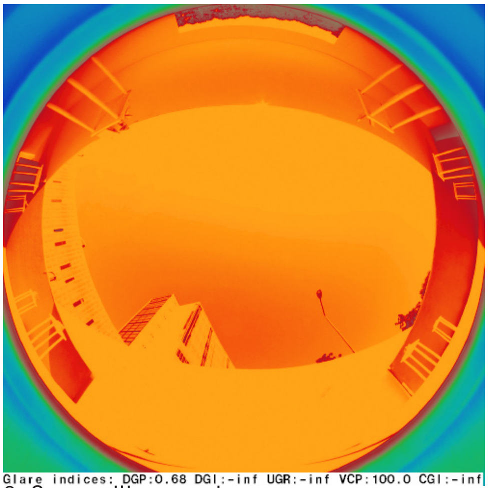
position	1		2		3	
	lux	K	lux	K	lux	K
1. Closed						
inside	145	3130	185	3015	150	2990
2. Open						
inside	10390	3555	11060	3540	9660	3580
3. Sir John Soane museum						
inside	4835	3415	5245	3440	3840	3420
4. Vitra design museum						
inside	250	2955	2180	3470	330	3030
5. Kimbell art museum						
inside	340	3195	445	3200	400	3165
6. Kimbell Piano Pavilion						
inside	3100	3400	3415	3390	3000	3430
7. de Young museum						
inside	755	3050	1075	3150	575	3085
8. Kunsthaus Bregenz						
inside	2970	3260	2940	3220	2915	3240
outside	13550	3530				

B.4 Experiment results of variants in daylight simulator with constant illumination.

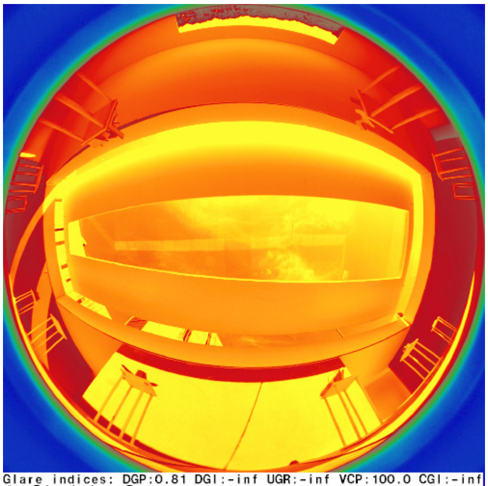
Bright sunlight clear sky	11.00-11.30pm	20-8-2015
outside	80000 lux	- Kelvin



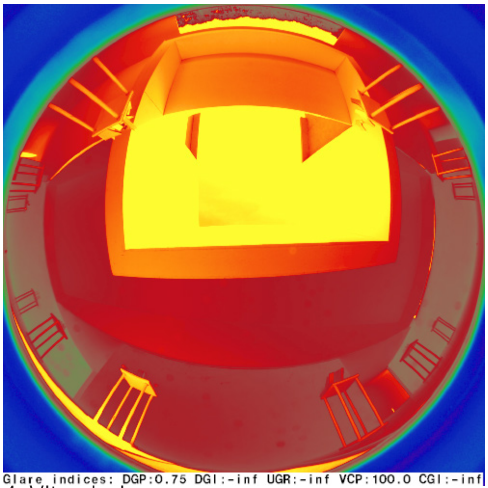
1. Closed ceiling



2. Open ceiling opening

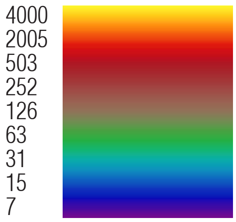


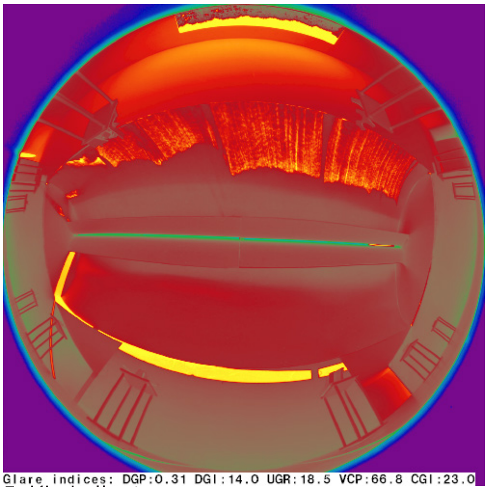
3. Sir John Soane museum



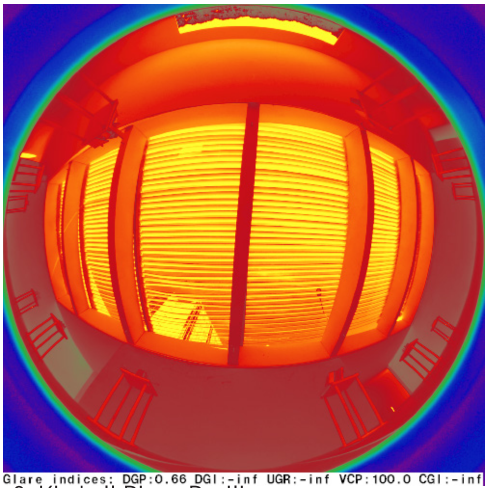
4. Vitra design museum

light intensity in cd/m²:

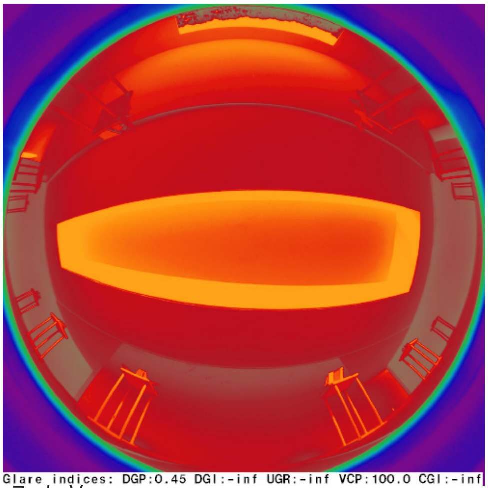




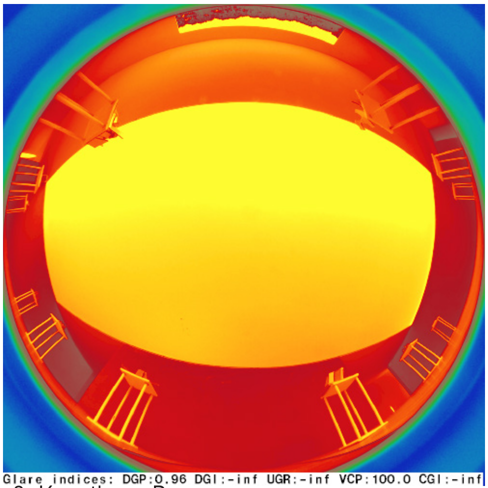
5. Kimbell art museum



6. Kimbell Piano Pavilion



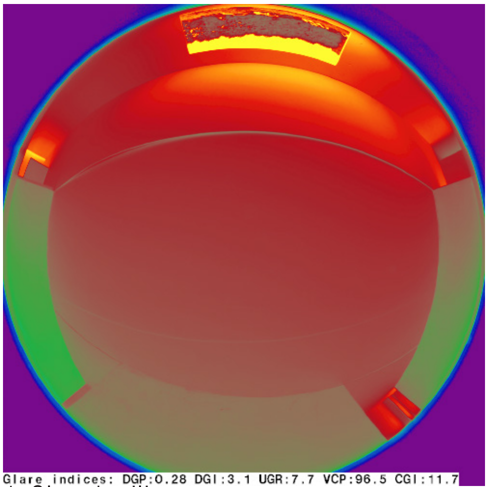
7. de Young museum



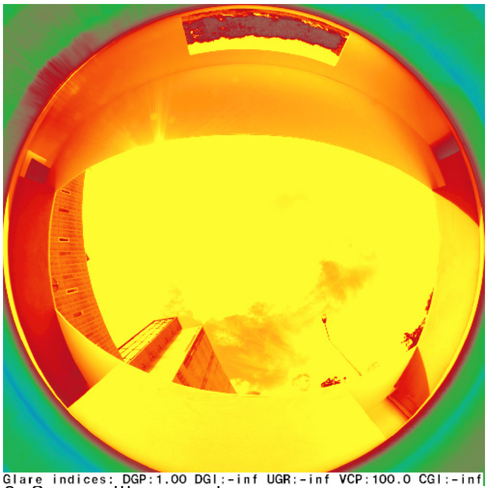
8. Kunsthaus Bregenz

B.5 Experiment results of variants in Bright sunlight clear sky 11.00am

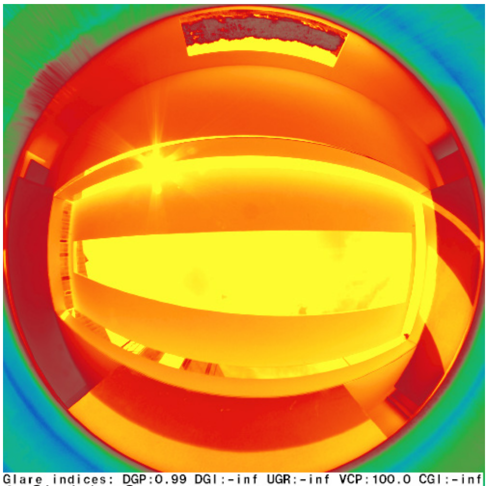
Bright sunlight clear sky 13.30-14.30pm 19-8-2015
outside 94000 lux 5750 Kelvin



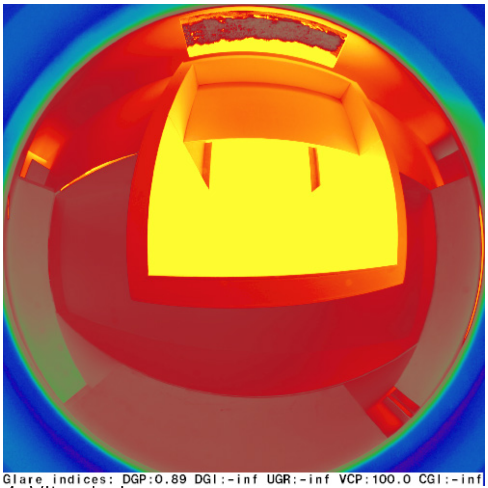
1. Closed ceiling



2. Open ceiling opening



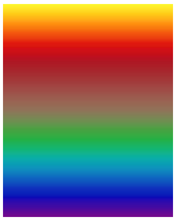
3. Sir John Soane museum

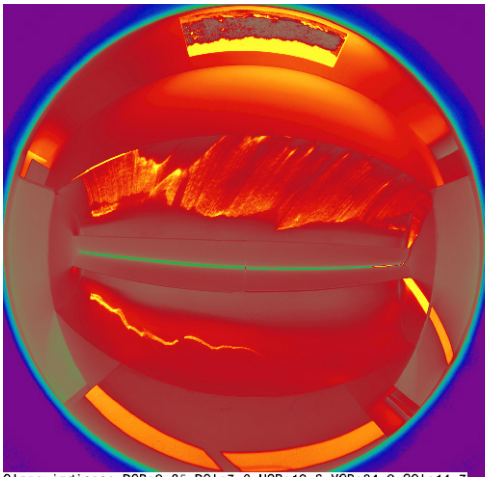


4. Vitra design museum

light intensity in cd/m²:

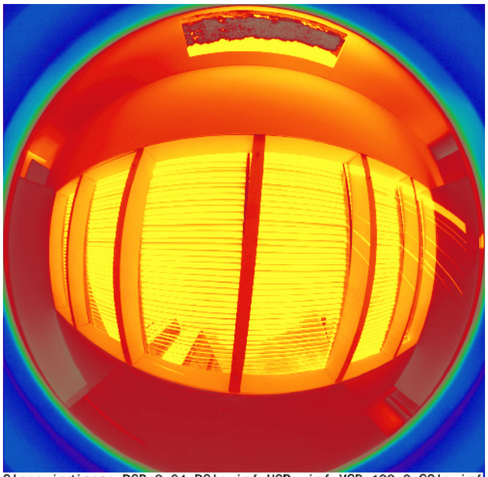
4000
2005
503
252
126
63
31
15
7





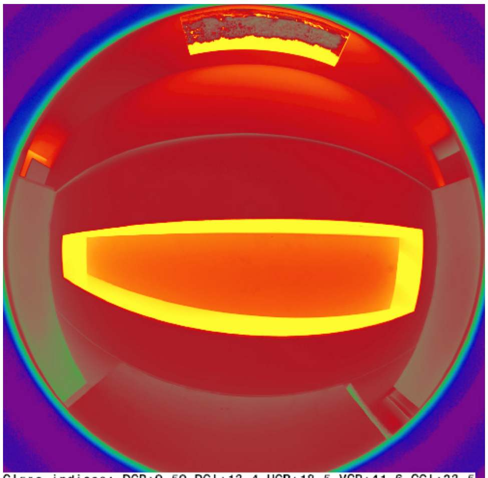
Glare indices: DGP:0.35 DGI:7.3 UGR:10.6 VCP:84.0 CGI:14.7

5. Kimbell art museum



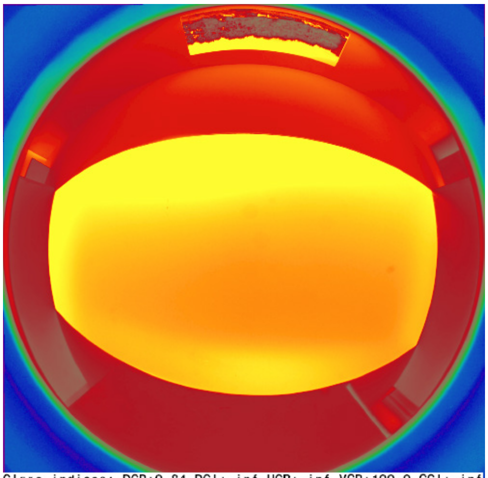
Glare indices: DGP:0.94 DGI:-inf UGR:-inf VCP:100.0 CGI:-inf

6. Kimbell Piano Pavilion



Glare indices: DGP:0.50 DGI:13.4 UGR:18.5 VCP:41.6 CGI:23.5

7. de Young museum

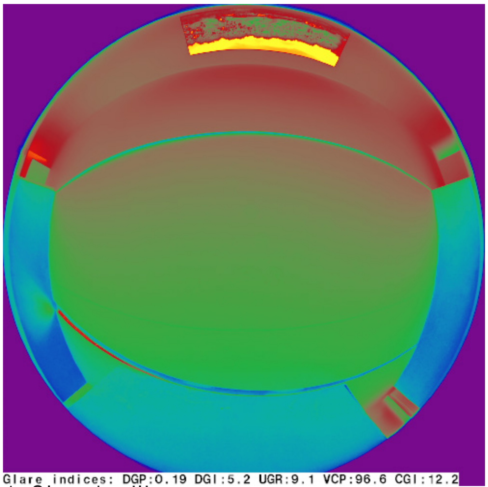


Glare indices: DGP:0.84 DGI:-inf UGR:-inf VCP:100.0 CGI:-inf

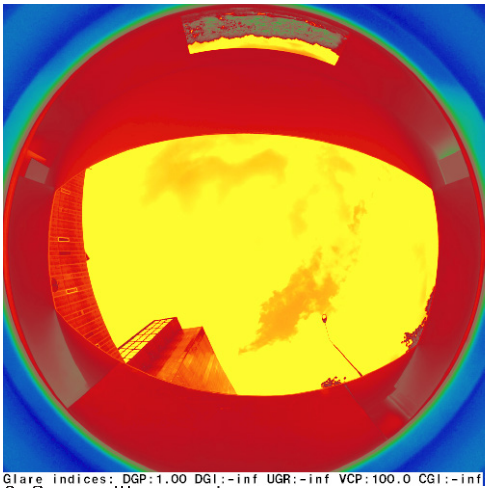
8. Kunsthaus Bregenz

B.6 Experiment results of variants in direct sunlight clear sky 13.00pm 19 august 2015

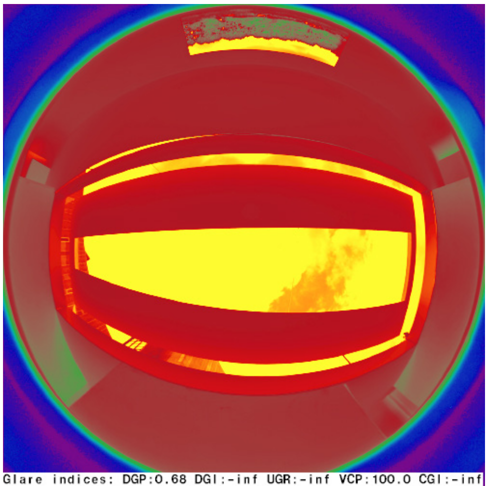
Clouded overcast sky 13.30-14.30pm 19-8-2015
outside 20000 lux 7140 Kelvin



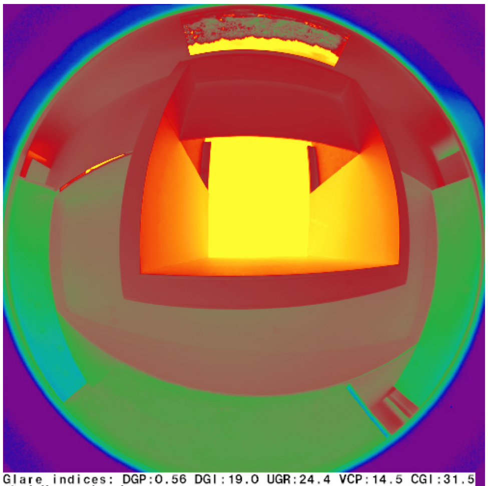
1. Closed ceiling



2. Open ceiling opening



3. Sir John Soane museum



4. Vitra design museum

light intensity in cd/m²:

4000
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15
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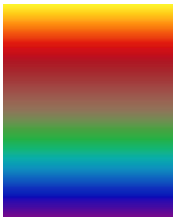
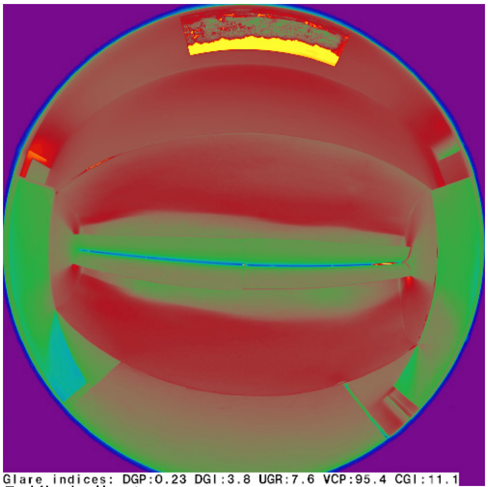
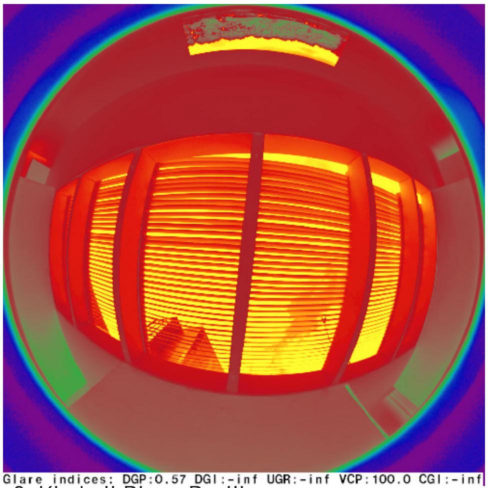


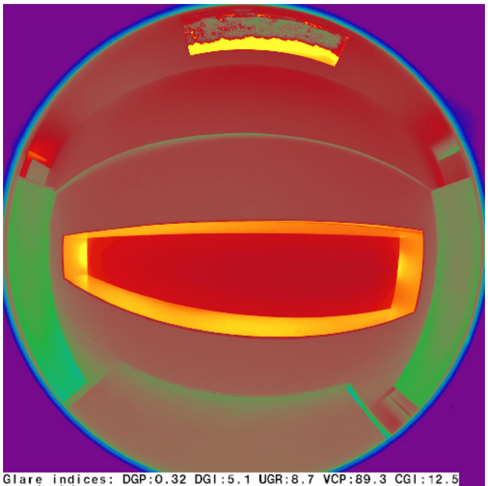
B.7 Experiment results of variants in clouded overcast sky 14.00pm 19 august 2015



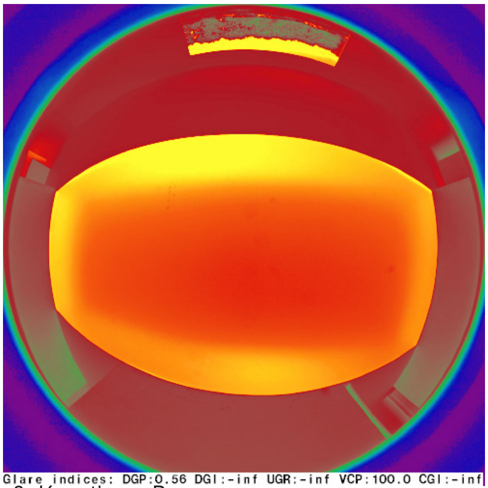
5. Kimbell art museum



6. Kimbell Piano Pavilion

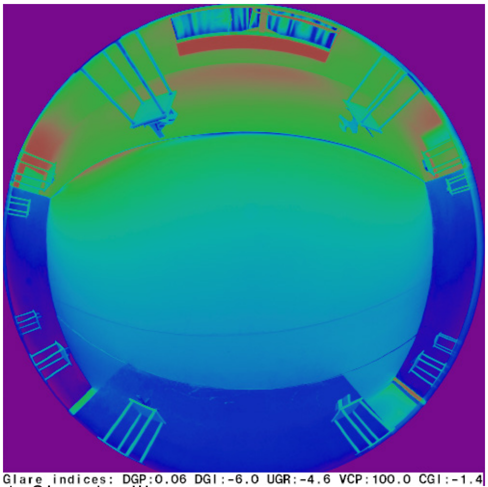


7. de Young museum

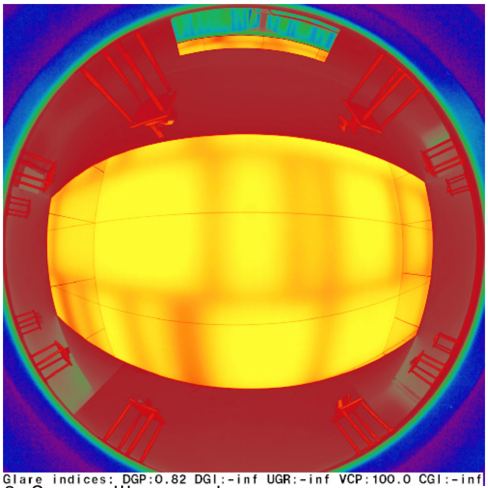


8. Kunsthaus Bregenz

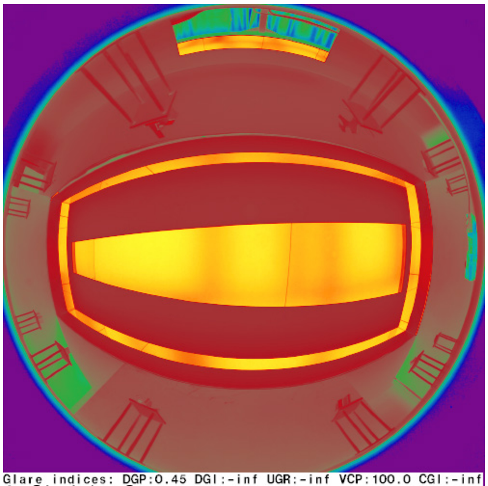
Daylight simulator with constant illumination 21-8-2015
outside 13550 lux 3530 Kelvin



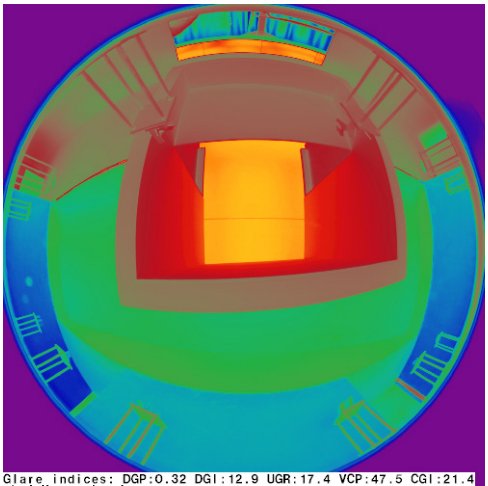
1. Closed ceiling



2. Open ceiling opening



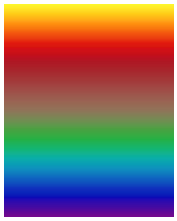
3. Sir John Soane museum

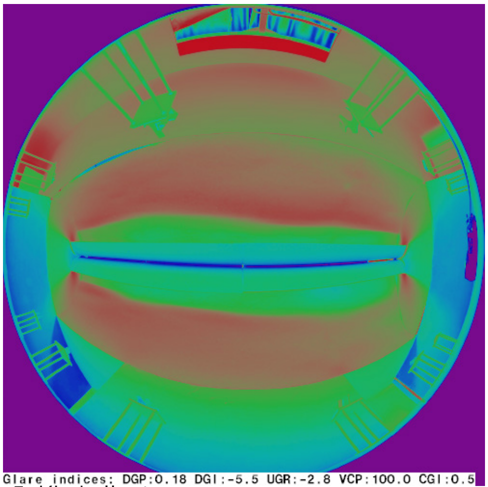


4. Vitra design museum

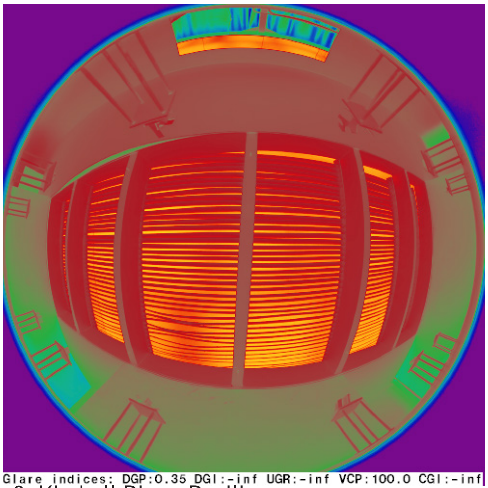
light intensity in cd/m²:

4000
2005
503
252
126
63
31
15
7

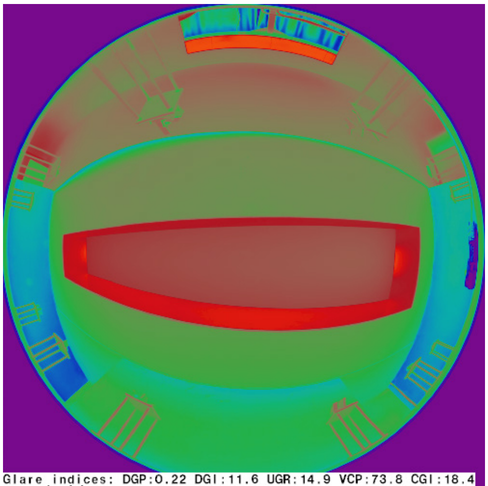




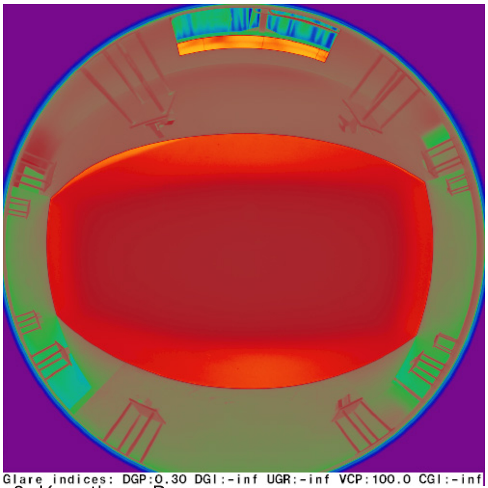
5. Kimbell art museum



6. Kimbell Piano Pavilion



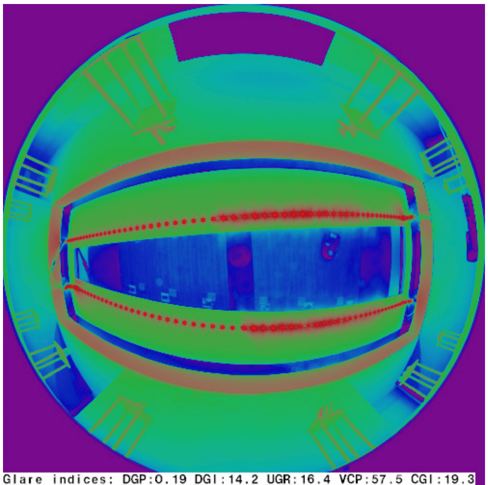
7. de Young museum



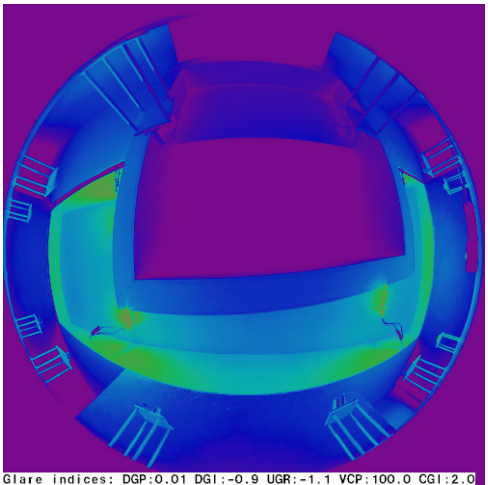
8. Kunsthaus Bregenz

B.8 Experiment results of variants in daylight simulator with constant illumination.

Dark space 21-8-2015
outside 5 lux - Kelvin



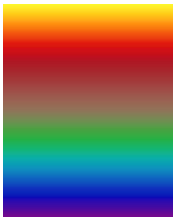
3. Sir John Soane museum

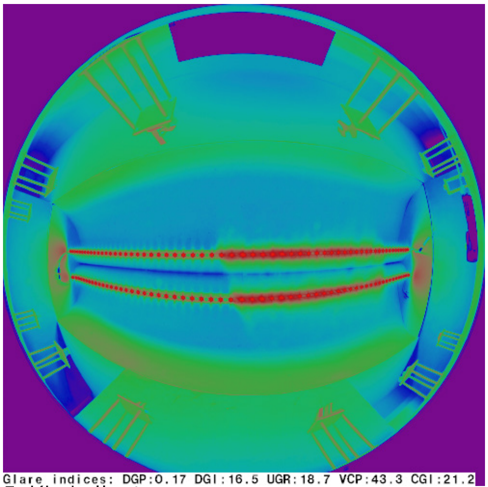


4. Vitra design museum

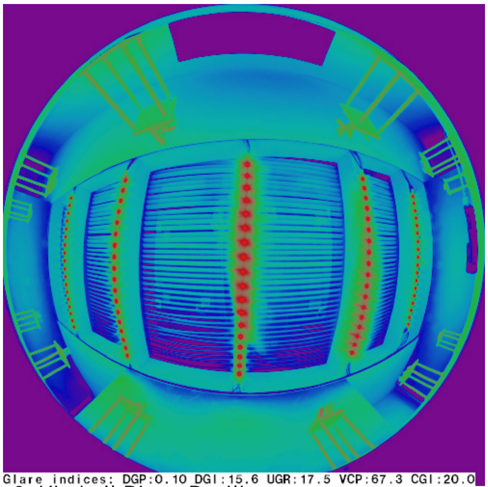
light intensity in cd/m²:

4000
2005
503
252
126
63
31
15
7

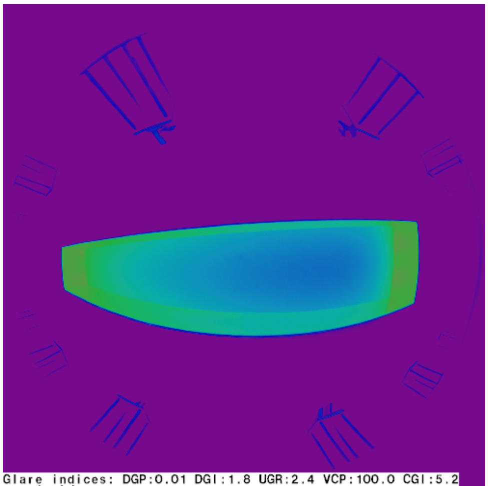




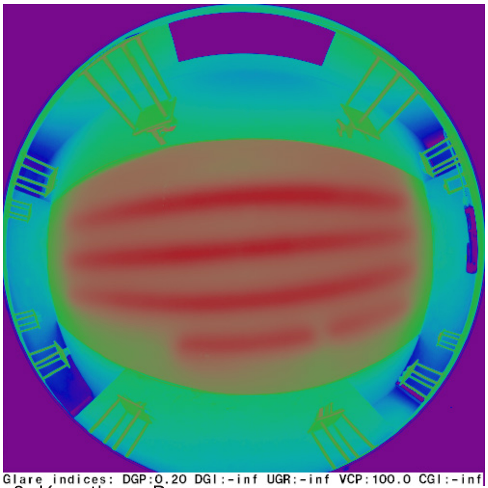
5. Kimbell art museum



6. Kimbell Piano Pavilion



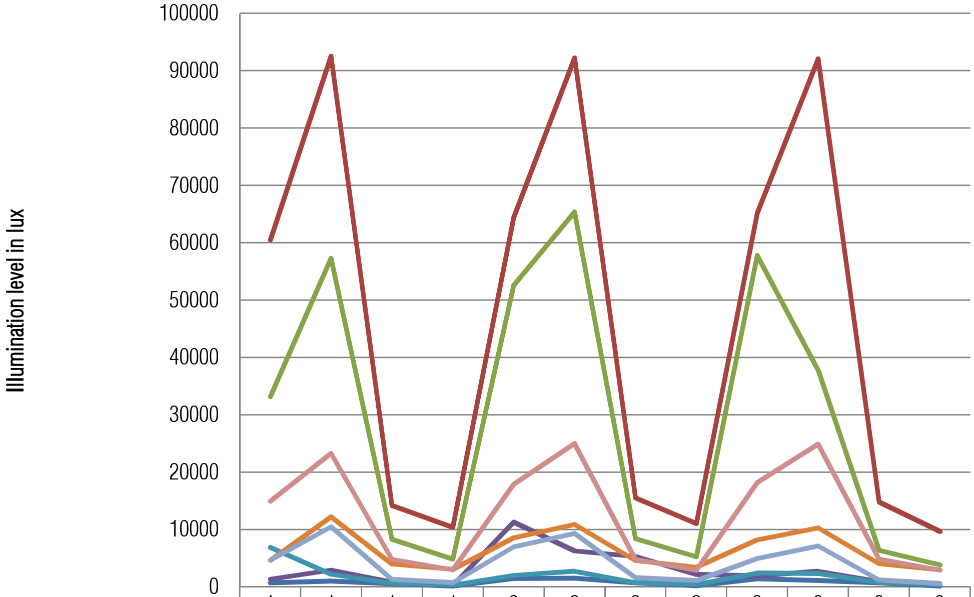
7. de Young museum



8. Kunsthaus Bregenz

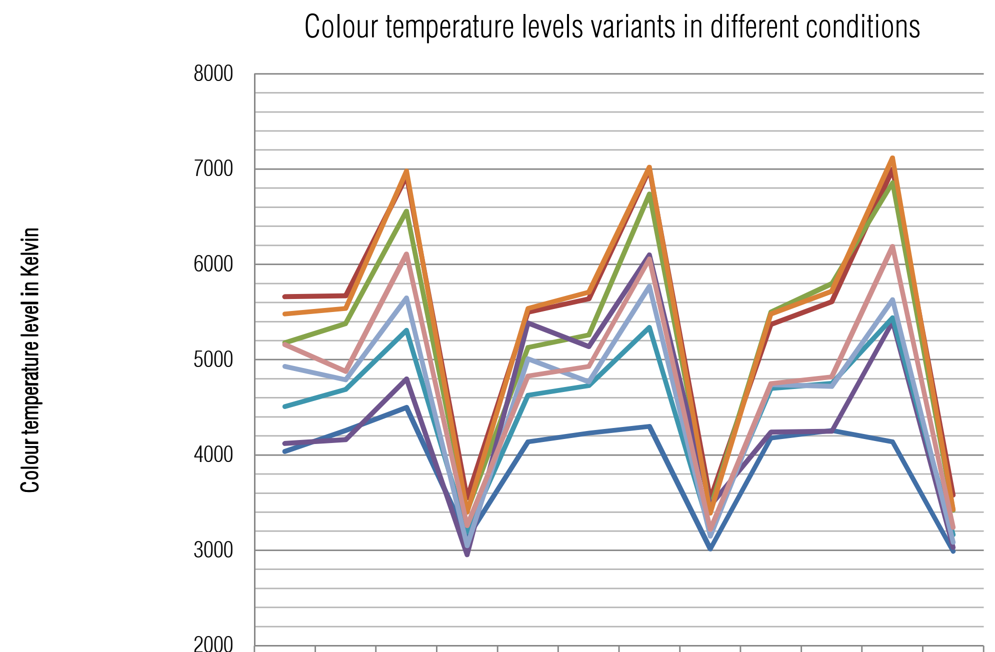
B.9 Experiment results of variants in dark space with integrated artificial LED lighting.

Illumination levels variants in different conditions



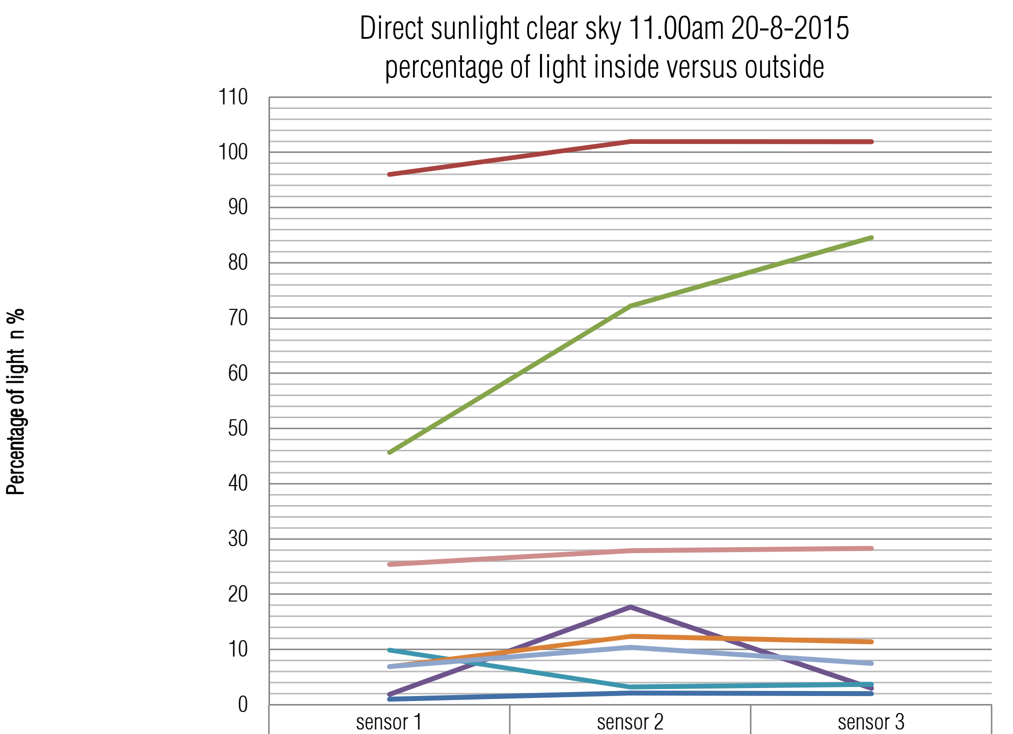
	1 direct 11h	1 direct 13h	1 overcast	1 simulator	2 direct 11h	2 direct 13h	2 overcast	2 simulator	3 direct 11h	3 direct 13h	3 overcast	3 simulator
1. Closed	705	990	540	145	1435	1500	700	185	1380	1115	715	150
2. Open	60500	92550	14200	10390	64400	92270	15500	11060	65200	92100	14800	9660
3. Sir John Soane	33200	57300	8300	4835	52600	65400	8390	5245	57800	37800	6360	3840
4. Vitra Design	1350	2900	820	250	11300	6300	5300	2180	1920	2700	940	330
5. Kimbell Art	6870	2220	620	340	2030	2740	760	445	2440	2340	800	400
6. Piano Pavilion	4640	12200	3980	3100	8560	10900	4610	3415	8200	10300	4040	3000
7. de Young	4640	10480	1280	755	6990	9320	1580	1075	4950	7150	1220	575
8. Kunsthaus Bregenz	14960	23300	4800	2970	17920	25000	4800	2940	18230	24900	4870	2915

B.10 Graph illumination levels of the variants in different conditions. Measurements sensors 1, 2 and 3. Direct sunlight clear sky at 11am and 13pm, clouded overcast sky and daylight simulator.



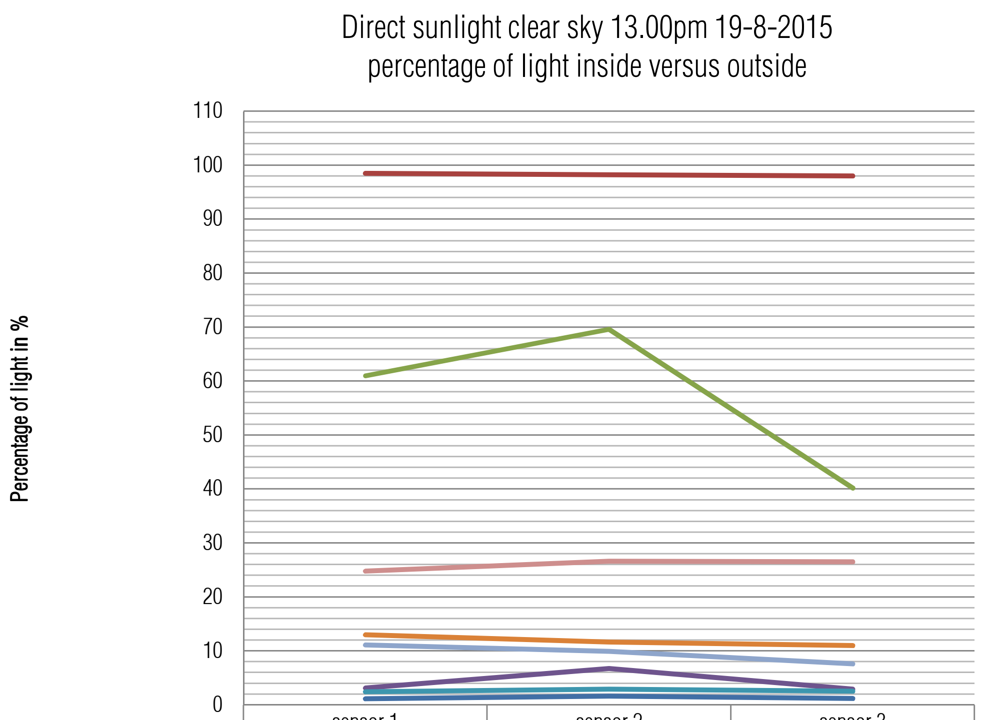
	1 direct 11h	1 direct 13h	1 overcast	1 simulator	2 direct 11h	2 direct 13h	2 overcast	2 simulator	3 direct 11h	3 direct 13h	3 overcast	3 simulator
1. Closed	4040	4260	4500	3130	4140	4230	4300	3015	4180	4260	4140	2990
2. Open	5660	5670	6930	3550	5500	5640	7000	3540	5370	5610	7000	3580
3. Sir John Soane	5180	5380	6560	3415	5130	5260	6740	3440	5500	5800	6860	3420
4. Vitra Design	4120	4160	4800	2955	5385	5140	6100	3470	4240	4250	5400	3030
5. Kimbell Art	4510	4690	5310	3195	4630	4730	5340	3200	4700	4750	5440	3165
6. Piano Pavilion	5480	5540	6980	3400	5540	5710	7020	3390	5480	5720	7120	3430
7. de Young	4930	4790	5650	3050	5010	4770	5770	3150	4740	4720	5630	3085
8. Kunsthaus Bregenz	5160	4880	6110	3260	4830	4930	6060	3220	4750	4820	6190	3240

B.11 Graph colour temperature levels of the variants in different conditions. Measurements sensors 1, 2 and 3. Direct sunlight clear sky at 11am and 13pm, clouded overcast sky and daylight simulator.



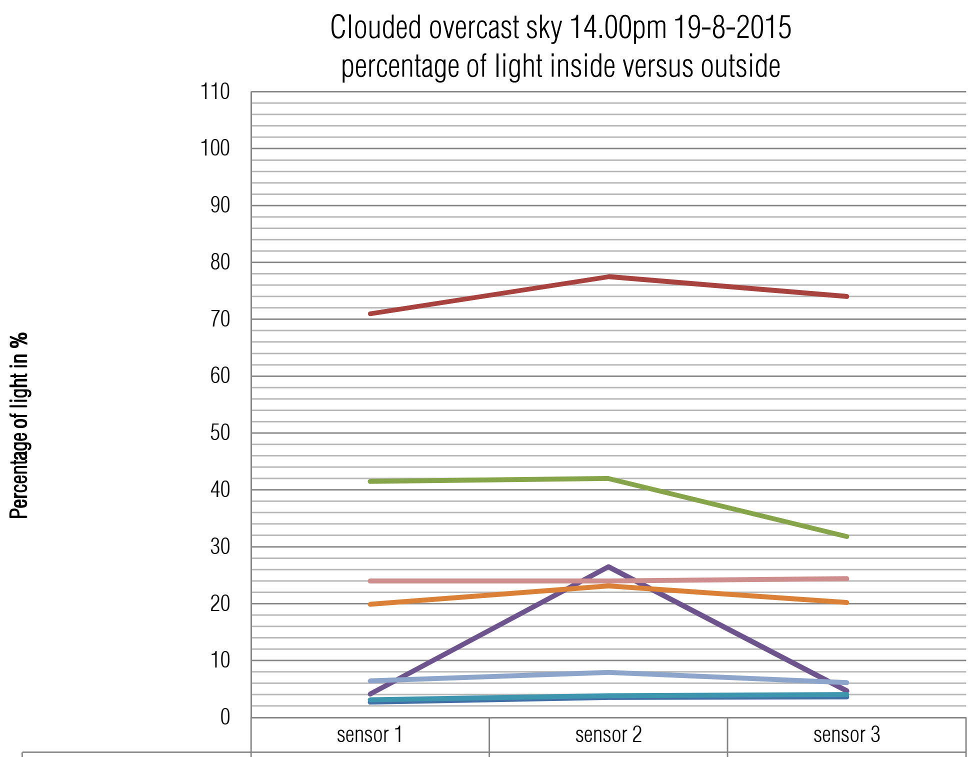
	sensor 1	sensor 2	sensor 3
1. Closed	1	2,1	2
2. Open	96	102	101,9
3. Sir John Soane	45,7	72,2	84,6
4. Vitra Design	1,9	17,7	3
5. Kimbell Art	9,9	3,2	3,7
6. Piano Pavilion	6,9	12,4	11,4
7. de Young	6,9	10,4	7,5
8. Kunsthaus Bregenz	25,4	27,9	28,3

B.12 Graph percentage of light change inside versus outside for direct sunlight clear sky 11.00am on 20-8-2015.



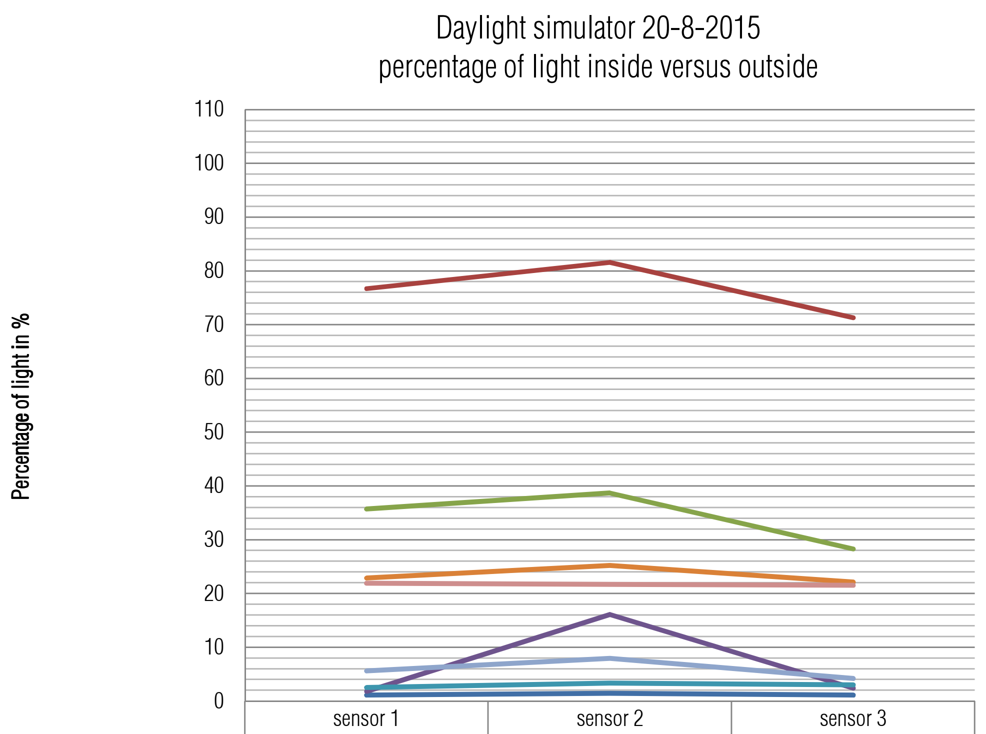
	sensor 1	sensor 2	sensor 3
1. Closed	1,1	1,6	1,2
2. Open	98,5	98,2	98
3. Soane	61	69,6	40,2
4. Vitra	3,1	6,7	2,9
5. Kimbell	2,4	2,9	2,5
6. Piano Pavilion	13	11,6	11
7. de Young	11,1	9,9	7,6
8. Kunsthaus Bregenz	24,8	26,6	26,5

B.13 Graph percentage of light change inside versus outside for direct sunlight clear sky 13.00am on 19-8-2015.



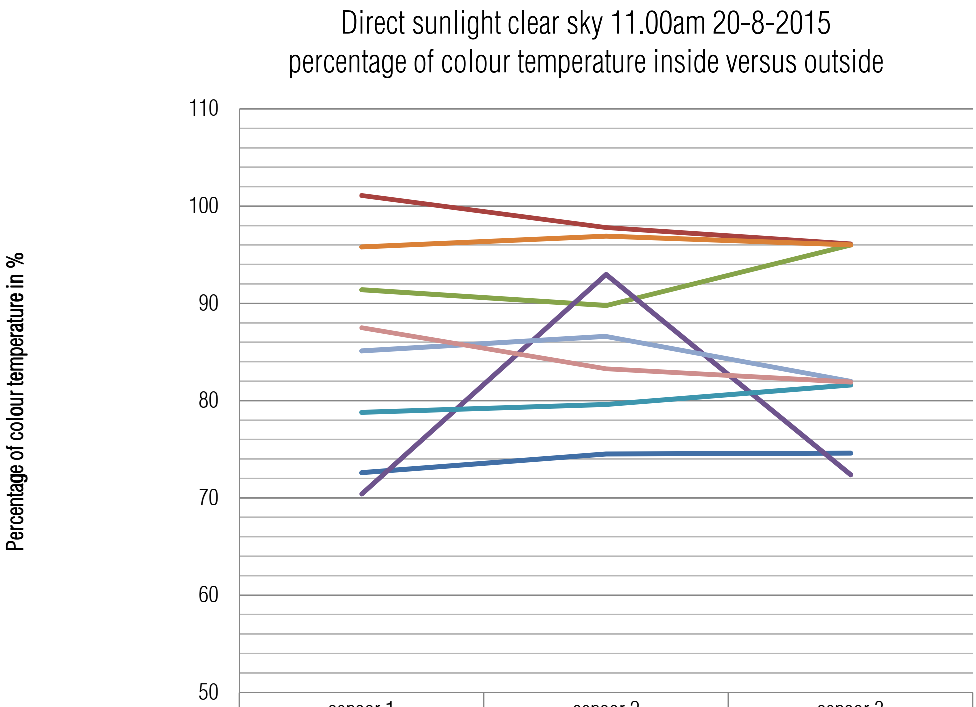
	sensor 1	sensor 2	sensor 3
1. Closed	2,7	3,5	3,6
2. Open	71	77,5	74
3. Soane	41,5	42	31,8
4. Vitra	4,1	26,5	4,7
5. Kimbell	3,1	3,8	4
6. Piano Pavilion	19,9	23,1	20,2
7. de Young	6,4	7,9	6,1
8. Kunsthaus Bregenz	24	24	24,4

B.14 Graph percentage of light change inside versus outside for clouded overcast sky 14.00pm on 19-8-2015.



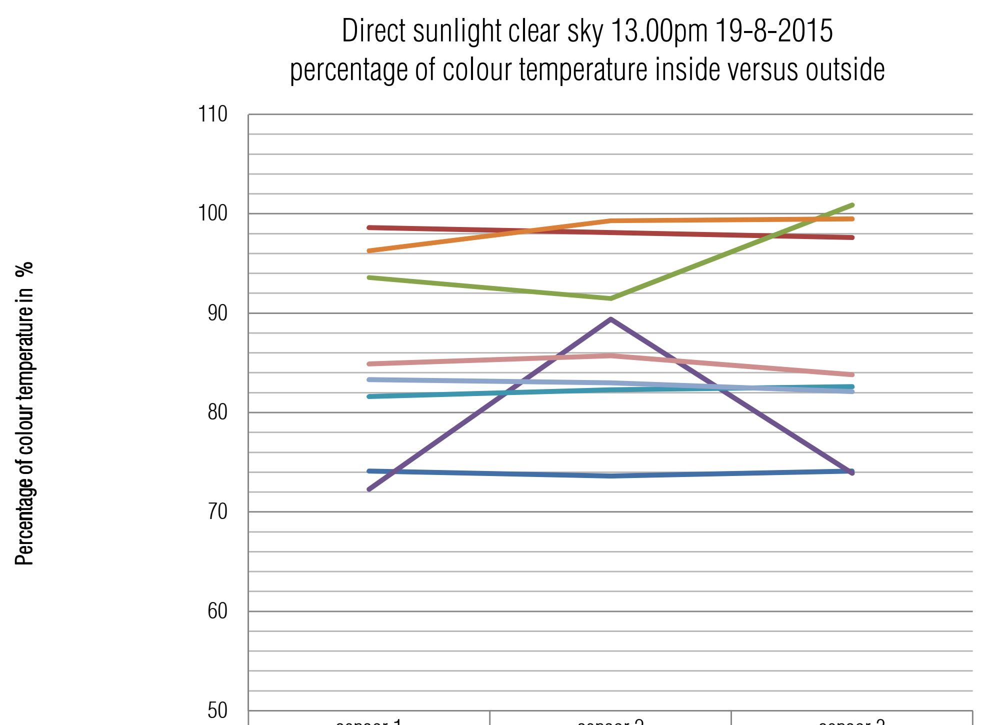
	sensor 1	sensor 2	sensor 3
1. Closed	1,1	1,4	1,1
2. Open	76,7	81,6	71,3
3. Soane	35,7	38,7	28,3
4. Vitra	1,8	16,1	2,4
5. Kimbell	2,5	3,3	3
6. Piano Pavilion	22,9	25,2	22,1
7. de Young	5,6	7,9	4,2
8. Kunsthaus Bregenz	21,9	21,7	21,5

B.15 Graph percentage of light change inside versus outside for daylight simulator.



	sensor 1	sensor 2	sensor 3
1. Closed	72,6	74,5	74,6
2. Open	101,1	97,8	96,1
3. Sir John Soane	91,4	89,8	96
4. Vitra Design	70,4	93	72,4
5. Kimbell Art	78,8	79,6	81,6
6. Piano Pavilion	95,8	96,9	96
7. de Young	85,1	86,6	82
8. Kunsthaus Bregenz	87,5	83,3	81,9

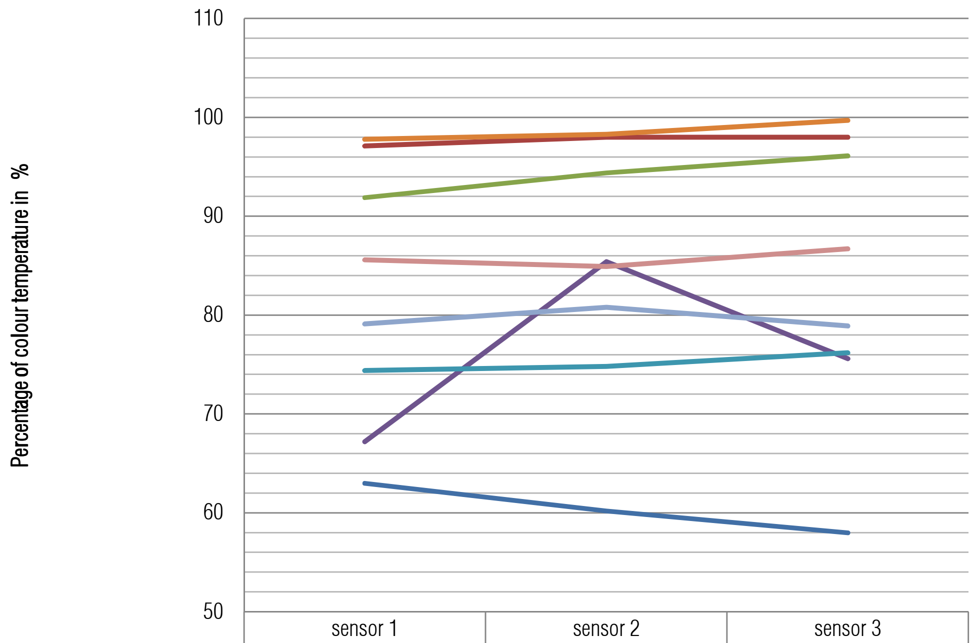
B.16 Graph percentage of colour temperature change inside versus outside for direct sunlight clear sky 11.00am on 20-8-2015.



	sensor 1	sensor 2	sensor 3
1. Closed	74,1	73,6	74,1
2. Open	98,6	98,1	97,6
3. Soane	93,6	91,5	100,9
4. Vitra	72,3	89,4	73,9
5. Kimbell	81,6	82,3	82,6
6. Piano Pavilion	96,3	99,3	99,5
7. de Young	83,3	83	82,1
8. Kunsthaus Bregenz	84,9	85,7	83,8

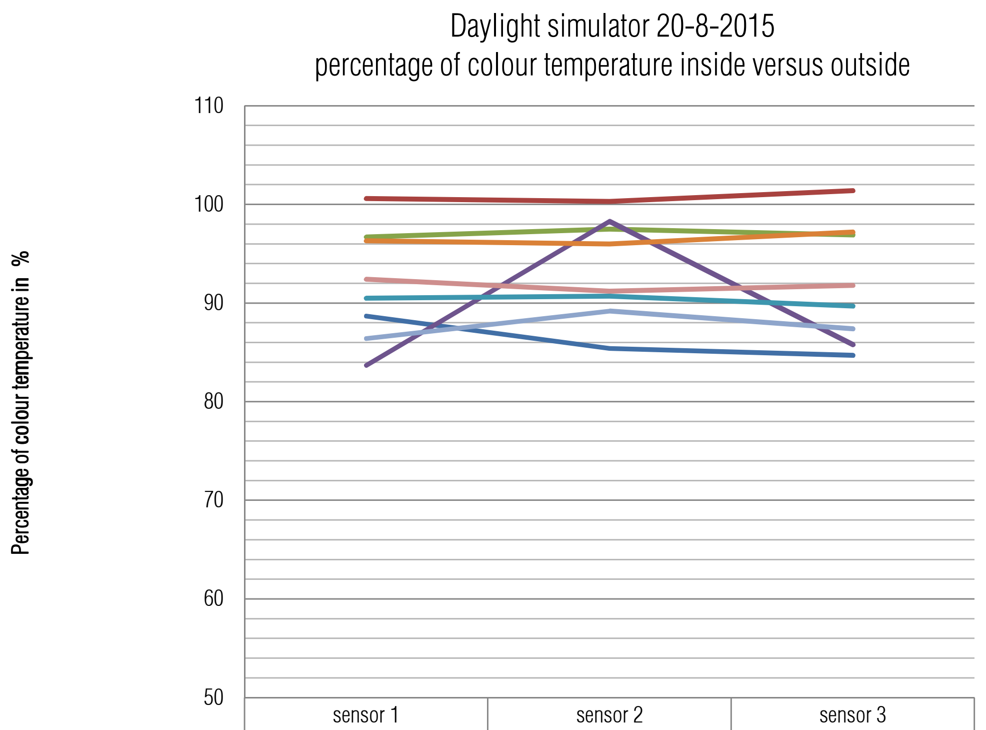
B.17 Graph percentage of colour temperature change inside versus outside for direct sunlight clear sky 13.00am on 19-8-2015.

Clouded overcast sky 14.00pm 19-8-2015
percentage of colour temperature inside versus outside



	sensor 1	sensor 2	sensor 3
1. Closed	63	60,2	58
2. Open	97,1	98	98
3. Soane	91,9	94,4	96,1
4. Vitra	67,2	85,4	75,6
5. Kimbell	74,4	74,8	76,2
6. Piano Pavilion	97,8	98,3	99,7
7. de Young	79,1	80,8	78,9
8. Kunsthaus Bregenz	85,6	84,9	86,7

B.18 Graph percentage of colour temperature change change inside versus outside for clouded overcast sky 14.00pm on 19-8-2015.



	sensor 1	sensor 2	sensor 3
1. Closed	88,7	85,4	84,7
2. Open	100,6	100,3	101,4
3. Soane	96,7	97,5	96,9
4. Vitra	83,7	98,3	85,8
5. Kimbell	90,5	90,7	89,7
6. Piano Pavilion	96,3	96	97,2
7. de Young	86,4	89,2	87,4
8. Kunsthaus Bregenz	92,4	91,2	91,8

B.19 Graph percentage of colour temperature change inside versus outside for daylight simulator.