AT3 Castelvecchio Study

Contributors

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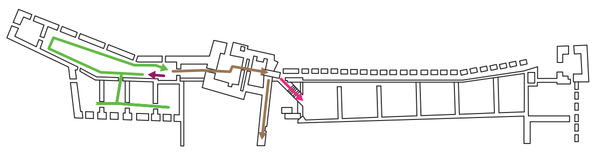
Castelvecchio Museum Restoration Introduction

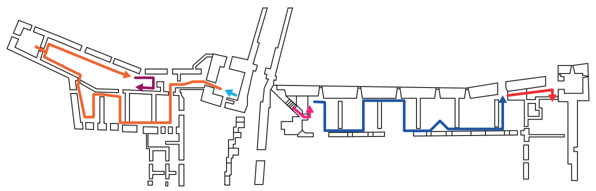
Carlo Scarpa (1906-78) is the architect behind the 1958-75 renovation of Castelvecchio Museum into the icon of historical building intervention that it represents today.

The building has a long and historic past. Originally a military fortress to the Scaligeri Family of Verona, the castle remained a military fortress under the rule of the Venetian Empire before Napoleon took control of the site. Napoleon carried out extensive building work, creating a barracks along the riverside courtyard edge and adding further fortifications. In 1923 the museum went through a change of use, converting its military past to a cultural future in the form of a Municipality Art Museum, displaying the City of Verona's art collection. This change of use came with a major change of appearance, with Antonio Avena reflecting 'restoration' values of the time by making the building appear as a Gothic and Renaissance palace.

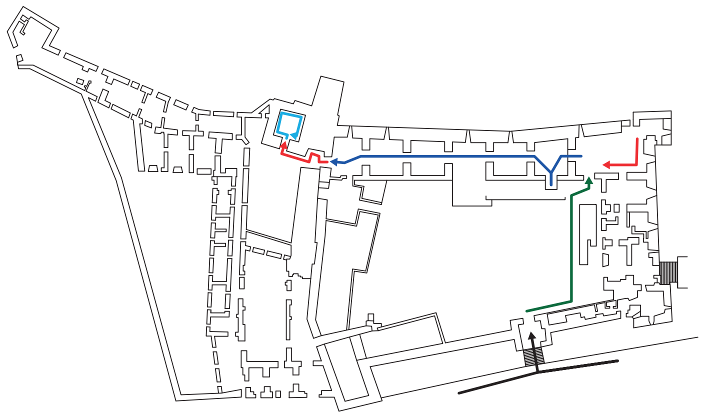
Scarpa was tasked with his first renovations to the museum in 1957, where he began his clinical process of historical clarification and presentation. Whilst his initial aim was to remove 'bogus' decoration from the 1923 development, he took the idea a step further by viewing the museum as a 'museum of itself'. Through creative excavation and selective demolition of specific elements, Scarpa was able to pick back through the layers of the historic building fabric. Responding with acute technical understanding and respectful additions until 1975, the final creation is a building acting as an exhibit on its own growth and progression. Scarpa worked in an on-site office using sketches and verbal instruction to craftsmen to create what came to be regarded as the great example of sensitive historical installation work, setting a precedent for the renovation typology.



Second Floor 1:2000



First Floor 1:2000



Ground Floor 1:2000

Site Plan 1:3000

Sustainability Statement

Scarpa's Castelvecchio is a Modern renovation which pioneered a new typology of high-end building refurbishment. The renovation's work showcasing the architectural potential that historic buildings provide has inspired generations of architects, saved countless historic structures from demolition and redefined the way we view the future of architecture. Reducing global demolitions and encouraging re-use has saved unmeasurable quantities of carbon emissions and changed the profession's view on how to create a sustainable future.

However, the renovation was carried out before the climate crisis became a pressing issue and architects were designing projects with climate considerations at the forefront of the decision making process.

Scarpa's work reflects the time period that it was built in, compared to modern environmental standards the work is non-conforming, harmful to the environment and requires further technical improvements to be considered a climate responsible project.

Understanding the Space

The entrance to the courtyard was moved to the drawbridge and gate at the South-East corner. Once inside, the visitor walks around the courtyard to the entrance at the North-East corner, passing the exterior of the Sacello on the left-hand side. Once inside, the visitor walks down the ground floor of the Napoelonic Wing, including the Sacello interior. Moving outside, the path goes through the excavated Porta del Morbio and into the Mastio tower, progressing up a staircase to the second floor galleries in the Reggia.

Emerging into the Reggia gallery on the First Floor, the visitor progresses around the space before moving up and internal staircase. They are then able to view the Second Floor Reggia Gallery before progressing over a bridge to the top of the old city wall. The visitor can then travel around the top of the walls, or descend down to the First Floor Canagrande Space. The First Floor Napoleonic Wing can then be viewed, before leaving via the exit stairs at the end of the gallery which take the visitor back down to the reception.

Technical Study Aim

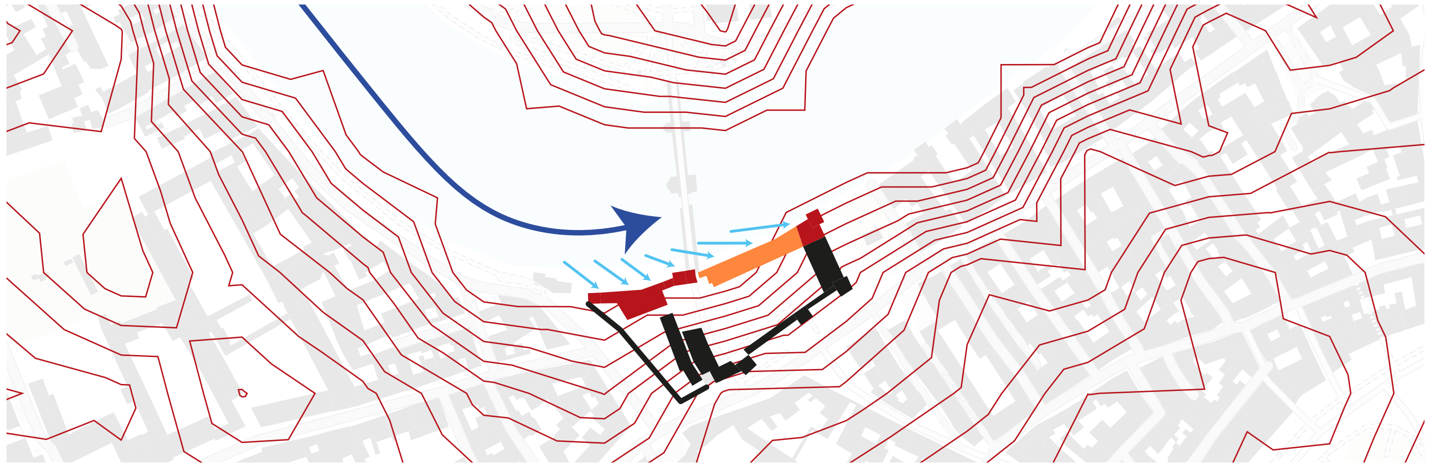
It is our group aim in this technical study to re-imagine Castelvecchio's restoration in a new climate age, with new standards of what is 'correct'.

We will analyse the technicalities of the work carried out by Carlo Scarpa within the context of the time, and highlight areas which do not meet the standards expected for a public building in the current day. Using further technical knowledge, contemporary regulations, guidance and an understanding of the precedent, we will propose technical developments which could potentially form the next layer of Castelvecchio's history.

With regard to Scarpa's work, the building's sensitive context within the climate challenge and the local context we will analyse the building through 4 key lenses: Structural Strategy, Construction Strategy, Building Performance and Building Services.

Through the combined critical analysis from the perspective of the climate emergency, we believe that we can form an integrated and comprehensive report of how Castelvecchio can continue its evolution, redefining what it means to be a 'renovated' project in the new climate age.

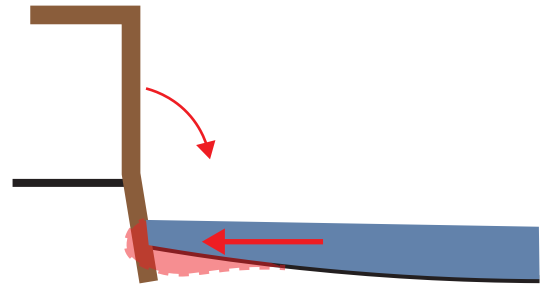
George Palmer



Terrain

Castelvecchio is located in Verona on the south bank of the River Adige. The Adige is Italy's second longest river which runs from the Alps to the Adriatic, carrying alpine melt-water as well as precipitation.

The positioning on the outside of the river-bend creates erosion against the North foundations. A great masonry river-wall was constructed, however the more modern Napoleonic wing is at greater risk as there was originally an open courtyard to the river in its place which was less-protected.



Climate

Using a weather data file from Lyon, a city with a very similar climate profile due to an equal latitude and proximity to the Alps mountain range, Climate Consultant[1] has been used to provide suitable models for climate evaluation through the California Energy Code Comfort Model 2013.

The temperature range model shows that winter/spring temperatures (Oct - March/Apr) drop below the comfort zone, requiring the building to be heated. The summer months also on average have a mean temperature below the comfort range, however at the peak of summer there is significant overheating of the design on warm days, creating discomfort and requiring ventilation to cool the space for public-use.

This overheating could be due to the reduced sky cover during the summer months, where a greater radiation range correlates to increased solar direct gains. This requires window shading to reduce internal overheating. However, Scarpa has not included sun-shading techniques for windows, creating discomfort within the summer months.

The ground temperature does not on average drop below freezing during the winter, even at a 4m depth. However, during the colder-months ground temperatures can drop below 10°C for extended periods of time. This reduces groundwater evaporation and could create a saturated envrionment leading to water ingress.

The wind prevails from the North-West, however The Adige is likely to create a more localised air-flow specific to the building due to its snow-melt cold waters causing local convection currents. The courtyard form of the building protects the interior spaces from any strong winds.

The psychrometric chart from Climate Consultant provides an evaluation of the related climate factors on the building's comfort zone. Sun Shading of Windows, Fan-Forced Ventilation, Two-Stage and Direct Evaporative Cooling and Humidification/ Dehumidification have been turned off, as these are active strategies which Castelvecchio does not use.

The heating of Castelvecchio is vital to its comfort. Without the heating system, the space is only comfortable 49.3% of the time. Not only is this reliance on energy-dependant heating (4,438 hours) unsustainable and wasteful due to the poor heat-retention of the building, such dependance on active strategies for comfort risks the entire museum's user-experience on a system which could break or be out of operation for vital maintenance.

Identification of Relevant Building Regulations

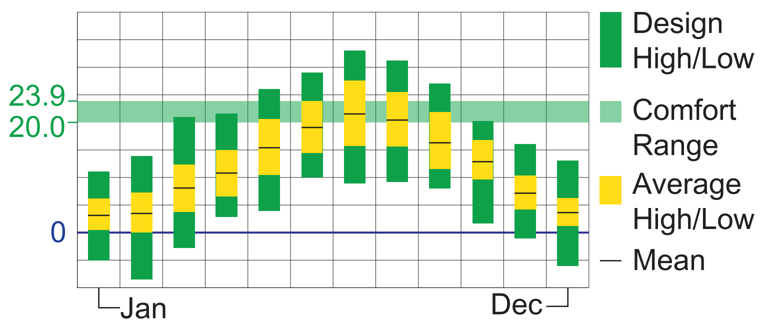
The most important climate-issue for the renovation is the poor building performance creating a high energy demand due to poor efficiency.

UK Approved Document L on the conservation of fuel and power provides strong guidance to improve the performance including U-Value requirements for retrofit buildings. CIBSE Guide A provides targets and guidance to improve building services such as light and acoustics, key impacts of technology on the user experience.

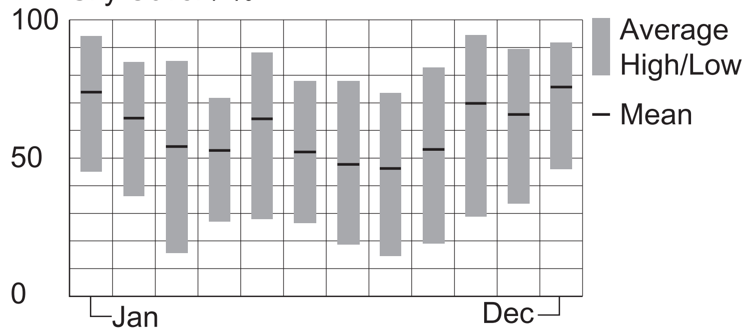
To ensure the building is safe to use, Approved Documents B and M provide guidance on Fire Safety and Accessibility, areas which have undergone major legislative developments since Scarpa's time, and which are inkeeping with modern societal values.

Eurocode 1991-1-1:2002 gives structural regulation aligned with modern standards to ensure the structure remains safe with more advanced structural knowledge.

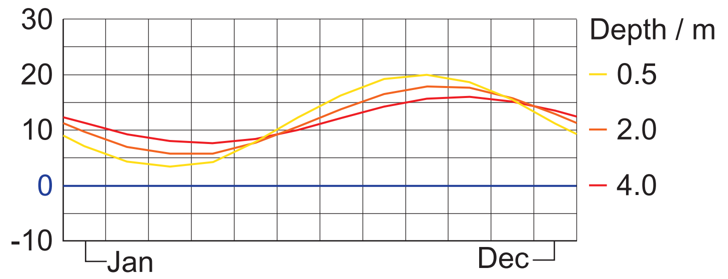
Temperature Range / °C



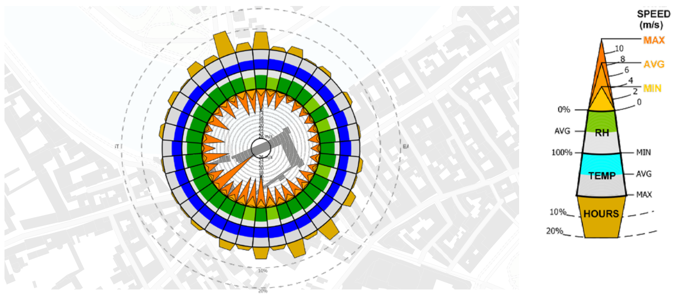
Sky Cover / %



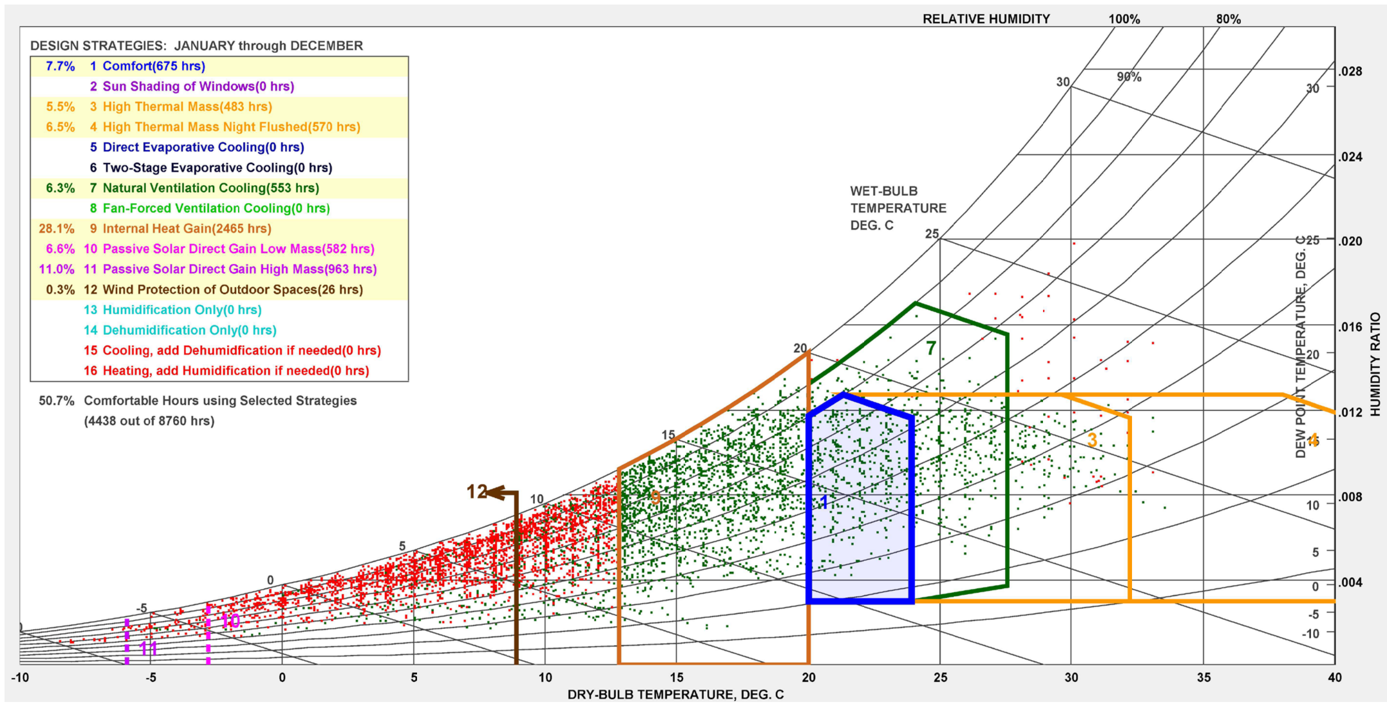
Ground Temperature / °C



Wind Rose[2]



Psychometric Chart[3]



1 Society of Building Science Educators, 2021. Climate Consultant (V6). [software]
2 & 3 - Figures provided by, Ibid, [software]

George Palmer

Structural Elements - Overall Philosophy

The general structural philosophy of Scarpa's Castelvecchio mirrors the existing fabric, in that the main means of distributing load to ground is through load bearing masonry and concrete. This is, however, creatively synthesised by joining load-bearing elements with framed elements - those being the roof, concrete beams, and the steel girder in particular.

Instead of being limited by the existing structure and needing to perfectly mirror it in his design, Scarpa used it to his maximum advantage. A particular example of this is in an exhibition space in one of Castelvecchio's towers - a floating floor is suspended atop raking steel members, which transfer load from the floor into the thick masonry wall, which then transfers this load to the ground. This, like many other structural moves in Scarpa's intervention, allows for an uninterrupted exhibition, with no columns interrupting the sequence of spaces.

What Was Done Well

According to current precedent with respect to sustainability, Carlo Scarpa's intervention in Castelvecchio is an excellent example of how we should use existing structural fabric.

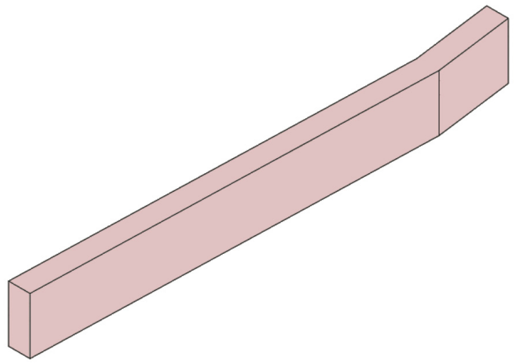
Rather than gutting the building and inserting a regular frame, Scarpa made use of the thick castle walls as much as possible, so minimal additional members were required for his intervention.

What Could Be Improved

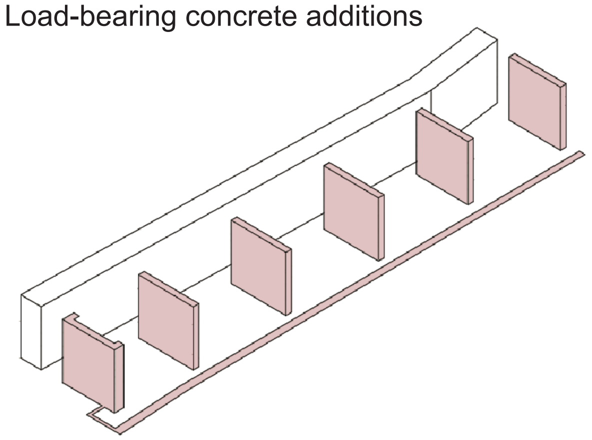
While the existing fabric is used extensively, Scarpa's new structures were perhaps not made with maximal regard to sustainability.

In the Napoleonic wing, a concrete frame is used which is supplemented with a steel girder. However, deeper concrete could have been used for the primary beam, which would have lowered the embodied energy by eliminating the need for steel - which demands high temperatures during manufacture.

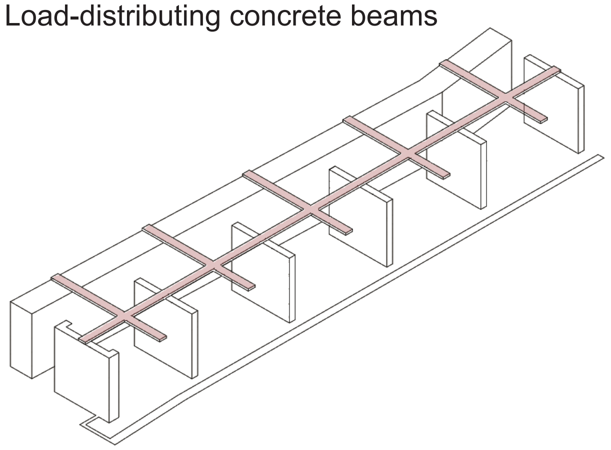
1. Existing 13th Century masonry castle wall



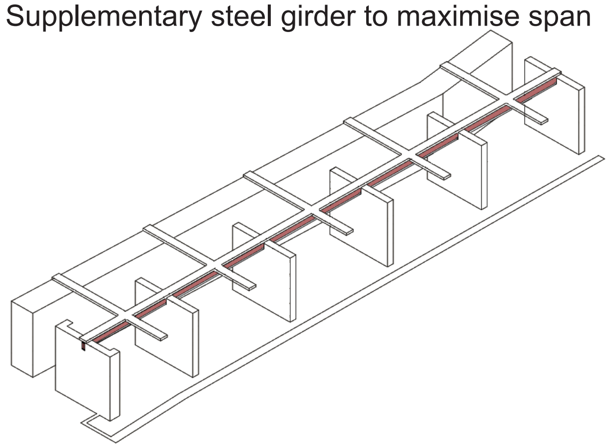
2. Load-bearing concrete additions

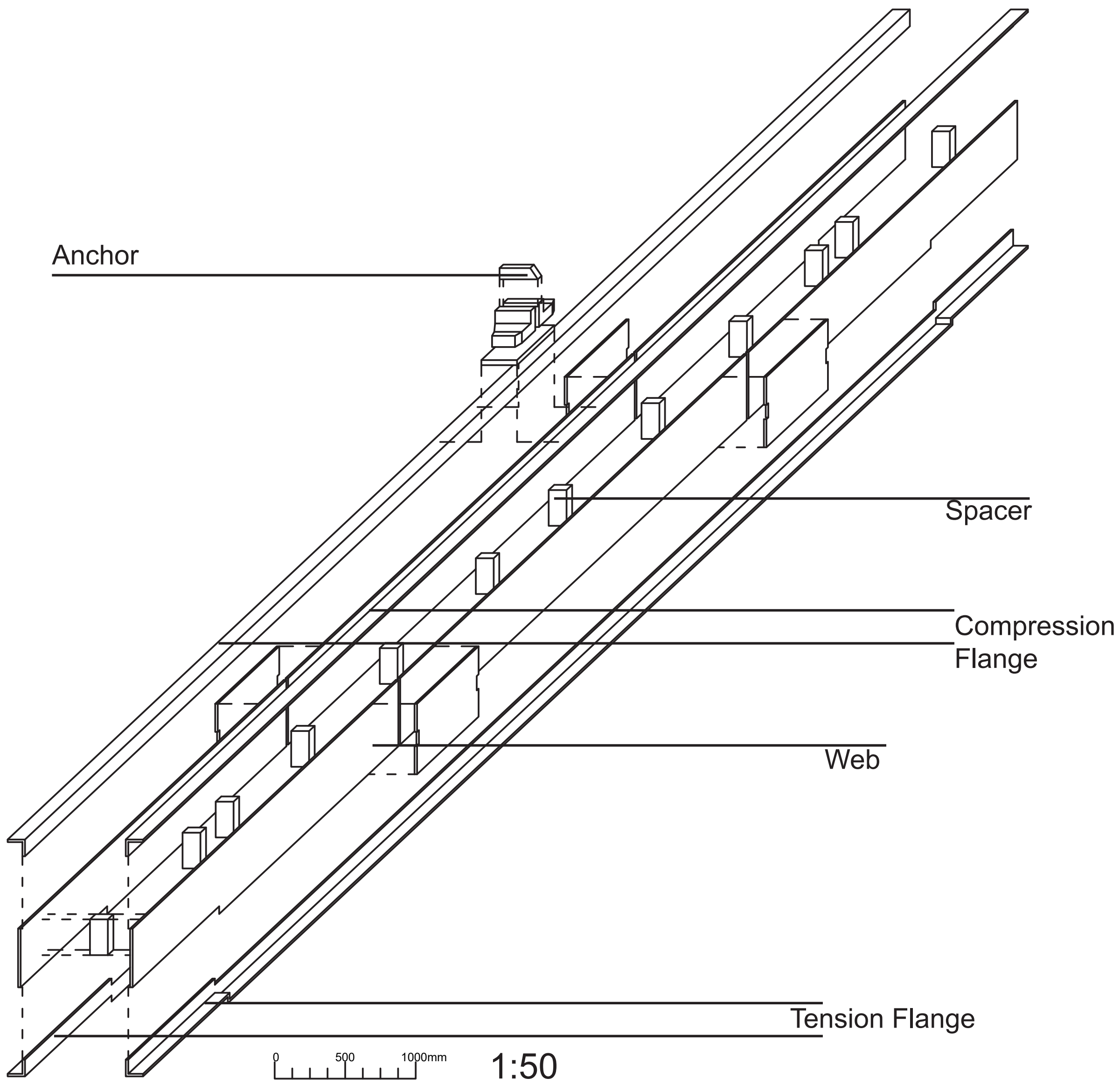


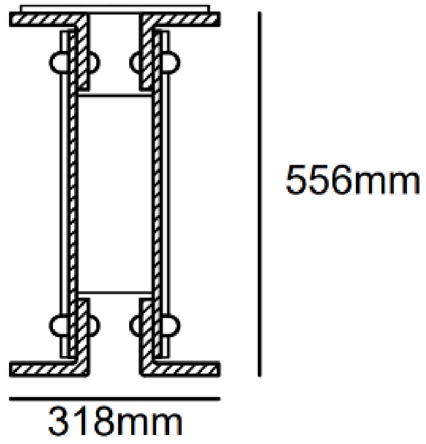
3. Load-distributing concrete beams



4. Supplementary steel girder to maximise span







Second moment of area (Ixx) =

$$\frac{H^3 b}{12} + 2\left[\frac{h^3 B}{12} + \frac{hB(H+h)^2}{4}\right]$$

Effective values:-
H = 519mm
B = 238mm
h = 18.5mm
b = 84mm

Ixx = **161,500cm4 (4sf)**

Max. deflection = $\frac{WL^3}{48EI}$

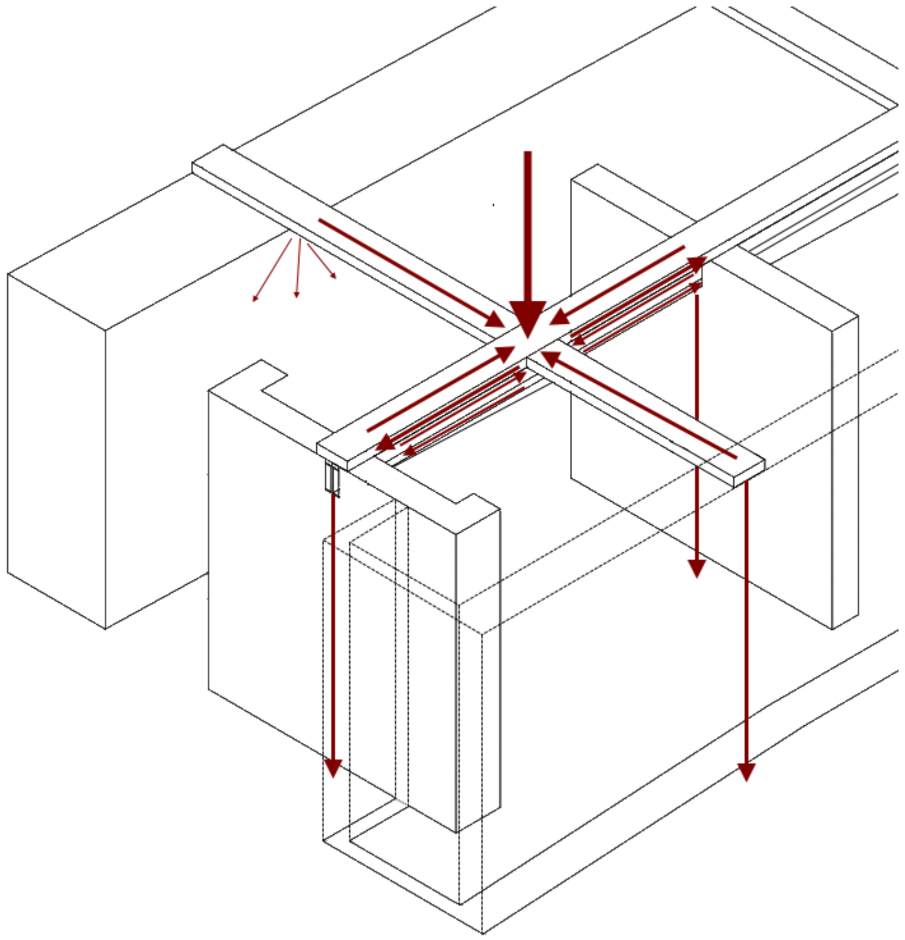
= 34635/(48*210000*0.001615)
= 2.13mm

Elastic Modulus = Ixx/0.5(H+2h)
= 5,810cm3

Min. Yield Strength = Mmax/Modulus
=(17.5*100000)/5810
= 301 N/cm
= 30.1 N/mm
(S235 and above comply)

1- Formula for deflection from Arya, Chanakya. 2009. Design of Structural Elements : Concrete, Steelwork, Masonry, and Timber Designs to British Standards and Eurocodes (London ; New York: Taylor & Francis), p. 22
Cameron Linden Green

2- Second Moment of Area formula from https://amesweb.info/section/second-moment-of-area-calculator.aspx accessed 27 Dec 2023
3- Beam axonometric and section drawn based on Murphy, Richard, Arrigo Rudi, and Alba Di Lieto. 2017. Carlo Scarpa and Castelvecchio Revisited (Edinburgh, United Kingdom: Breakfast Mission Publishing), p. 116

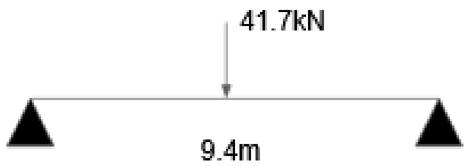


Ultimate Load, Maximum Moment and Yield Strength (in bending)

Wult = 1.35Gk + 1.5Qk

Building Category- C3 (EN 1991-1-1:2002 Table 6.1)
Gk = Dead Load (Self-weight of concrete beams)
Qk = Imposed Load (4kN, EN 1991-1-1:2002 Table 6.2)

Focusing on effective load with respect to the steel girder,
Wult = 1.35*299 + 1.5*4
= 410kN
Over an area of 245m2, the steel girder is responsible for:
1.69kN/m2
8.34kN/m



Mmax = WL/4
= 98.0kNm (3sf)

Moment / Modulus = Minimum Yield Strength

98kNm = 98,000,000Nmm
5,810cm3 = 5,810,000mm3

98,000,000Nmm / 5,810,000mm3
= 16.87 N/mm2

S275 Yield Strength = 275N/mm2
16.87 > 275, so **girder is likely S275 steel**

SUMMARY

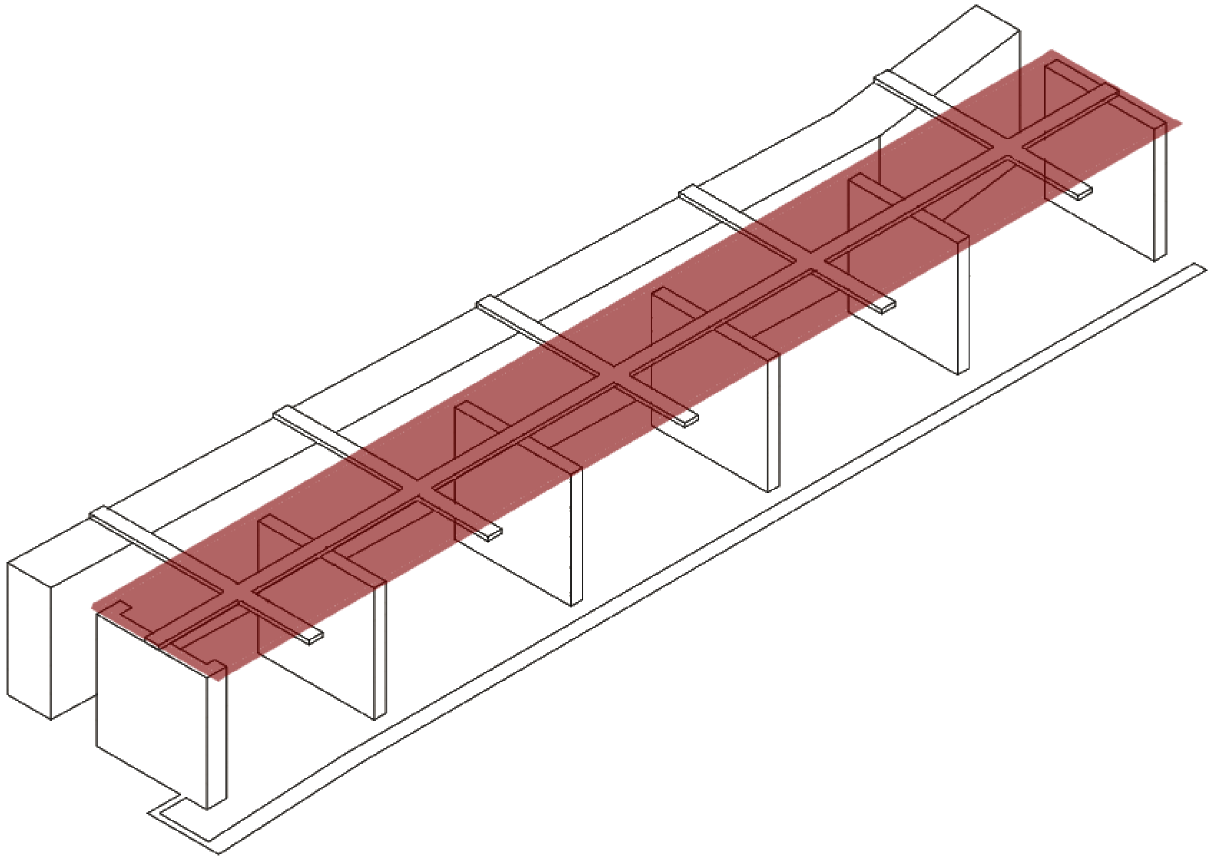
W_{ULT} = 410kN
= 1.69kN/m2

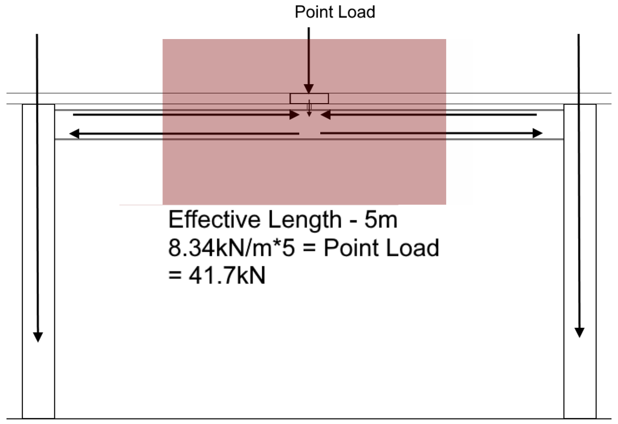
M_{max} = 98.0kNm

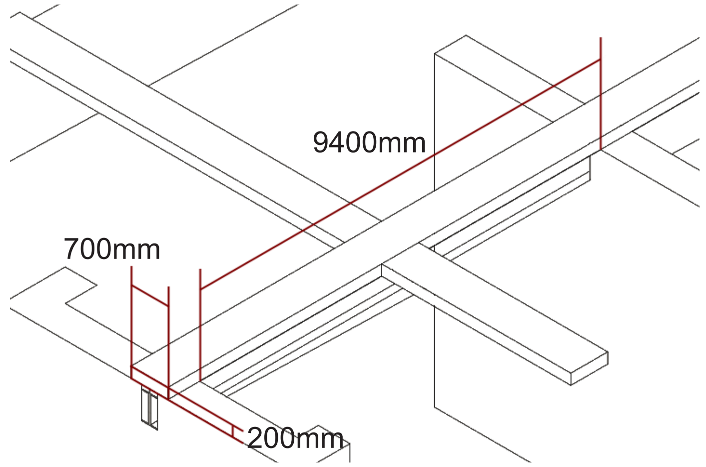
δ_{max} = 2.13mm

$F_{y,MIN}$ = 16.87N/mm2
F_y = 275N/mm2

Diagrams







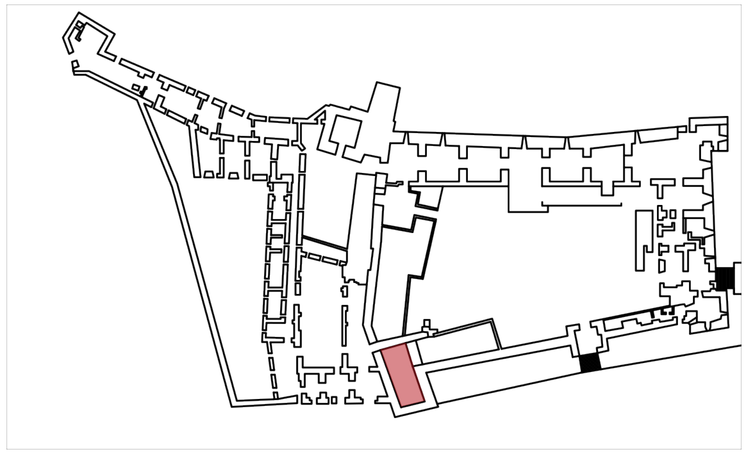
The steel girder that runs through the length of the museum's purpose is to carry the load that heavy statues impose on the floor plate, and to carry this load through to ground through the load bearing walls.

The girder's section performs well - the minimum yield strength required is well below standard strengths of steel. S275 offers a strength of 275N/mm2, the ultimate load only demands a strength of 16.87N/mm2.

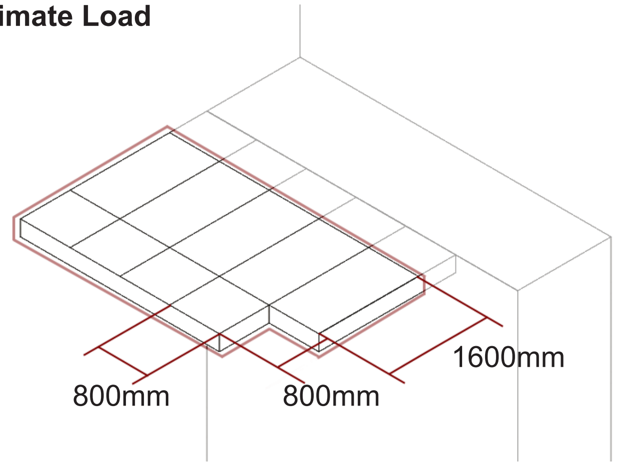
This specific beam is constructed so that it can latch onto a stone 'shelf' in the building itself to distribute load into the ground, becoming deeper between each shelf to accommodate the load from the floor plate above.

The girder exists to eliminate the need for a column, which would have been the orthodox solution - however, this would have interrupted the visual rhythm of the exhibition spaces.

Structural Elements - Floating Floor



Ultimate Load

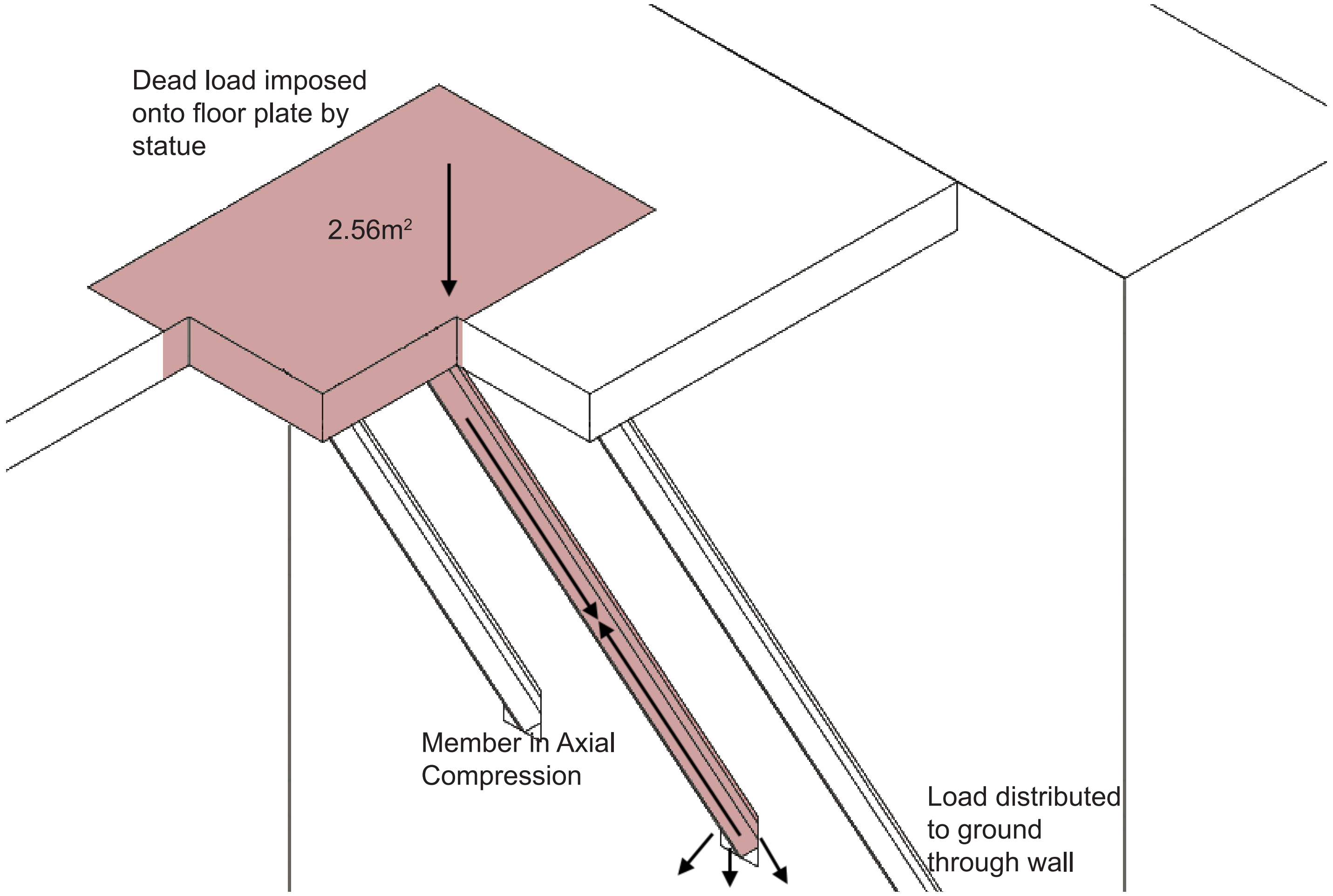


Assumed Materials

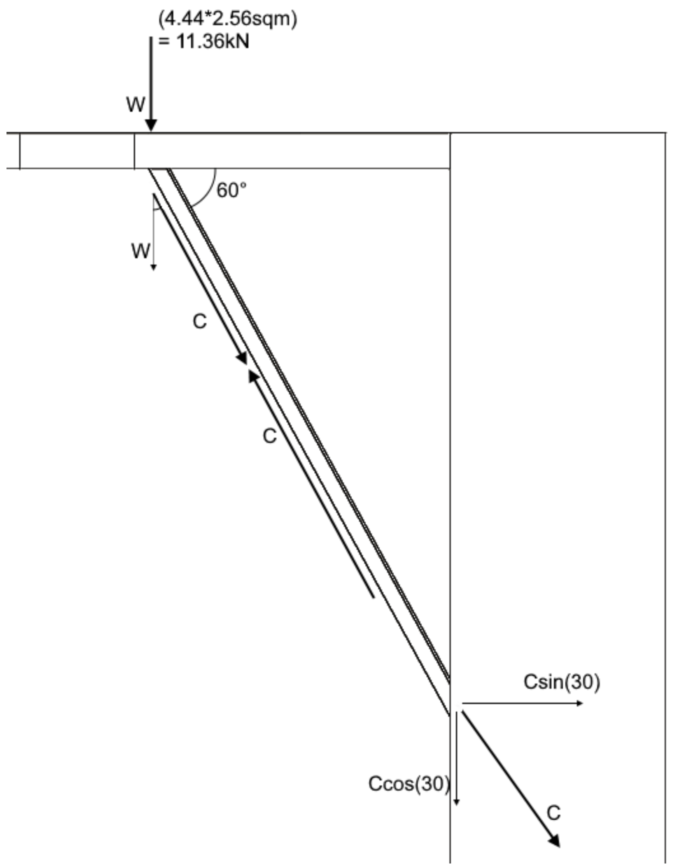
Steel member - 254x127x84 UC Tee
Length = 18.4m
Infill - 60mm thick White Prun Stone
Density[1] = 2660kg/m^3

G_k = (18.4*84) + (11.36*0.06*2660) = 32.9kN

Wult = (32.9*1.35) + (4*1.5)
= 50.4kN
= 4.44kN/m^2



Axial Compression



Let C = Axial Compression
W = Load

Point load on highlighted member (W)
= Wult * A
= 4.44 * 2.56
= 11.36kN

C = W*cos(30)
= 11.36cos(30)
Axial Compression = 9.83kN

Minimum Axial Load capacity =
Design Stress * Section Area[3]

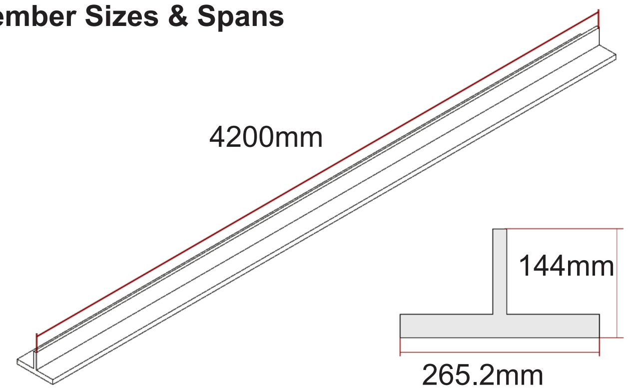
therefore

$A_{s,MIN} = C / 0.87f_y$

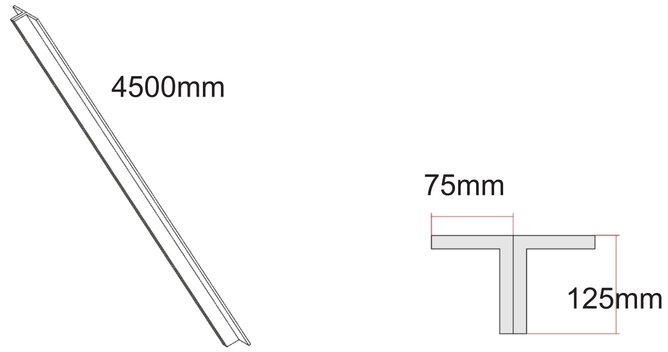
Assuming S275 steel is used,
$A_{s,MIN}$ = 9830 / (0.87*275)
= 41.1mm^2 = 0.411cm^2

According to the Tata Steel Blue Book, the **minimum member size is 60x40x5 Unequal Leg Angle.**

Member Sizes & Spans



254x127x84 UC Tee - Floor Plate



125x75x12 Back to Back Unequal Leg Angle Compression Member

What Was Done Well

The floating floor is another example of Scarpa's philosophy with regards to intervention in Castelvecchio - the steel members utilise the compressive strength of the thick masonry walls to distribute the load imposed from statues to the ground.

The use of this technique also reflects the aesthetics and structure of ancient drawbridges, further reflecting the design DNA of Castelvecchio.

What Could Be Improved

From the calculations, we can see that the member in axial compression, even in its' maximum load state, is not responsible for much load, and the member in use is potentially oversized and therefore not optimally efficient.
Steel is also an unorthodox choice for compression - concrete or stone would have been a better choice for this member, as it has higher compressive strength. Alternatively, a deeper steel member could have been used in the floor, eliminating the need for the compression members.

1- https://mignollialfonso.it/our-materials/?lang=en accessed 17 Jan 2024
Cameron Linden Green

Cangrande Statue Plinth

The Cangrande statue in Castelvecchio is one of the key exhibits that bookends the Napoleonic wing. It is central to the experience of the user as they navigate through the different spaces, and enter into the interior.

In kind, Carlo Scarpa designed a plinth for the statue in order to make it central to a void space that existed between his Napoleonic wing and one of the original towers.

Firstly, it can be argued that concrete is an unorthodox choice for a structural feature that is predominantly in tension. While it is operating well within its' capacity in its' function, it can be said that it is not working as efficiently as possible - more material is being used than is necessary.

It is for this reason on top of the fact that concrete has a high environmental impact through embodied energy and carbon emissions, that it could be said that this cantilever is not optimally sustainable.

Statue

Width = 0.5m
Height = 1.94m
Length = 1.73m

Volume = 1.68m3
Concrete Density[1] = 2400kg/m3

Mass = 4,032kg
Load = 39.52kN

Self-Weight

Section Area = 0.295m2
Length = 3.1m
Volume = 0.915m3

Mass = 2195kg
Load = 21.53kN

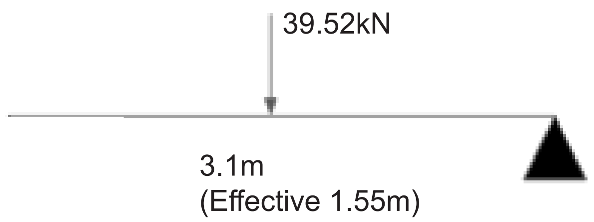
TOTAL LOAD = MAX. SHEAR
Vmax = 61.1kN

The statue's plinth is a reinforced concrete cantilever, clearly designed with reference to the strategies used in the shaping of steel beams - with a tension 'flange' on top supported by two 'webs' on either side underneath.

The cantilever protrudes out from a newly constructed wall by **3.1 metres**, and only supports the statue that sits atop it. This means that the cantilever is operating well within its' capacity, **deflecting by only 0.209mm.**

To increase material efficiency and general sustainability, Carlo Scarpa could have instead used a large steel member with a stone floor plate in order to withstand the load imposed on the cantilever by the statue.

The stone would be locally sourced from mountains no more than 50km away from Verona, and the steel member's volume would be far lower than that of the concrete member that exists. Therefore, even though steel is still not optimal in terms of its' embodied energy, it would still be preferable to concrete as a solution for this plinth.



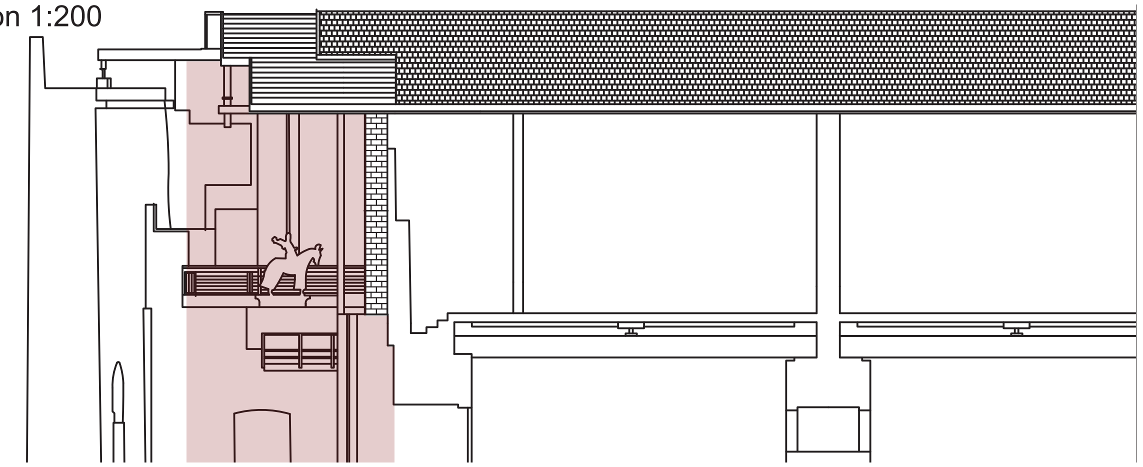
Mmax = F*d
= 39.52 * 1.55
= 61.26kNm

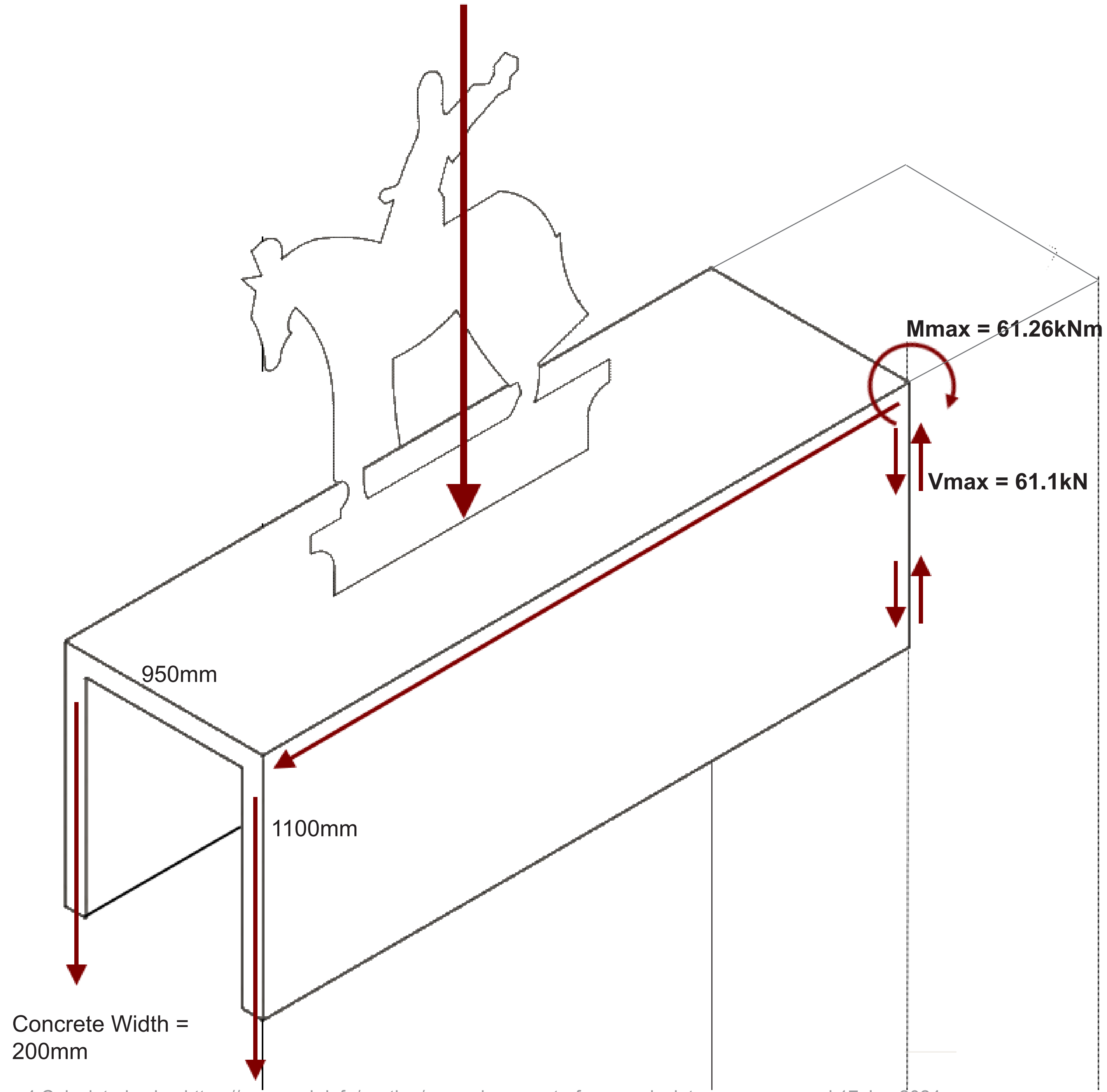
Deflection Calculations
Maximum safe deflection[2] = L/250 = 12.4mm

Assuming the concrete strength is C20/25,
Modulus of Elasticity[3] = 30GPa
Second Moment of Area (Iyy)[4] = 62,553,333,760mm^4

Max. Deflection[5] = $(WL^3)/(3E*I_{yy})$
δ_{max} = 0.209mm

Section 1:200

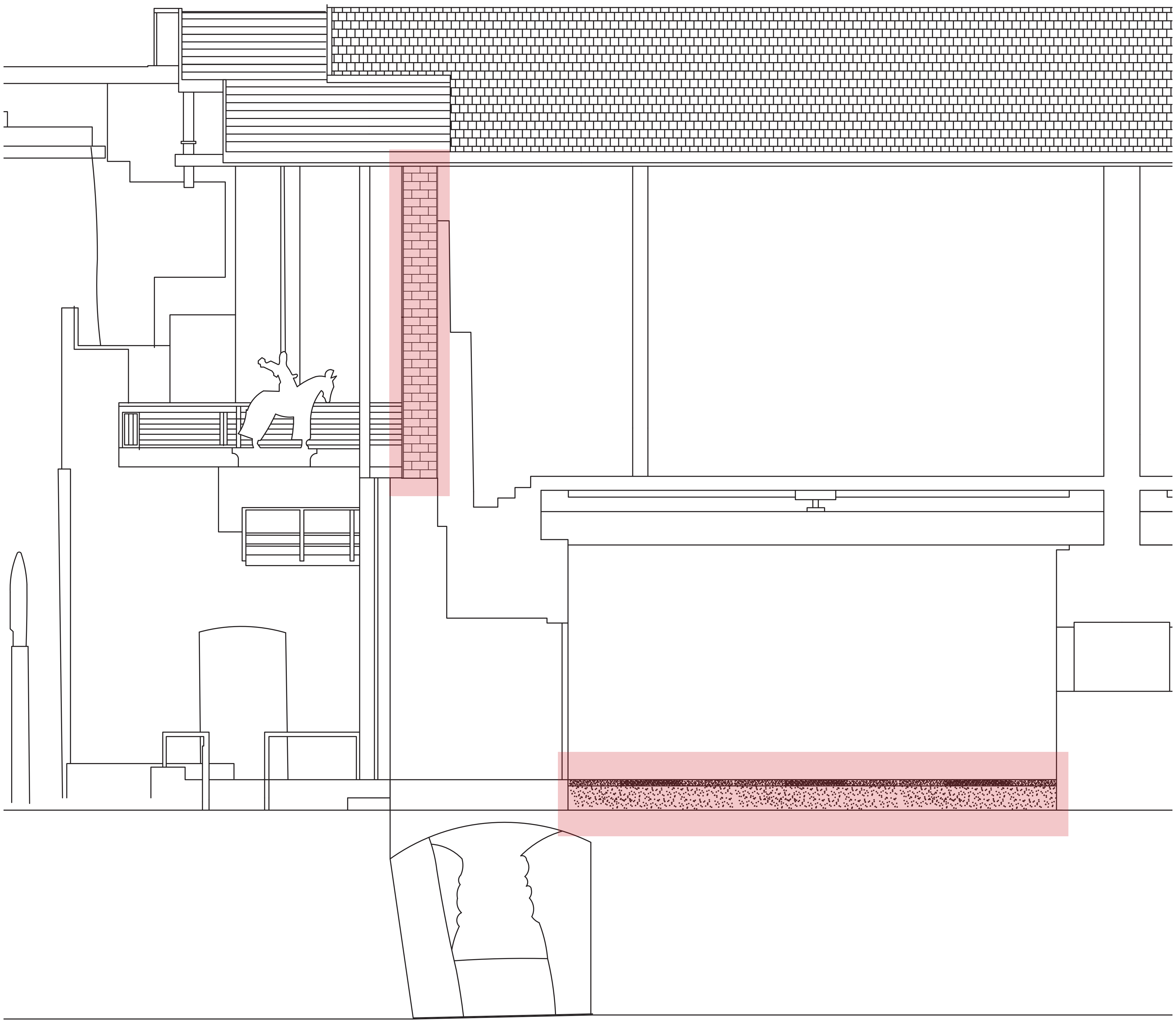




1 https://www.homedit.com/civil-engineering/materials/concrete/density-of-concrete/ accessed 17 Jan 2024
2 https://primeengineers.com.au/deflection-in-reinforced-concrete-structures/ accessed 17 Jan 2024
3 https://eurocodeapplied.com/design/en1992/concrete-design-properties accessed 17 Jan 2024

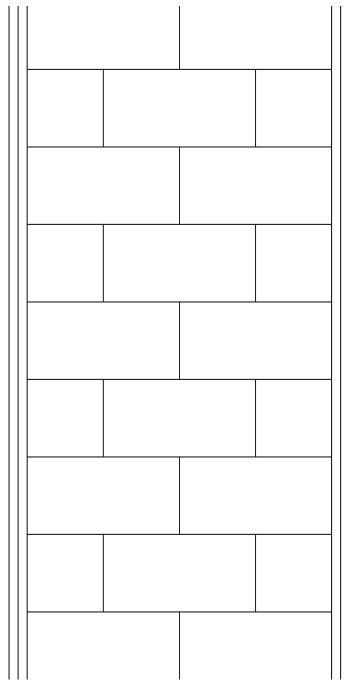
4 Calculated using https://amesweb.info/section/second-moment-of-area-calculator.aspxaccessed 17 Jan 2024
5 Formula for deflection from Arya, Chanakya. 2009. Design of Structural Elements : Concrete, Steelwork, Masonry, and Timber Designs to British Standards and Eurocodes (London ; New York: Taylor & Francis), p. 22

Construction Detail (1:50)



Wall Structure (1:10)

- **12mm** new lime render
- **12mm** old lime render
- **402mm** masonry
- **12mm** stucco

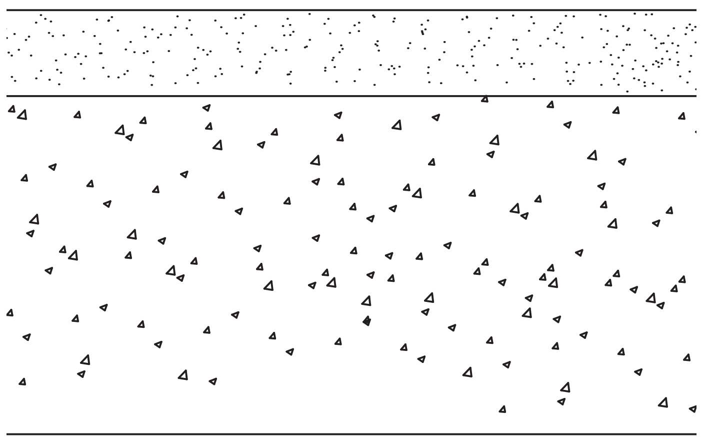


Key Points:

- There is no insulation, meaning the thermal performance is likely below standard.

- Thick masonry wall means that the building likely experiences good solar gains due to thermal mass.

Floor Structure (1:10)



- **75mm** white prun stone around the perimeter
- **370mm** reinforced concrete from pine formwork

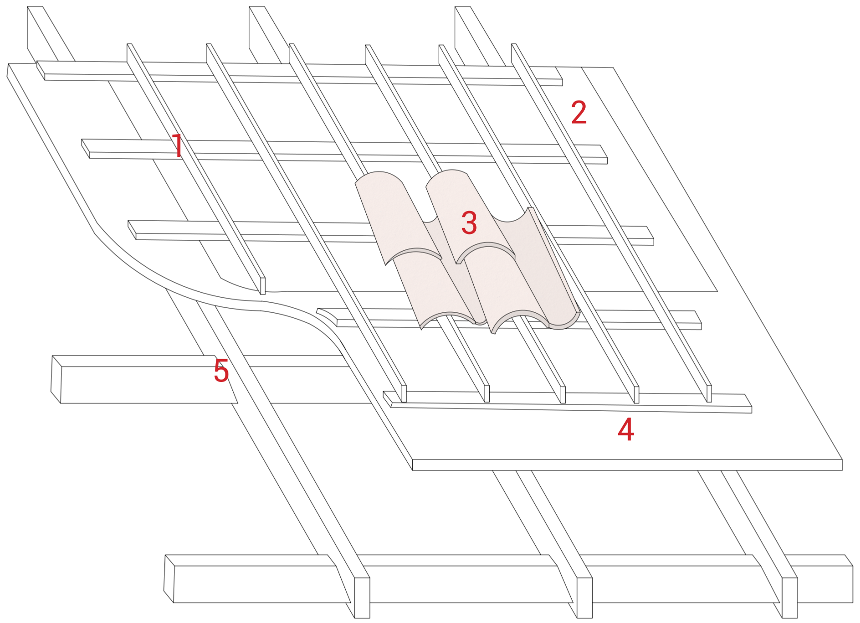
Key Points:

- Once again, there is no insulation, although concrete, similar to masonry, has good thermal mass properties

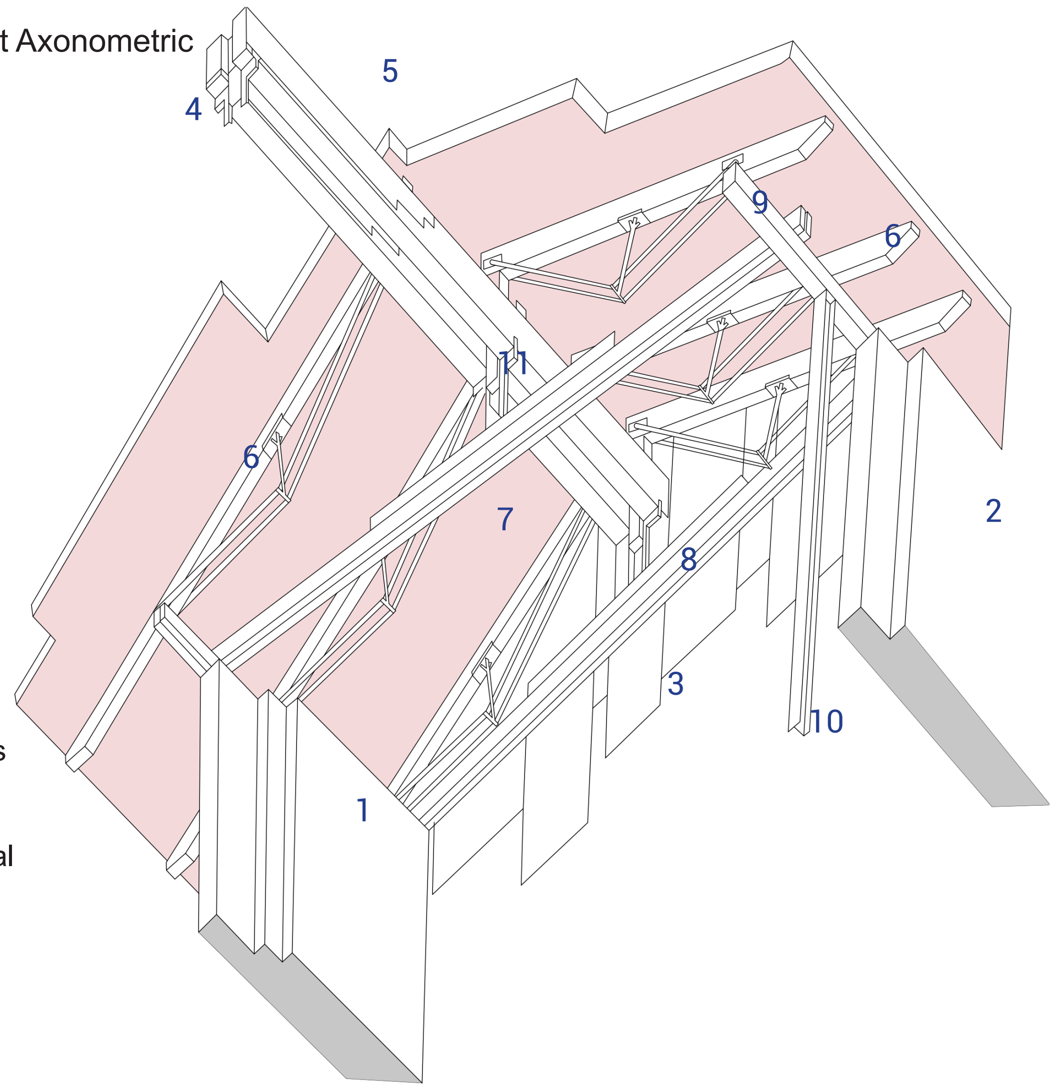
Roof Construction Study

Key:

1. Wooden Frame work
2. Lead water proof- ing
3. Terracotta Tiles
4. Timber Under layment
5.Timber Joinery



Soffit Axonometric

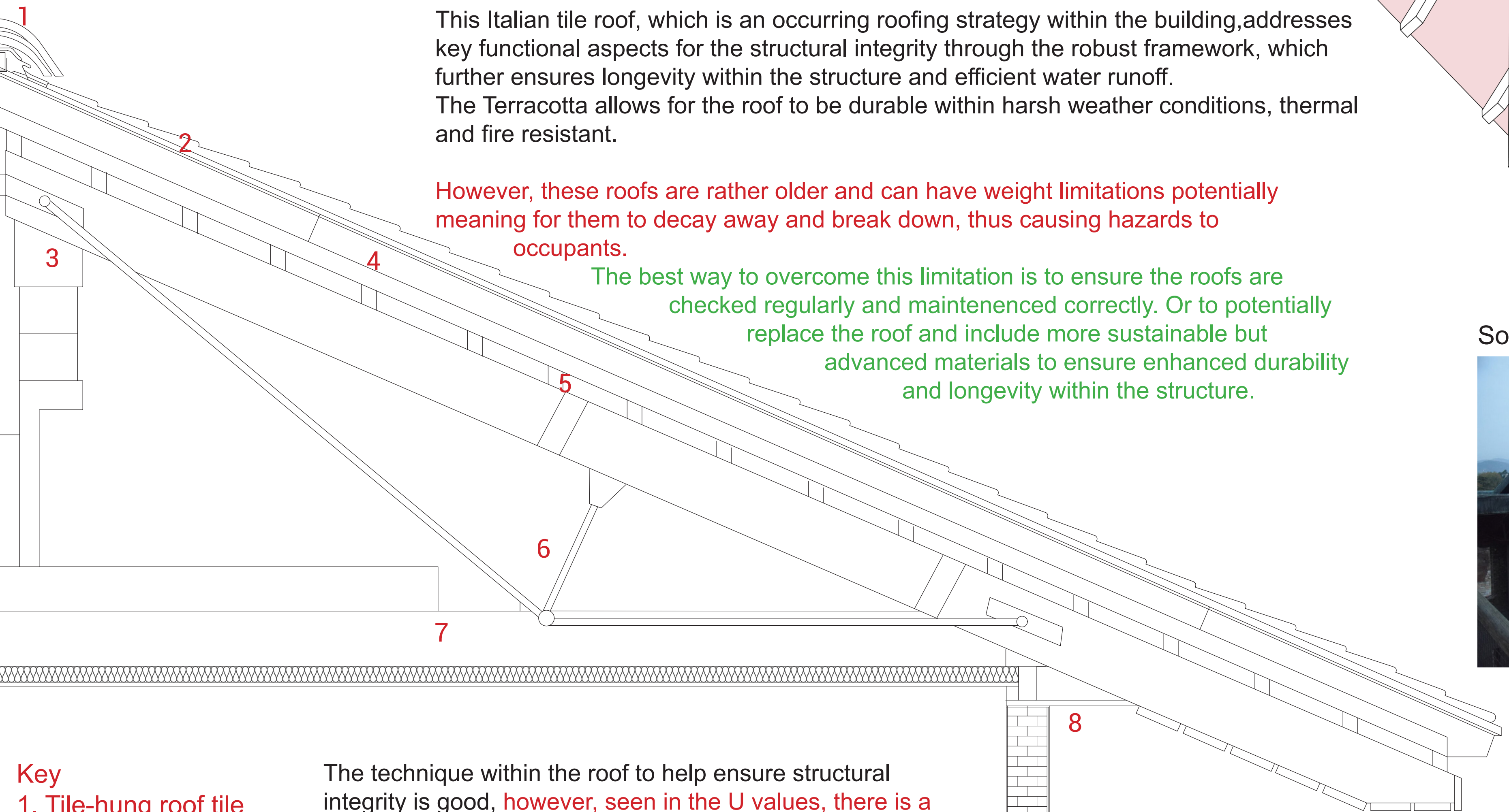


Key:

1. Trancated river - wall
2. Napolionic Facade
3. Hanging Tympanum panels
4. Commune wall
5. Double ridge beams
6. Trussed rafter structure aligned with the gallery
7. Main N-S strcuture angled to the gallary geometry
8. Main N-S aligned to the gallery geometry
9. Eaves beam
10. Steel column sitting on the ground floor section of the Napolionic facade
11. Steel carriage supporting the ridge beams

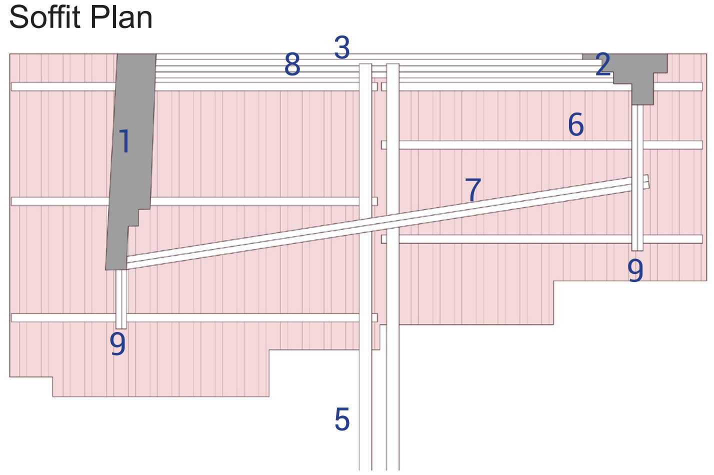
This Italian tile roof, which is an occurring roofing strategy within the building,addresses key functional aspects for the structural integrity through the robust framework, which further ensures longevity within the structure and efficient water runoff.
The Terracotta allows for the roof to be durable within harsh weather conditions, thermal and fire resistant.

However, these roofs are rather older and can have weight limitations potentially meaning for them to decay away and break down, thus causing hazards to occupants.
The best way to overcome this limitation is to ensure the roofs are checked regularly and maintenenced correctly. Or to potentially replace the roof and include more sustainable but advanced materials to ensure enhanced durability and longevity within the structure.



Soffit

Soffit Plan



Key
1. Tile-hung roof tile
2. Terracotta Tile
3. Copper cladding to the end of larch ridge beams
4. Timber Beam
5. Timber ridges
6. Trust Rafter juntion
7. Insulation
8. Juntion of Wall and Roof

The technique within the roof to help ensure structural integrity is good, however, seen in the U values, there is a massive difference between the required and provided. This is due to a lack of insulation paired with potentially open air within the timber beams, which are although good thermal conductors, there are not enough of them to ensure a better equated U value.
The best way to improve the roofing is to include better insu- lation - potentially between the timber beams or tiles, which are protected so they will not decay. Improving a material such as wood (key 4 and 5) to a better thermal conductor can also enhance the overall U value drastically.

CastelVecchio Roof U value = 0.77 W/m^2k
(See page 12)
Required U value (Approved by Document L) [1] = 0.16 W/m^2k

Overall, the U value difference between these values is 0.61 W/m^2k. Although the building relies upon thermal mass to maintain sufficing heat within the building, this is subsequently lost due to the roof's performance.

Although a prompted design strategy by Carlo Scarpa. The Copper Soffit (the exposed surface located on the underside of the roof) is an integral part of the Castelvecchio's redesign. Technically, the soffit choice of material, copper, works well, not only to an aesthetic appeal, but it also requires low maintenance as the life span of copper can last up to 100 years, thus making it a sustainable choice for the re-works. Additionally, the copper soffit is durable and weather resistant, ensuring long term performance and durability.

In comparison to the roof and soffit, the roof does need to be updated to ensure a longer life span as well as an improved U value. As, although the thickness of the old walls of the structure does ensure improved thermal conductivity, this is all essentially lost through the poor performance of the roof.

1. Approved Document Volume 2 Buildings other than dwellings Conservation of fuel and power 2022 Edition (n.d.). Available at: https://www.gov.wales/sites/default/files/publications/2022-09/approved-document-l-vol-2.pdf.

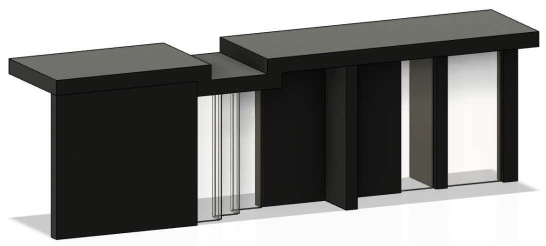
Alexander Hussell

Interior Remodelling

The three arched loggia exterior was the 1926 entrance to the museum. Through his approach of historical de-layering, Scarpa took the opportunity to preserve the loggia whilst adding his own disconnected layer behind. This layer consisted of two screen layers separated by a concrete multi-planar soffit. The screens are independent from each other, however, the upper screen has a much higher glazing proportion giving it a lightness which suspends it above the soffit atmospherically. The lower screen on the other hand has concrete elements with the same heavyweight materiality as the soffit, rooting the wall construction to the ground with a sense of weight and heavyness.

Lower Screen: Contrasting Construction

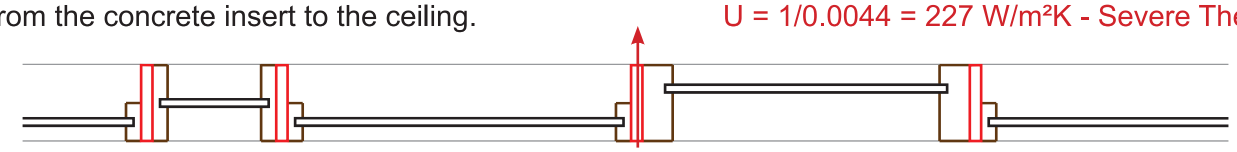
The lower screen's elements amplify the disruptive nature of their form through contrasting construction methods. The glass has been assembled without visible frames, with Scarpa opting to glue the panes together at their edges. The use of a high light-absorbant black lime plaster finish on the concrete monoliths absorbs the light dispered through the glass, which amplifies the effect of the void which its frameless detailing creates:



Upper Screen: Window Frames

The window-framing on the top-half of Scarpa's wall is delicate and artistic, however, performs poorly against building-construction standards. The panes of glass are directly held in solid frames cut from Slavonia Oak, finished with linseed oil. These frames are then attached onto the steel frame structure which spans from the concrete insert to the ceiling.

There are serious energy-efficiency issues, including a thermal-bridge through the 200mm thick exposed steel (λ= 0.0044)[1] and oak frame, and uncontrolled airflow through the unsealed glass-oak join.
U-Value: 1/Rt
R = l/λ = 0.2/45 = 0.0044
U = 1/0.0044 = 227 W/m²K - Severe Thermal-Bridging

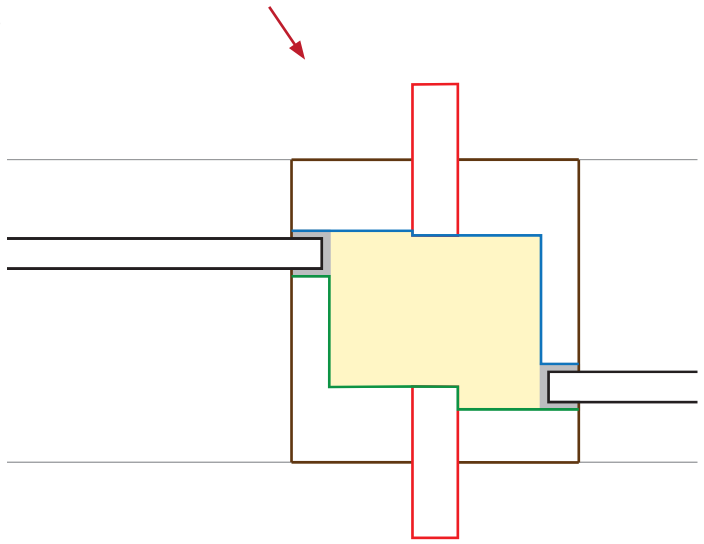


Window Frame Detail 1:20 - shown on Interior Facade

Suggested Sustainability Improvement

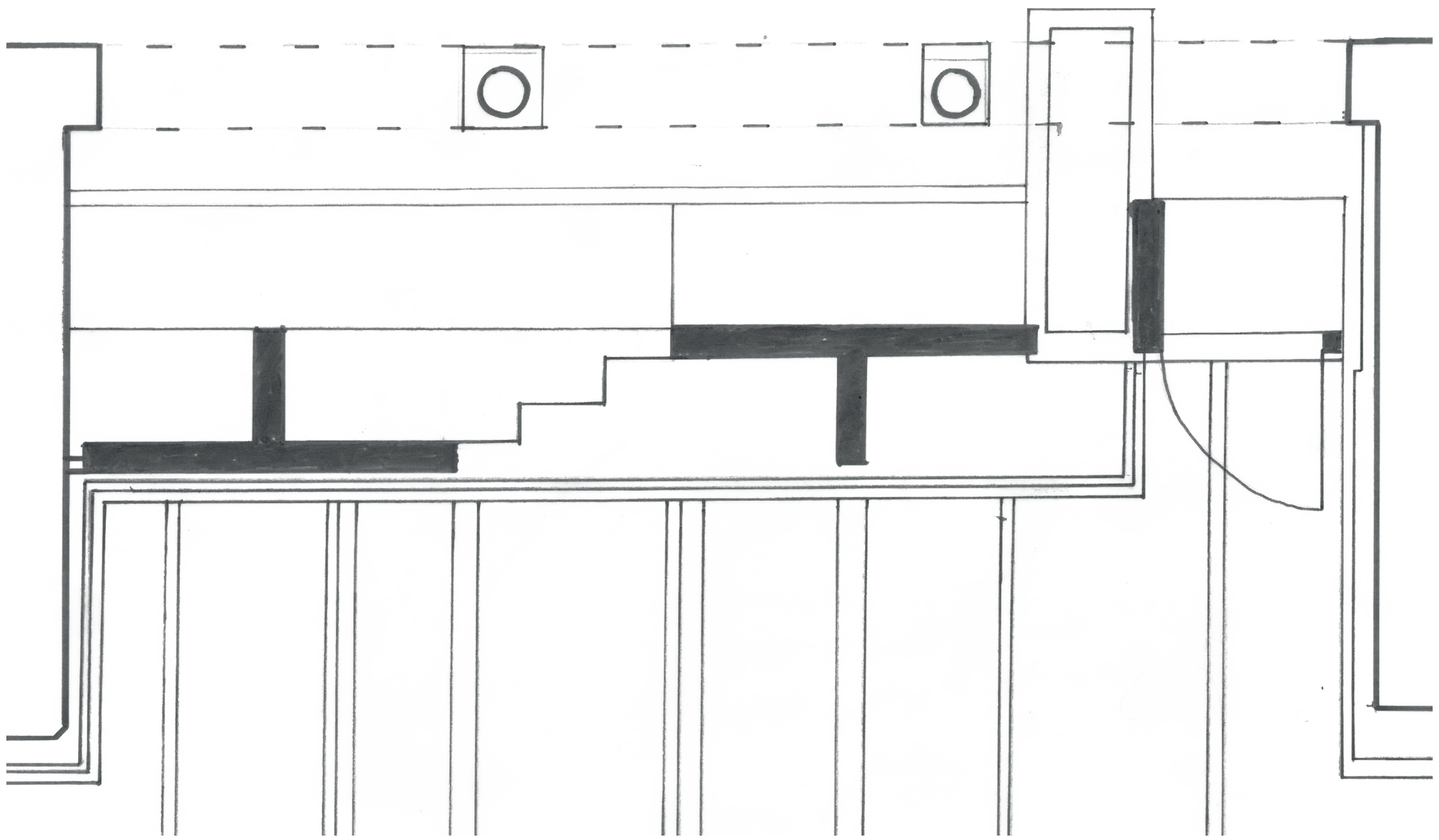
Following Approved Document L's[3] guidance for replacement windows, our proposed improvement bisects the steel to reduce thermal bridging and extends the frame to accommodate an infill of 80mm PIR Insulation Board (λ = 0.022)[2]. An aluminium inner-frame is used, allowing a waterproof-membrane to be applied on the exterior of the insulation with a Vapour Control Membrane applied on the interior to stop fluid transfer through the detail.
Resultant U-Value:
R_1 = 0.08/0.022 = 3.636; R_2 = 0.2/45 = 0.0044
U= 1/(3.636 + 0.0044) = 0.27 W/m²K

This value is very close to meeting Approved Document L's wall-standard of 0.26 W/m²K. This development would strike a fair compromise between the building's historic design and climate needs in a potential renovation process.

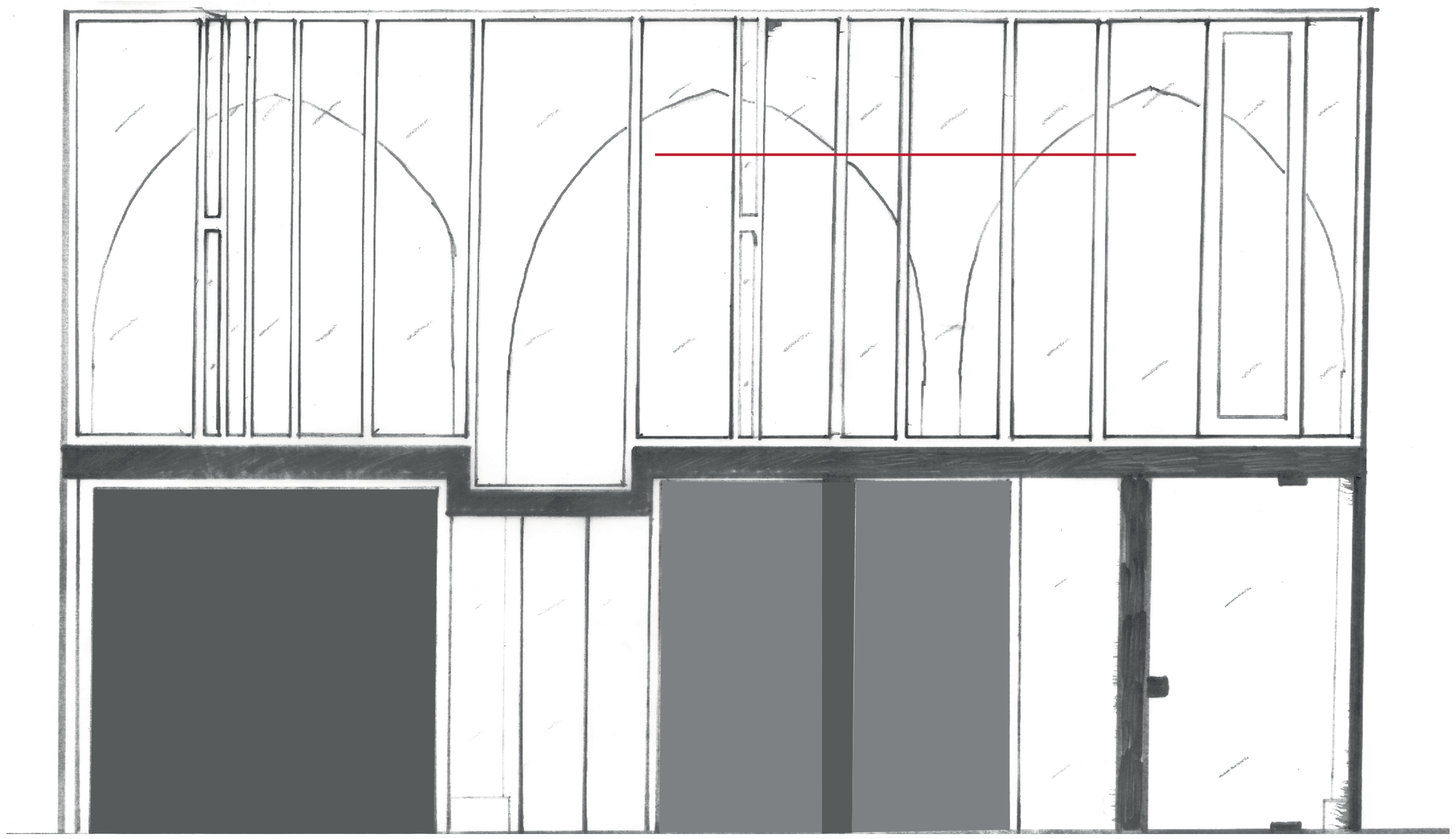


Proposed Improved Detail 1:5

Due to Castelvecchio's porous fabric, a porous insulation without membranes could be more suitable.



Plan of Loggia Wall 1:50



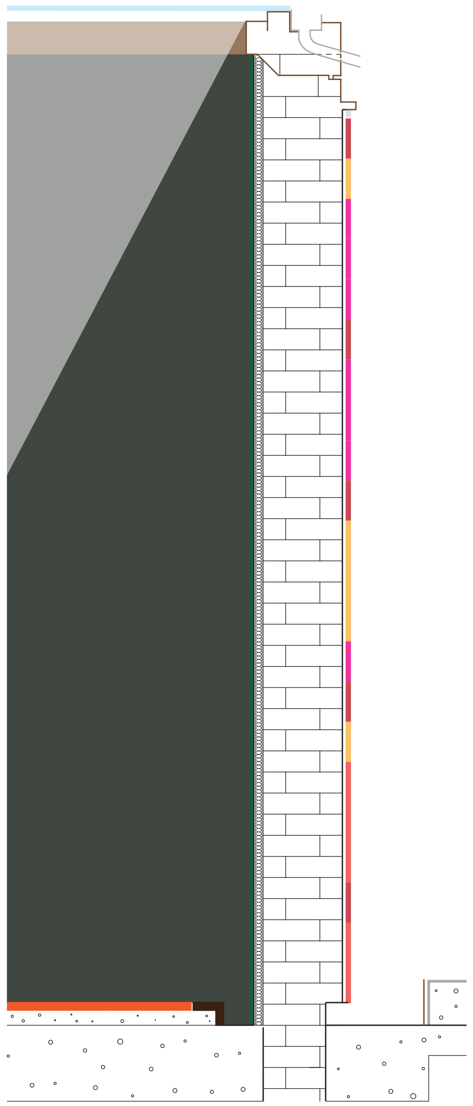
Interior Facade of Loggia Wall 1:50

1 Thermtest Inc. (n.d.). Materials Database - Thermal Properties. [online] Available at: https://thermtest.com/thermal-resources/materials-database.
2 Kingspan, *Types of Insulation - A Guide* (2022) <https://www.kingspan.com/gb/en/knowledge-articles/types-of-insulation-a-guide/> [accessed 4 January 2024]
3 HM Government, *The Buidling Regulations 2010: Approved document. L, Conservation of fuel and power* (London: H.M.S.O.)

George Palmer

Sacello

The Sacello is Scarpa's new-build extension of the ground floor exhibition into the courtyard. The volume reflects Scarpa's pioneering use of architectural technology with relation to a historical context to enhance the visitor experience. The space exhibits artefacts from Longobardic Tombs, Scarpa therefore only allowed light-admission through a horizontal window in the roof, and used a mixture of Bottle Green, Prussian Blue and Black pigmented plaster to create a tomb-like atmosphere which is pierced by a ray of sunlight. The exterior of the Sacello is clad in four hues of local Prun Stone. The colours were intitially very vivid, and served as a visual reminder to those entering about the comprehensive interior work. However, poor maintenance has meant that the stones have faded and lost their impact.

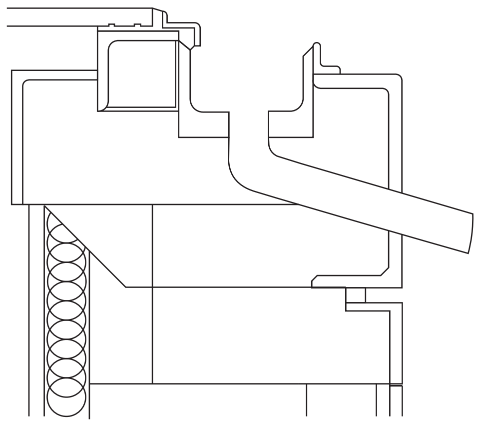


Scarpa's exterior wall to the Sacello has a masonry construction, including a 25mm insulation board applied internally.

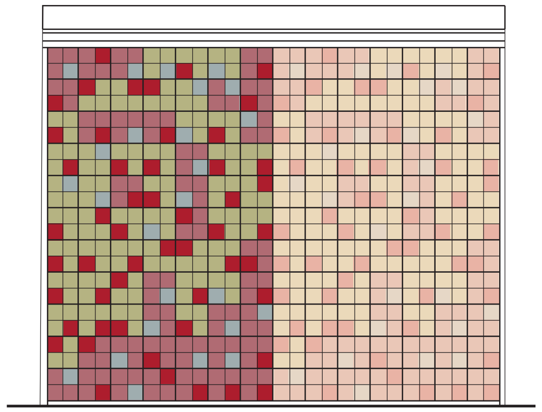
R1 = 0.01/0.209 = 0.0478
R2 = 0.025/0.022 = 1.14
R3 = 0.2/0.711 = 0.281
R4 = 0.01/1.757 = 0.00569
Rt = 1.47449
U = 0.68 W/m²K
Thermal Values from database.[1]

This does not meet Approved Document L's[2] standard of 0.26. To align the thermal performance of the wall construction with modern regulations the insulation would have to be 59mm thick. Whilst providing a greater level of building performance, the increased width would disrupt Scarpa's precise dimensional relationships. With historic areas of the building having a U-value much greater than the Sacello's 0.68, the retrofit of extra insulation here would have little impact on overall performance, causing greater disruption to the design experience.

Sacello Exterior Wall 1:20



Gutter Detail 1:5



Prun Stone Facade showing the effect of poor maintenance 1:50

Construction Evaluation and Improvement

The gutter detail shows responsible water management from the glass roof and creates an artistic form from a technical necessity.

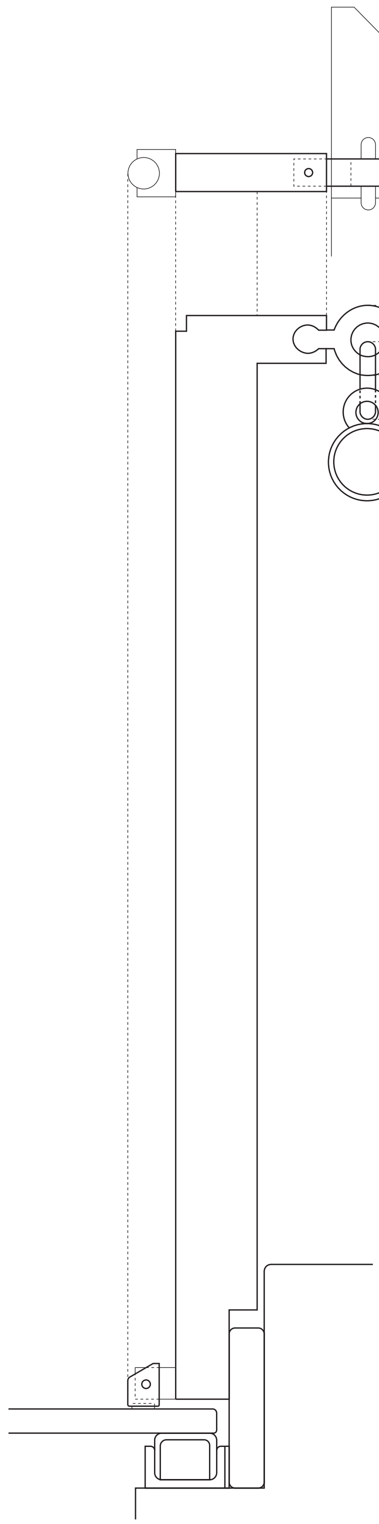
The exterior Prun stone cladding is very porous, and is left exposed to rain, requiring constant maintenance. The brick walls and concrete floors are at risk of severe water ingress due to there being no waterproofing to the ground floor construction. Damp could rise up the wall and where the porous concrete meets the non-porous floor fixtures, water could become trapped.

The plaster used on the interior is a lime plaster. Lime plaster is Alkaline, with a pH of 8.6 when dry. This reduces the possibility of fungal growth in areas of water ingress.

We therefore recommend that when rennovation/ maintenance occurs, a layer of lime plaster is introduced on porosity thresholds. This would likely be a non-invasive process on the aesthetics, as the plaster will be hidden behind non-porous fixings and the plaster can be pigmented to reduce further impact.

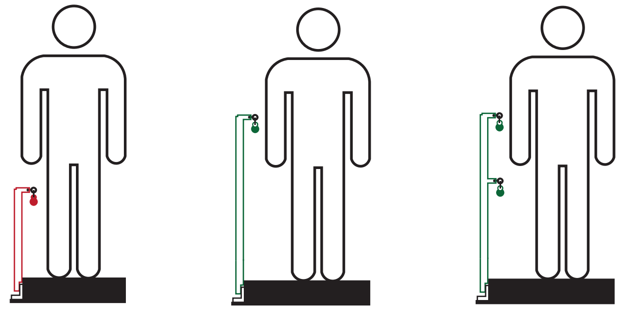
Handrails

Scarpa excavated a historic moat underneath the ground-floor of the Napoleonic Wing and placed a glass pane in the floor to allow viewing of the space. A combined frame and handrail was designed to elegantly hold the glass in-place whilst stopping visitors from walking over the installation.



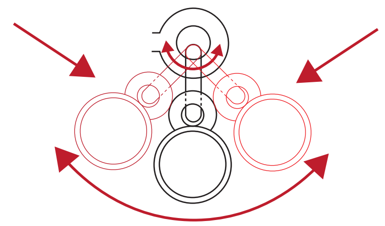
Original Handrail detail 1:5

The vertical height to the top of the upper handrail on the original design is 525mm. This does not fit the range of 900-1100mm as stated in Approved Document M and is impractical for use and a potential trip-hazard. Therefore, to improve Scarpa's handrail design to correlate with contemporary accessibility requirement, we would suggest increasing the length of supports by 500mm, placing the handrail height at 1025mm, within the Approved Document range. As the handrail is a 'guarding' handrail, to further comply with Approved Document M, a secondary rail at 600mm should in installed. We would repeat Scarpa's modified detail below:

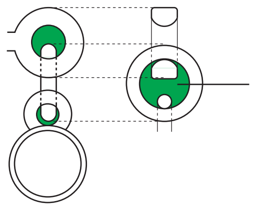


Revised handrails with Approved Document M 1:50

The handrail is suspended from posts through a series of circular rings, which allows them to slide in a circular motion when force is applied:



This motion defies Approved Document M, as it is not 'slip resistant'. It is reasonable to assume that a visitor of limited mobility would use the handrail for support, resulting in unexpected movement. This is unsafe as it could lead to a fall and/or an injury. As a result, we suggest an improvement to the detail. The ring form can be preserved to retain the artistic ambitions, however a solid steel insert could be fabricated into the rings, removing the rotation potential. This will allow users of limited mobility to support themselves without any movement in the rail, creating a safe and accessible environment:



Handrail detail aligned to Approved Document M 1:5

1 Thermtest Inc. (n.d.). Materials Database - Thermal Properties. [online] Available at: https://thermtest.com/thermal-resources/materials-database.
2 HM Government, *The Buidling Regulations 2010: Approved document. L, Conservation of fuel and power* (London: H.M.S.O.)
3 HM Government, *The Buidling Regulations 2010: Approved document. M, Access to and Use of Buildings* (London: H.M.S.O.)

George Palmer

U-Value Study (Napoleonic Wing)

$R = d / K$ $R_T = Rso + R1 + R2 + ... + Rsi$ $U = 1 / R_T$

Wall Calculation $R_T = (0.012/0.209) + (0.402/0.711) + (0.024/1.674) = 0.637$ **U = 1.569**

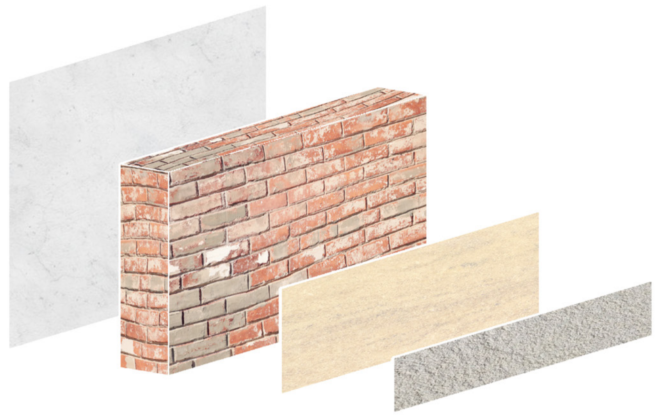
Floor Calculation $R_T = (0.37/0.753) = 0.491$ **U = 2.037**

Roof Calculation $R_T = (0.56/0.431) = 1.299$ **U = 0.770**

K-Values Obtained from online database[1]

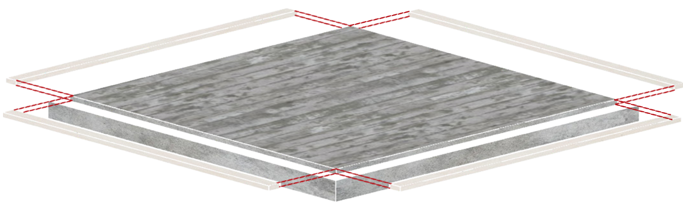
Wall Envelope

Element	Thickness (mm)	K Value (W/mK)	R Value (mK/W)
Stucco	12	0.209	0.057
Masonry	402	0.711	0.565
PIR Retrofit (Suggested Improvement)	50	0.022	2.273
Old Lime Render	12	1.674	0.007
New Lime Render	12	1.674	0.007
Total	**438 (488)**	**N/A**	**0.636 (2.909)**



Floor Components

Element	Thickness (mm)	K Value (W/mK)	R Value (mK/W)
Cast Concrete (From Pine Formwork)	370	0.753	0.491
White Prun Stone (Around the Edges)	75	1.757	0.043



Roof Improvement

Element	Thickness (mm)	K Value (W/mK)	R-Value (mK/W)
Polished Plaster Soffit	560	0.431	1.299
Mineral Wool Insulation (Suggested Improvement)	400	3.008	13.3

The ceiling on the upper level utilises an interior structure known as a soffit. This is used to conceal the timber frame roof structure. The hollow space above that is likely susceptible to heat loss due to the lack of insulation and old roof structure. It is likely that heat escapes quite easily through the roof ties.

In response to this, an addition I would suggest is a layer of mineral wool insulation that sits on top of the soffit, providing an additional layer that prevents heat loss. This area can't be seen, so there is no impact on the desired aesthetic.

Analysis

Verona experiences Annual lows of -8°c, so adequate insulation within the building envelope is essential. Given that the structure is ancient, the building doesn't meet contemporary U-value regulations outlined in **Approved Document L**[2].

The required U-Values for walls, floors and pitched roofs are given as 0.26, 0.18 and 0.16, respectively. The obtained U-Values for the same elements currently are 1.569, 2.037 and 0.77. In order to reduce these so that they are nearer to the regulated values, intervention is required.

Improved Wall Section U-Value Calculations:

Wall
$R_T = (0.024/1.674) + (0.402/0.711) + (0.012/0.209) + 0.85 + 0.15 + 4 + (0.012/0.209)$
$R_T = 5.695$ $U = 1/5.695 = \mathbf{0.176}$

Roof
$R_T = (0.56/0.431) + 13.3 = 14.599$
$U = 1/14.599 = \mathbf{0.068}$

Element	Required U-Value (W/m²K)	Current U-Value (W/m²K)	Improved U-Value (W/m²K)
Walls	0.26	1.569	0.176
Floor	0.18	2.037	N/A
Roof (Pitched)	0.16	0.770	0.068

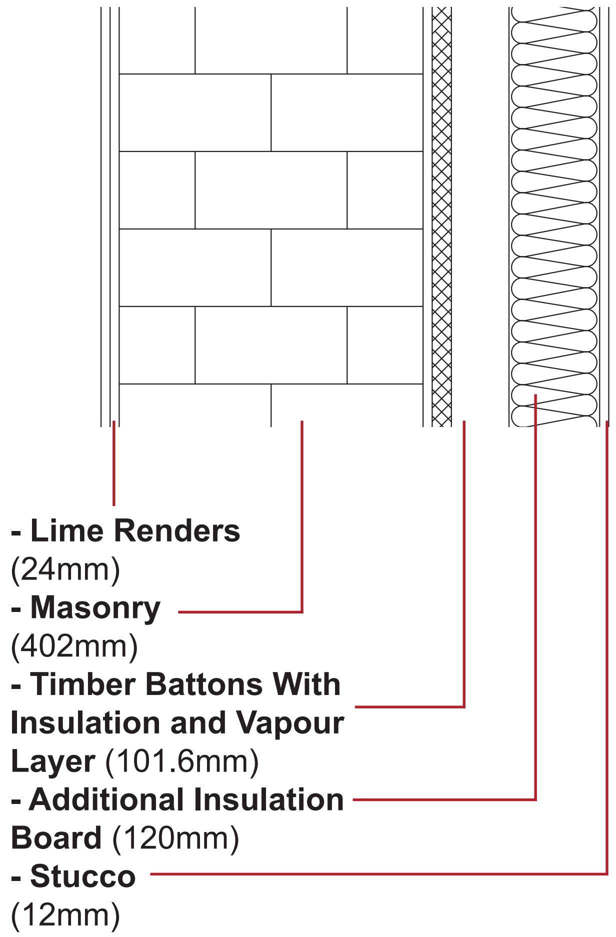
As demonstrated, the suggested improvements allow the wall and roof U-values to adhere to the standards outlined by the Approved Document L without having too large of an effect on the aesthetics.

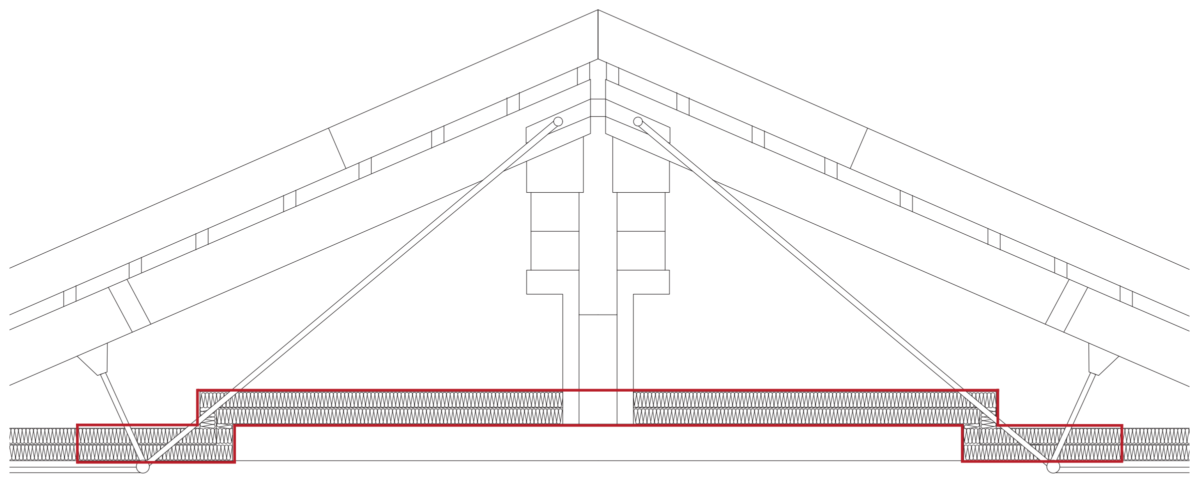
Additional Wall Insulation

(Suggested Improvement)

A layer of insulation can be added at the expense of gallery space - it just depends what is valued more. By adding board insulation and a new layer of stucco, the wall U-Values can go from **1.569** to **0.177**, which is well within the regulations displayed in Approved Document L.

Revised Wall Section (**1:10**):





1 Thermtest Inc. (n.d.). Materials Database - Thermal Properties. [online] Available at: https://thermtest.com/thermal-resources/materials-database.

2 Britain, G., Britain., G. and Britain., G. (2010). Approved document. L, Conservation of fuel and power. London: H.M.S.O.

Oliver Hall

Ventilation Strategy (Napoleonic Wing)

Given that Castelvecchio is a medieval castle, the ventilation strategy could be considered rather basic when compared to contemporary museums that have been designed in the years since. There is a large dependance on natural ventilation processes to enhance air movement. Tactical positioning of openings encourages processes such as cross ventilation which promote air movement, drawing in cool air from the exterior and removing stale air **(Figure 1)**.

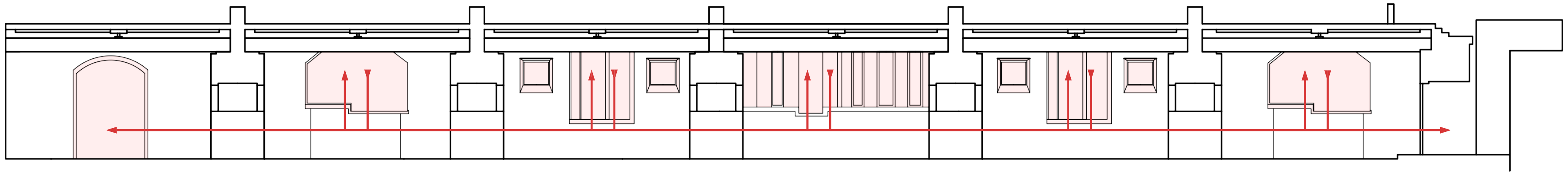


Figure 1 - Ventilation strategy in the Napoleonic wing. Windows placed along the space promote air movement throughout the space.

Aims and Challenges

Aims

- Mainly natural ventilation systems. It is inappropriate to incorporate HVAC system due to the medieval aesthetic and serene nature of the building.
- Provide a space which is ventilated adequately.
- Extract air that is hot from crowds of people within the space.

Challenges

- The Napoleonic wing is a vast space, which is long and open plan throughout. This will require a large amount of ventilation.
- The space is used by a lot of people every day, so it is important for hygiene reasons that fresh air is introduced as frequently as possible.

Passive Ventilation Effectiveness

Air Changes Per Hour Calculation

$$\textbf{ACPH} = \frac{\text{air supply rate}^1\ (\text{l/s}) \times \text{number of occupants} \times 3600\ (\text{s}) \times 0.001\ (\text{m}^3)}{\text{volume of space}\ (\text{m}^3)} \qquad \frac{10 \times 20 \times 3600 \times 0.001}{40 \times 20 \times 3.7} = 0.243$$

Approx. room volume = (40 x 20 x 3.7) = 2960m³
Max volume of air changed per hour = (2960 x 0.243) = 719.28 m³/h
Max volume of air changed per sec = 199.8 l/s
Total exchanged air = (199.8 x 2) = 399.6 l/s

As shown by the calculation, the space isn't adequately ventilated. **0.243** is a very low ACPH value and 399.6 l/s is a lower amount of air change than would be expected. Additional ventilation processes possibly need to be introduced.

Suggested Air Supply Rates (CIBSE Guide A)

Building/room type	Suggested air supply rate / (L·s⁻¹ per person unless stated otherwise)
Museums and art galleries:	
— display[25]	10[2]
— storage[25]	10[2]

Approach to Improvement

One of Castelvecchio's crowning features is its medieval aesthetic. From a design point of view, it would be inappropriate to introduce a HVAC system, therefore, any additions and alterations made would have to be understated.

Displacement ventilation is a simple process that uses convection to enhance air flow. This could work well in co-operation with slab cooling to have a positive effect on the ventilation of the space.

Displacement Ventilation

(Suggested Improvement)

Displacement Ventilation utilises buoyant air movement to promote ventilation. In this process, cool air is introduced at a low level. Stimuli such as people and machines heat this air, causing it to rise into a stratified warm layer - this process is known as convection. Extractor fans can be used to remove the heated air, which in turn leaves room for the fresher air to rise. This is an ongoing process that constantly introduces fresh air.

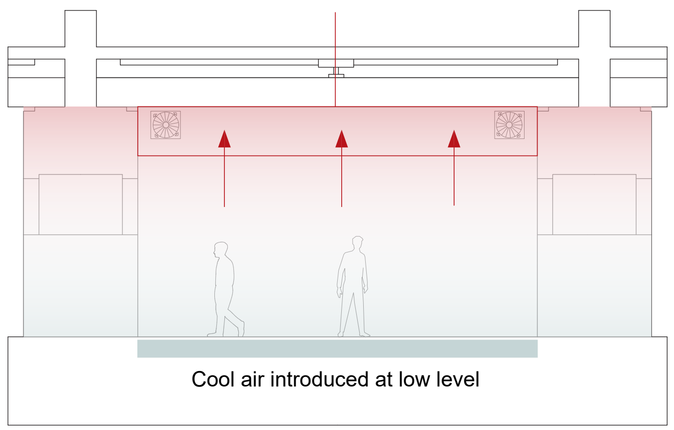
The cooling capacity of displacement ventilation systems is about 40 W/m². The rate of air supply is typically around 4 air changes per hour.[2] This addition requires large floor-to-ceiling height to maximise convection. The space is also required to have the room for low-level air supplies - Castelvecchio adheres to both of these design requirements. This addition to the space seems more appropriate than a HVAC system, which would contrast too much with the medieval aesthetic.

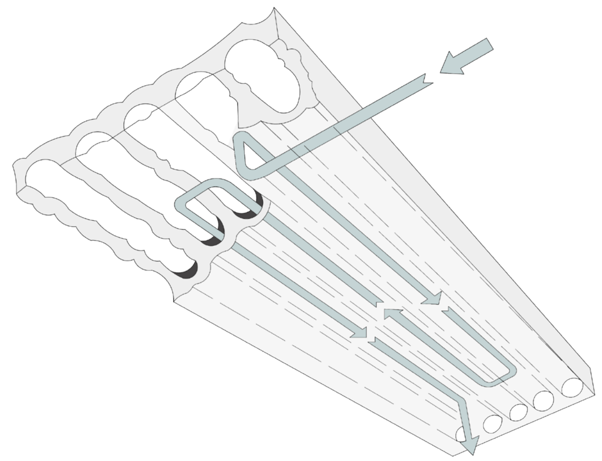
Slab Cooling Using Water

(Suggested Improvement)

Given Castelvecchio's close proximity to the Adige River, using water to cool structural slabs could be an appropriate means of cooling various spaces. Water is typically supplied between 15-18°c via pipes embedded in slabs of stone or concrete, for example. Cooling energy is stored in the slab whenever the circulating water is lower than the temperature of the slab. The slab then cools the space when the slab temperature is less than the air.[3]

Cooled floors can provide 30-40 W/m² of cooling with water supplied at 22°c and the occupied space at 26°C. Cooled ceilings can provide 40-50 W/m² of cooling with water supplied at 20°c and the occupied space at 26°c.[4] This system cools via radiant and convective heat transfer. This would be a low energy means of providing cooling in Castelvecchio. This is a versatile system which could also be used as a heating system in winter. The system is also not visible, so it is not an aesthetic hindrance.





1 CIBSE (2019). Environmental design : CIBSE guide A. London: Chartered Institution Of Building Services Engineers. Table 1.5
2 General Information Report 85, New ways of cooling - information for designers. Pg. 22
3 General Information Report 85, New ways of cooling - information for designers. Pg. 20
4 General Information Report 85, New ways of cooling - information for designers. Pg. 20

Oliver Hall

Thermal Qualities - Thermal Mass

While Castelvecchio may not use insulation in its' fabric, it maintains a reasonable energy balance through other means.

Scarpa's insertion features thick masonry walls, ranging from 400mm to upwards of 2000mm. Masonry has a relatively high specific heat capacity in comparison to other materials, and especially in comparison to insulated fabrics - which do not absorb much heat and release it soon after it is absorbed.

The heat that the building's fabric absorbs is released as the ambient temperature begins to drop, which means that even though some heat is lost through conduction, it is replaced in some capacity by the release of energy from the masonry wall.

This means that during the opening hours of Castelvecchio (1000hrs-1800hrs), the building heats up as the sun rises, and heat is released by the fabric as it sets.

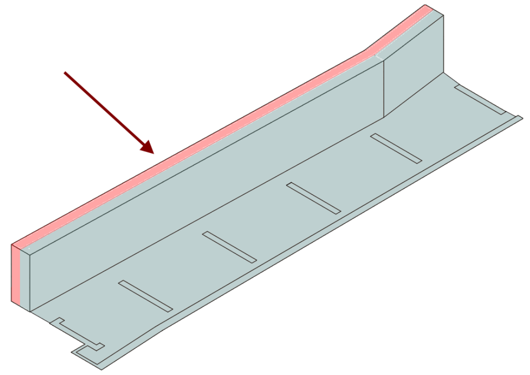
Despite being an effective traditional method of maintaining a balanced internal environment, the thick solid masonry does not provide enough insulation for the building to maintain a good energy balance. Any heat gains that the masonry emits are cancelled out by heat losses through the building fabric.

In the context of a museum like Castelvecchio, this could risk damage to paintings and artefacts kept in the museum for prolonged periods of time, due to undulating temperatures and conditions.

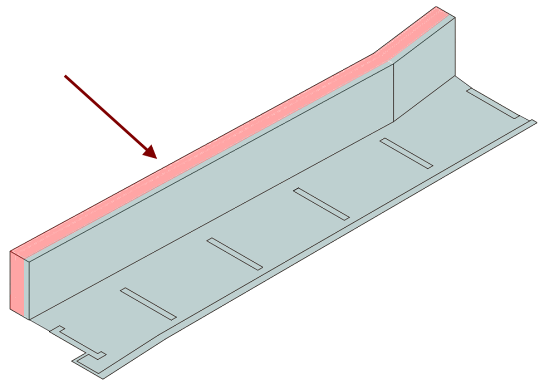
Looking only at technological performance, it is likely that retrofit with insulation is likely to be the best strategy - this would eliminate much of the heat loss that the building experiences, and in turn increase the efficacy of natural heating strategies in the winter (primarily solar gains).

However, any retrofit like this must be done with incredible sensitivity to the historical DNA of the building - which is likely the reason Scarpa chose to reflect the existing thermal mass strategy rather than installing insulated walls for his intervention.

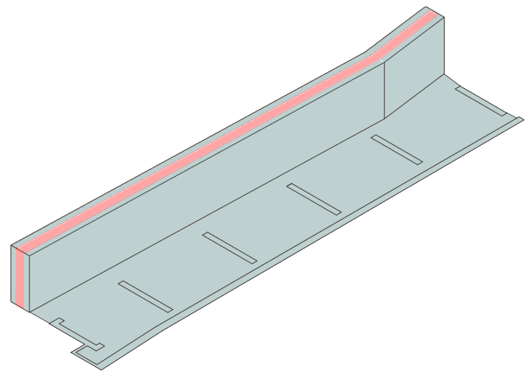
1. Heat is incident on the wall fabric through sunlight radiation and ambient temperature



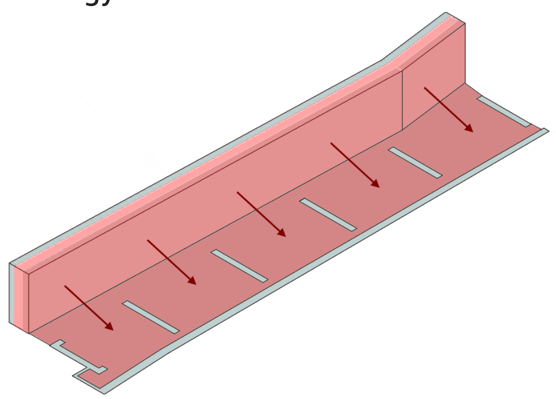
2. Incident heat is stored in the material.

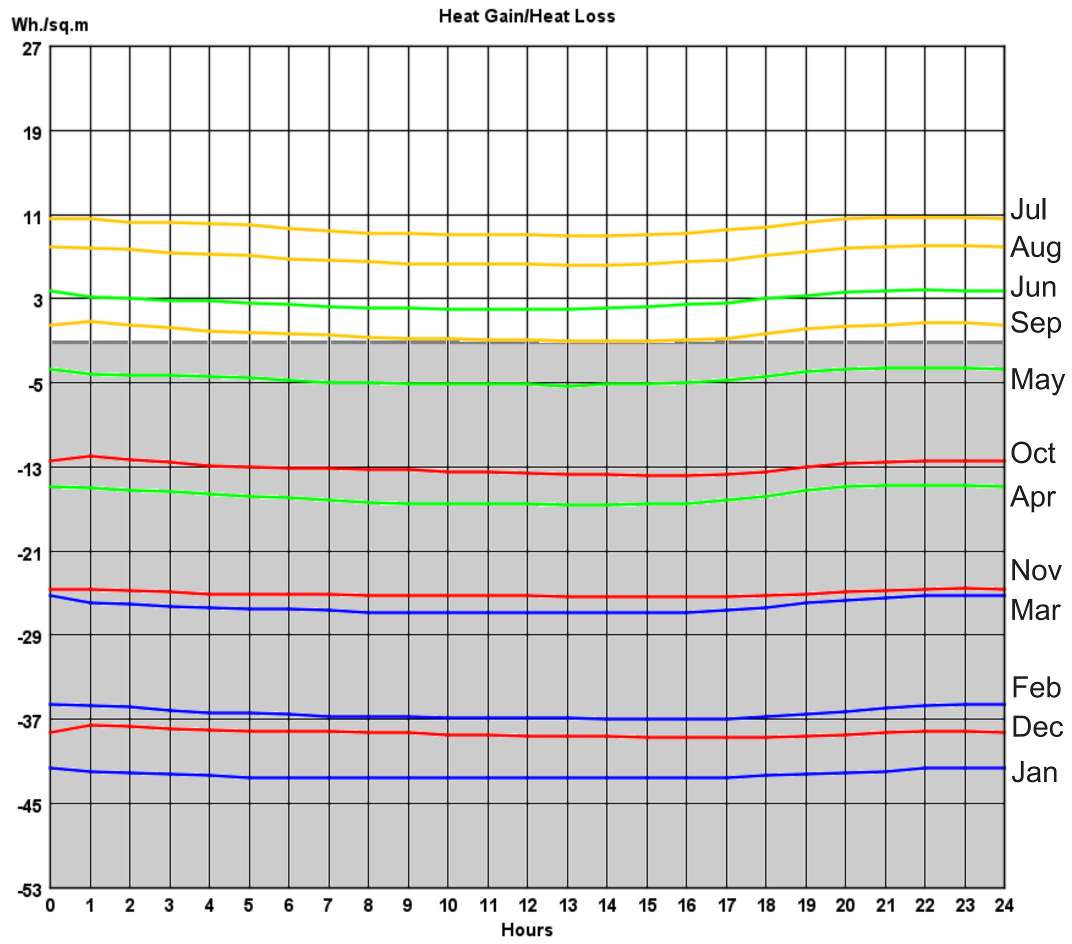


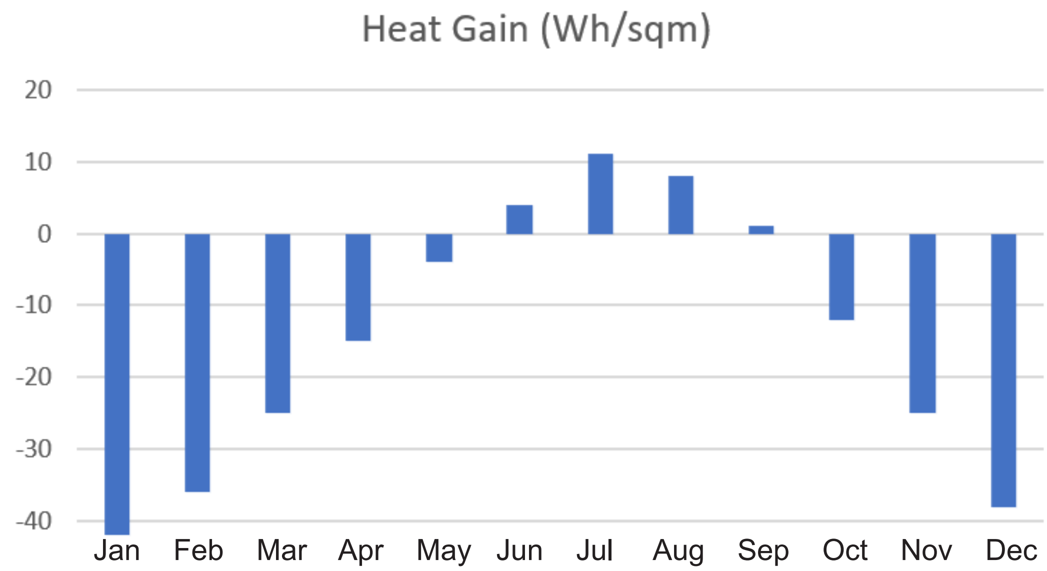
3. Incident energy is released 9hrs 10mins after being stored.



4. As the ambient temperature decreases, the stored energy is released as heat.







During the peak summer months (June through September), the thermal mass philosophy is incredibly effective - according to analysis of a 700mm section of masonry wall, the building gains heat overall in these months.

This is also in line with local climate and tradition - in the summer months this prevents the building overheating during the day and warms it gently in the night, and in the winter it works to prevent frost.

Despite being efficient during the summer months, for most of the year this wall construction means that the building is losing heat. This requires mechanical heating where solar gains cannot compensate for heat loss.

To ameliorate this issue, heat pumps could be used to power mechanical heating, using less external energy to maintain a balanced environment.

1 Climate data from https://energyplus-weather.s3.amazonaws.com/europe_wmo_region_6/ITA/ITA_Verona-Villafranca.160900_IGDG/ITA_Verona-Villafranca.160900_IGDG.zip accessed 19 Oct 2023

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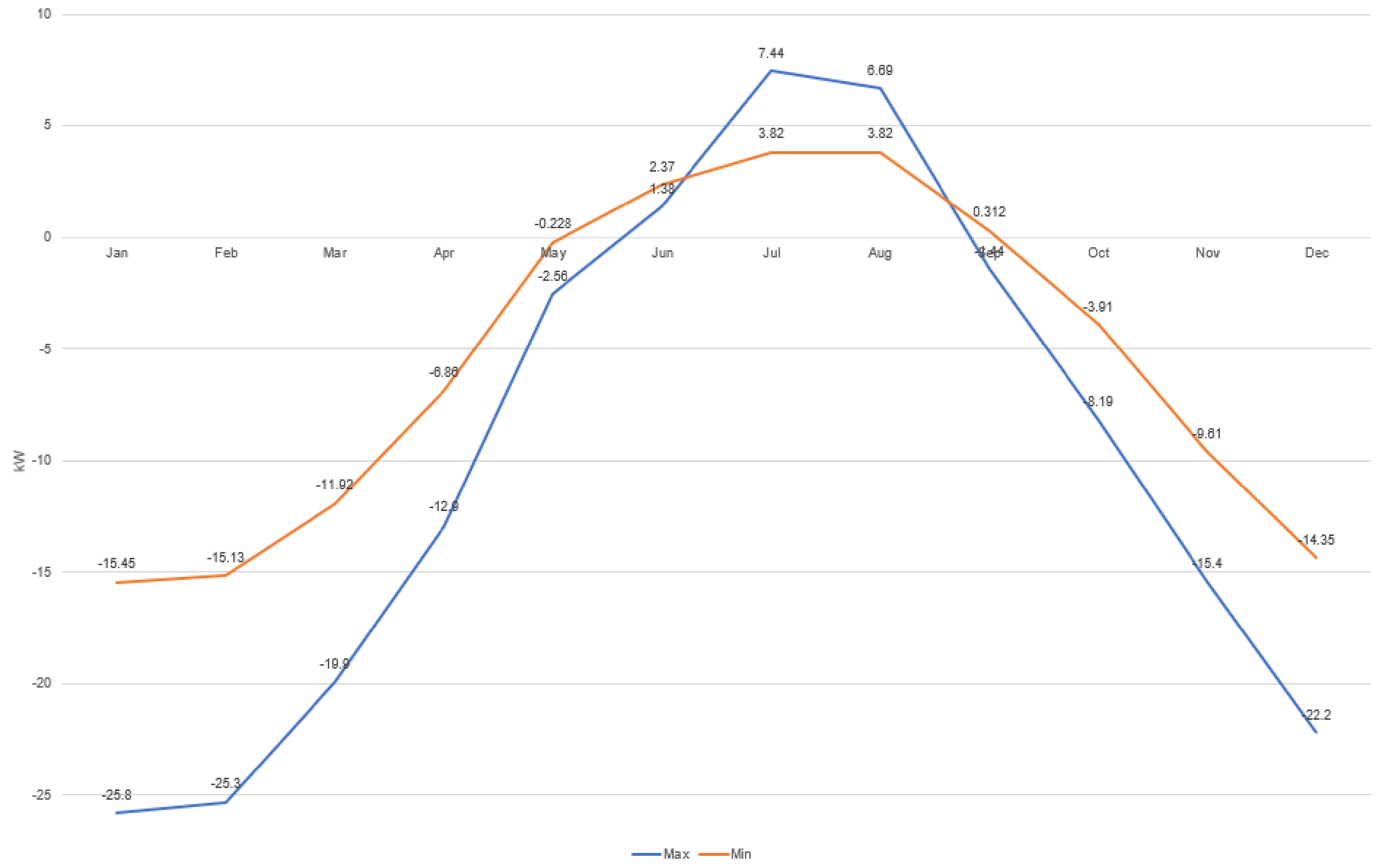
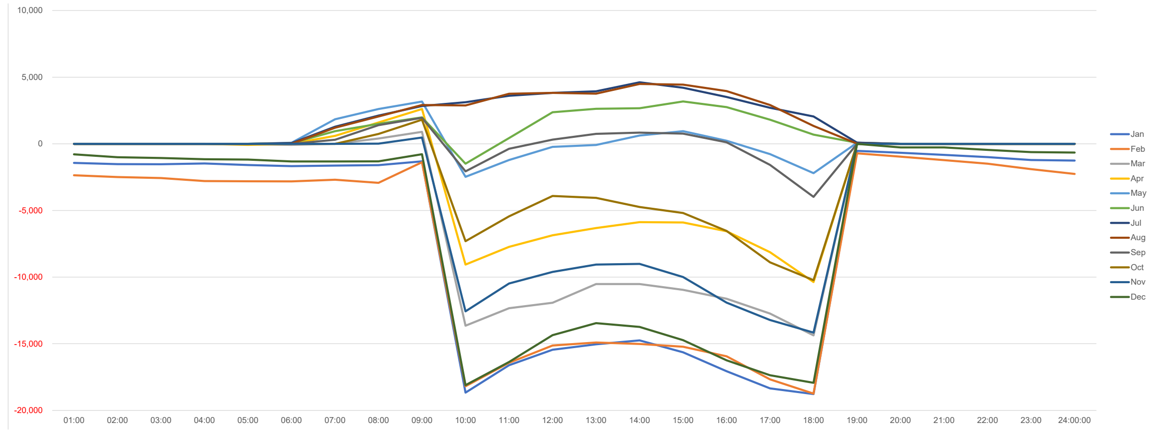
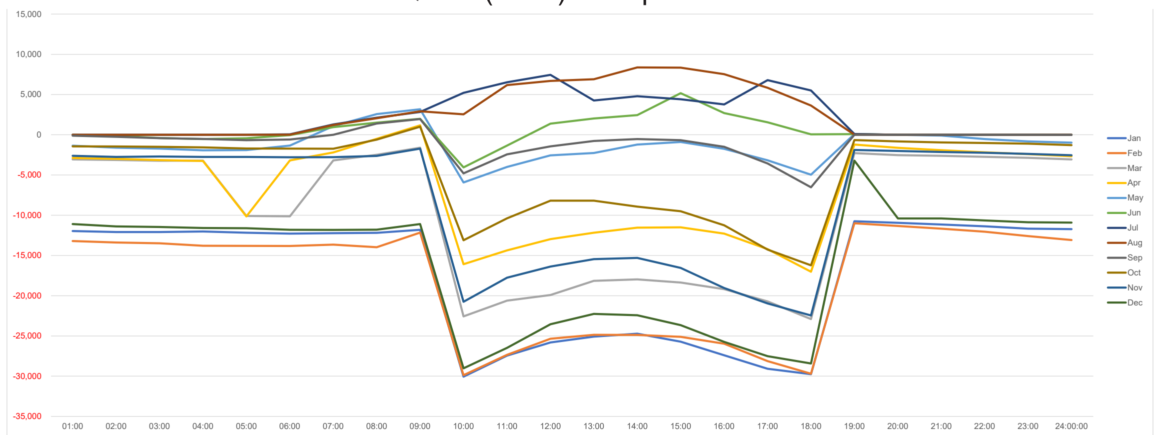
Qtotal in kW per month at 1200hrs



Qtotal (MIN) in W per month



Qtotal (MAX) in W per month



RIBA Challenge 2030 maxima
(kW/sqm/yr)

Castelvecchio energy use
(Napoleonic Wing, kW/sqm/yr)

Sustainable Outcome Metrics	Business as usual	2025 Targets	2030 Targets	MIN operational/year	MAX operational/year
non-domestic (new schools)	130.00	70.00	60.00	55.8	131.4

Heating

According to the psychrometric chart on the climate study, heating is required **49.3%** of the time across the year to achieve comfortable interior conditions (**20 - 23.9°c**). Therefore, there will be periods of the year where heating will be on all of the time.

By increasing the level of insulation in the building envelope, this will increase the amount of time that required levels of heat are sustained before escaping to the exterior, improving Castelvecchio's energy balance and thus making it more sustainable.

Energy Balance

Castelvecchio blends the outside and inside together seamlessly - meaning that energy balance was not Scarpa's primary focus, rather, the experience of the gallery and the exploitation of light was the centre-piece of his work.

The Napoleonic wing features a variety of wall thickness, ranging from 400 to 2200mm - leading to the U-value being as low as 0.23, or as high as 1.569.

Much of the glazing is on the southern face of the building, opening onto the courtyard - allowing for solar gains to form part of the energy balance.

The use of existing thick walls leads to a satisfactory energy balance - even if the U-value does not completely comply with current Italian regulations, according to the WSA Energy Balance Worksheet, the Napoleonic wing still nearly meets RIBA's 'business as usual' targets.

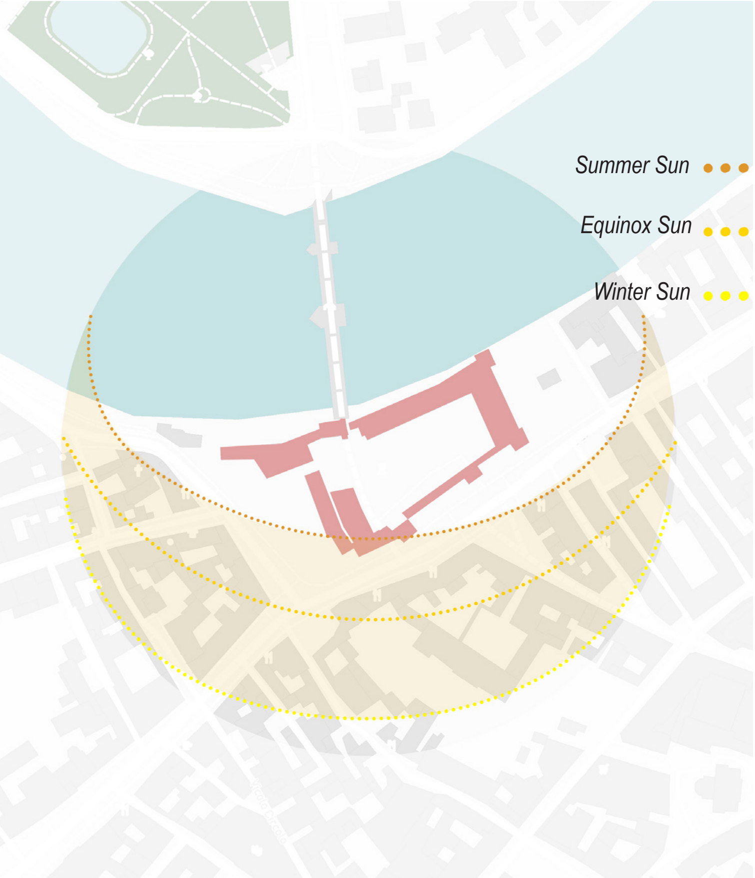
Despite being near 130kW/sqm/yr, the building's energy balance is still far from optimal. In the context of the climate emergency, as architects we need to strive to be using less energy or offsetting it by supplying it through sustainable means.

A 'fabric-first' approach is usually the most effective way of reducing energy use, however in Castelvecchio, this was not entirely possible from a design perspective due to the existing fabric.

Parts of Castelvecchio feature hidden areas where photovoltaic cells could be installed. This would need to be installed sensitively in order to preserve the historical fabric, however by installing such panels, it would be possible to offset much of the energy use.

As mentioned in the U-value study, by retrofitting insulation in the walls, it would be possible to reduce heat loss from the building fabric dramatically - which would reduce demand on mechanical heating systems.

Digital Lighting Study



The provided sun paths demonstrates the area of Castlevecchio.

Summer Solctice:
Sunrise - 5:35am
Sunset - 8:49pm

Spring/ Autumn Equinox:
Sunrise - 6:13am
Sunset - 6:23pm

Winter Solctice:
Sunrise - 7:35am
Sunset - 4:43pm

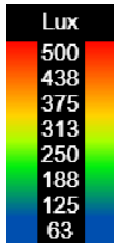


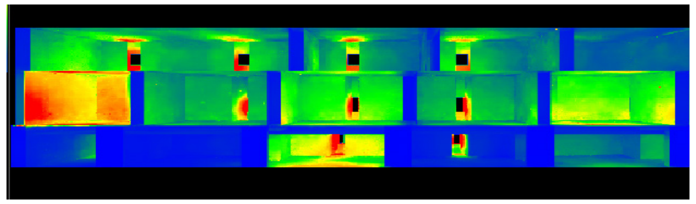
Table 1.1 Recommended comfort criteria for specific applications — *continued*

Building/room type	Winter dry resultant temperature range for stated activity and clothing levels* Temp. (°C)	Activity (met)	Clothing (clo)	Summer dry resultant temperature range† for stated activity and clothing levels* Temp. (°C)	Activity (met)	Clothing (clo)	Suggested air supply rate (L·s⁻¹·person⁻¹ except where stated otherwise)	Filtration grade‡	Maintained illuminance (lux)§	Noise rating (NR)¶
Museums and art galleries:										
— display[24]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F7–F8	200[25]	30–35
— storage[24]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F7–F8	50[25]	30–35

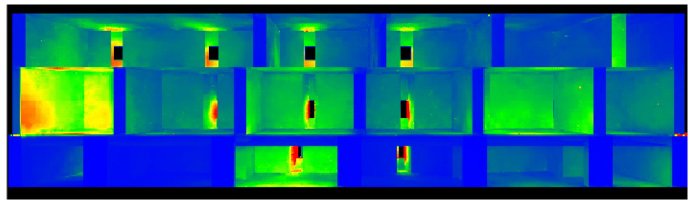
Table 1.1, extracted from CIBSE Guide A [1], helps us understand that the maintained illuminance required for Museums/ art Galleries is 200 lx for the display area, and 50 lx for storage area. 200 lux is a suitable and easily obtainable level of lighting for such areas. It is important that lighting conditions are suitable within an area like this as low lighting may hinder the vision of an occupant, resulting in unnecessary hazards.

Napolionic Wing Analysis:[2]

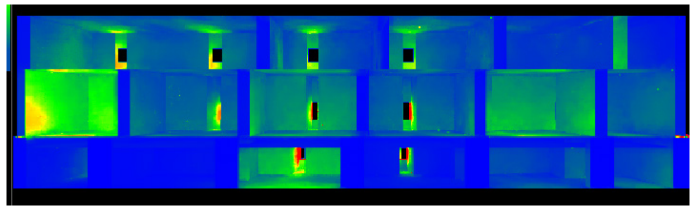
Summer Soltice



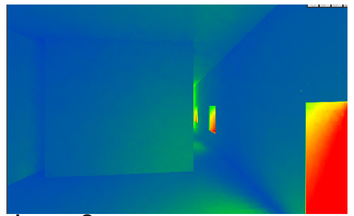
Spring /Autumn Equinox

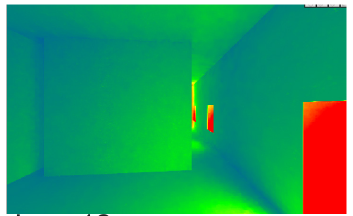


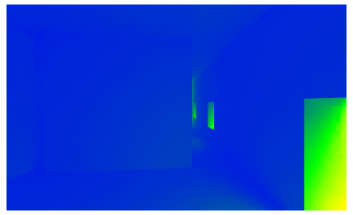
Winter Soltice



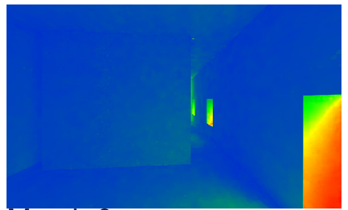
Floor One Interior Lux Evaluation[2]

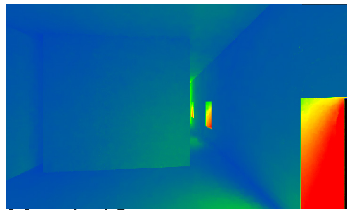

June 6am

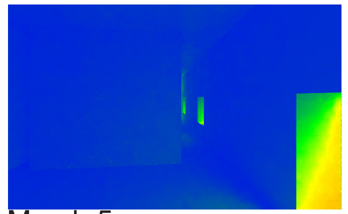

June 12pm


June 6pm

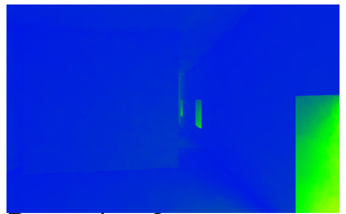
The morning and midday lux requirements are met, and slightly surpass the required 200 lx, but drop off again nearing the evening hours.

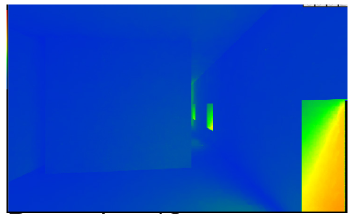

March 8am


March 12pm


March 5pm

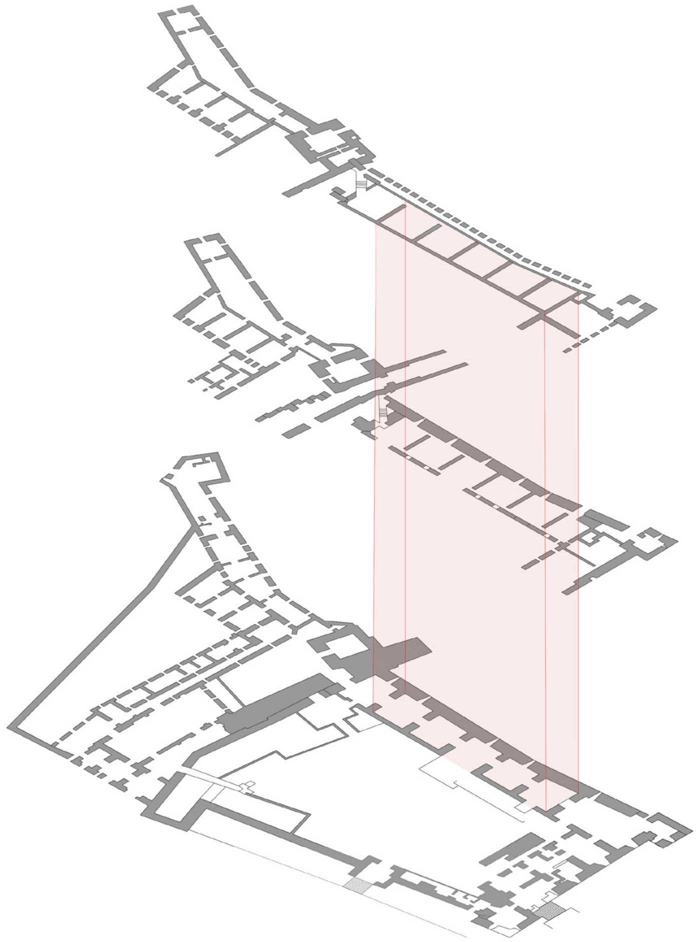
During the Equinox the lighting requirements are met during midday but are not met during morning and evening hours. Other lighting strategies will need to be considered


December 9am


December 12pm


December 4pm

During December, all received lux values during the day are poor, and another lighting strategy is heavily required to ensure good vision.



The Napoleonic Wing is an integral and arguably the most important part of Castelvecchio and is considered the “crooks” of Carlo Scarpas design. Hence why it is focused upon within this lighting study.

Overall, during the Solstice’s and Equinox’s the Lux values are averegly low. Considering the required amount of Lux is 200 for a gallery, the Napoleonic wing fails to meet this requirement in most rooms, thus potentially hindering the vision of occupant, causing unnecessary hazards.

One way to improve the lighting which is currently being used is artificial lighting. Considering the operating hours of the building are from 9am to 6pm, artificial lighting can be used during these hours, helping ensure the Lux values are met. But excessive use could harm sustainability, contributing towards energy waste.

The placement of majority of the windows are on the North facade of the building, due to this placement, solar gain is limited as the sun mainly faces the South and West facade of the building. Therefore, another more sustainable way to potentially improve the natural lighting of the building is to increase the size or numbers of windows upon the South Facade.

1. www.cibse.org. (2015). Guide A: Environmental design (2015) | CIBSE. [online] Available at: https://www.cibse.org/knowledge-research/knowledge-portal/guide-a-environmental-design-2015.
2. 2022. VELUX Daylight visualiser 3 (3.0.89), [analysis tool], [2024]

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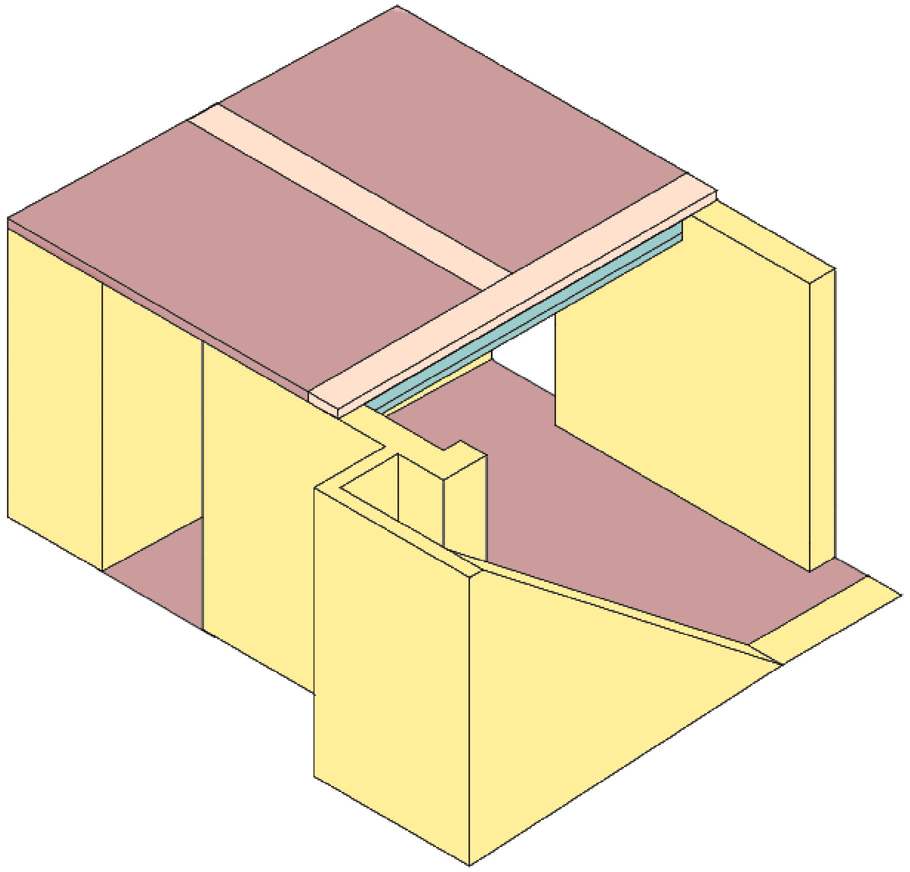

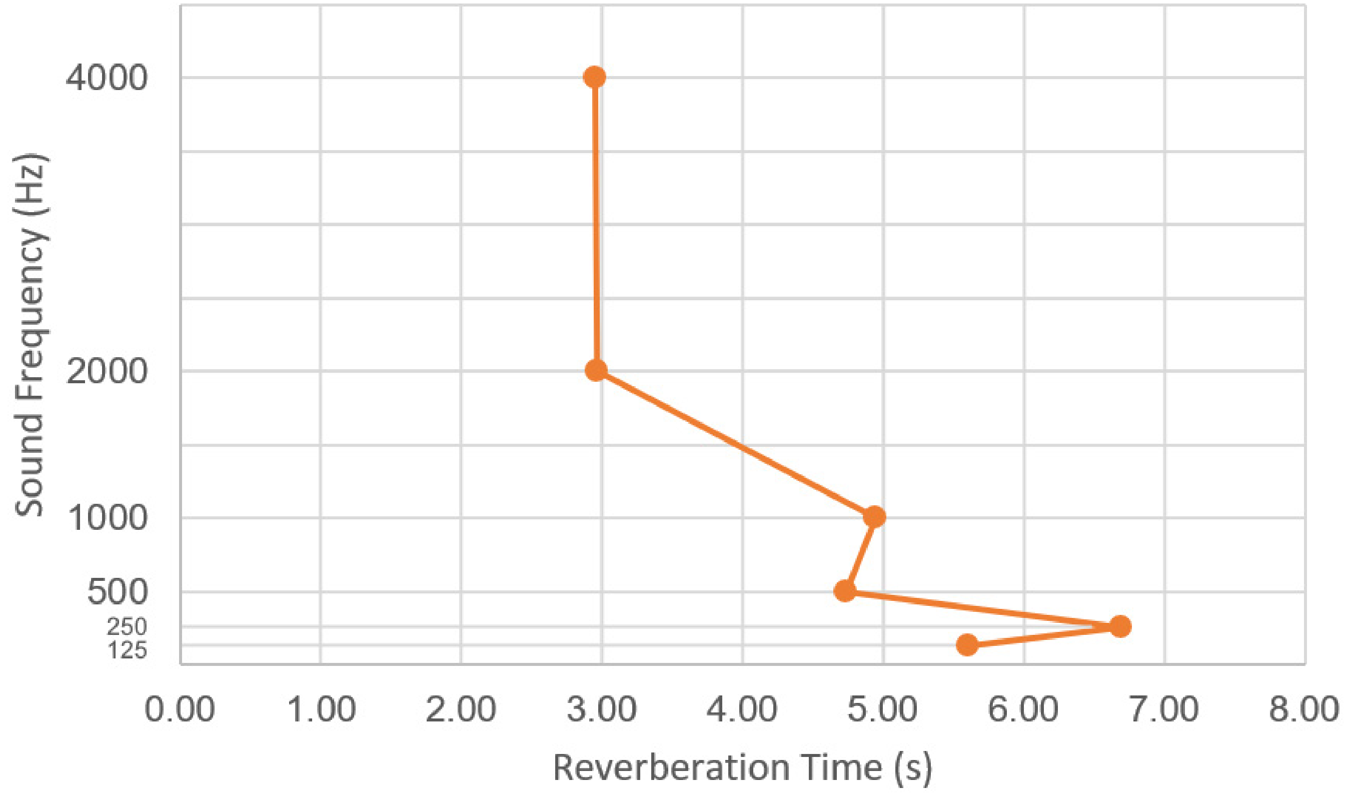

	Absorption Coefficient						Area (sqm)
Material	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	
Smooth Unpainted Concrete	0.01	0.02	0.04	0.06	0.08	0.1	19.536
Lime Plaster on Masonry	0.02	0.02	0.03	0.04	0.05	0.05	209.4
Stone floor and roof (Plain finish)	0.02	0	0.02	0	0.05	0.05	157.288
Windows	0.3	0.2	0.1	0.07	0.05	0.02	9.8
Steel Girder	0.13	0.09	0.08	0.09	0.11	0.11	16.71
Occupancy (Adults, standing)	1.5	3.8	4.2	4.3	4.5	4.5	

Reverberation Time Calculation - Sabine's Formula

$$RT_{60} \cong \frac{0.161 s/m\ V}{S_a}$$

V = 492.2m³

S_a = Area * Coefficient

S_a at each frequency:

125Hz S_a = 14.1
250Hz S_a = 11.8
500Hz S_a = 16.7
1000Hz S_a = 16.03
2000Hz S_a = 26.7
4000Hz S_a = 26.8

RT_{60} at each frequency:

125Hz = 5.60s
250Hz = 6.69s
500Hz = 4.74s
1000Hz = 4.94s
2000Hz = 2.97s
4000Hz = 2.95s

Using hardwood floor and roof:

125Hz S_a = 40.9
250Hz S_a = 48.0
500Hz S_a = 52.9
1000Hz S_a = 63.2
2000Hz S_a = 77.1
4000Hz S_a = 85.0

RT_{60} at each frequency:

125Hz = 1.94s
250Hz = 1.65s
500Hz = 1.5s
1000Hz = 1.25s
2000Hz = 1.03s
4000Hz = 0.93s

Acoustic Strategy

The Castelvecchio museum is designed to be a space of contemplation, and its' acoustic strategy follows suit.

The highest reverberation time occurs in the lower floor of the Napoleonic Wing, where mostly statues and sculptures are contained. The RT60 value most closely matches that of a cathedral[1], which creates a matching contemplative mood in these spaces.

What Was Done Well

The RT60 time range is appropriate for the kind of space that the Napoleonic Wing's ground floor is - ranging from 2.95s to 6.69s. This makes it more intimate than a cathedral, and matches the reverberation time advised for music.

This matches the historical DNA of the building, as spaces such as the Napoleonic Wing would have been historically used for chamber music - this therefore immerses the user in the historical fabric of the building in their auditory experience.

What Could Be Improved

The reverberation time is still considerably high for a museum, and while it achieves a similar atmosphere to a place of worship or a Baroque music chamber, the high reverberation time in the vocal range (125 and 250Hz) means that conversation is made difficult.

By using hardwood such as oak or mahogany in the floor and roof instead of stone, the reverberation time range can be cut down to 1.94s - 0.93s.

1- http://www.larsondavis.com/learn/building-acoustics/Reverberation-Time-in-Room-Acoustics accessed 17 Jan 2024
2- https://www.acoustic.ua/st/web_absorption_data_eng.pdf accessed 17 Jan 2024
3- https://www.acoustic-supplies.com/absorption-coefficient-chart/ accessed 17 Jan 2024

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Fire and Evacuation Study

Vehicle Access (Table 15.1) [1]

Castelvecchio does not give any record of fitted fire mains and is a substantially large building. Therefore, the building will need to provide up to 100% perimeter for access. However, due to the geographical location of Castelvecchio (being sat next to a large river), it hinders reaching the North of the building.
However, the building is sat next to a main road, suggesting easy access and if certainly needed the courtyard could potentially allow access.

Table 15.1 Fire and rescue service vehicle access to buildings not fitted with fire mains

Total floor area[1] of building (m²)	Height of floor of top storey above ground (m)[2]	Provide vehicle access to:	Type of appliance
Up to 2000	Up to 11 Over 11	See paragraph 15.1 15% of perimeter	Pump High reach
2000–8000	Up to 11 Over 11	15% of perimeter 50% of perimeter	Pump High reach
8000–16,000	Up to 11 Over 11	50% of perimeter 50% of perimeter	Pump High reach
16,000–24,000	Up to 11 Over 11	75% of perimeter 75% of perimeter	Pump High reach
Over 24,000	Up to 11 Over 11	100% of perimeter 100% of perimeter	Pump High reach

Fire Resistance (Table B4) [1]

There is no record of any sprinkler system on Castelvecchio, however, as this is a restoration project, it would be fair to assume the building has been fitted with an efficient sprinkler system, correctly situated within the vicinity.
It would be just to assume that due to the building's size and height, a 30min or more than 30min period of fire resistance is permitted.

Table B4 Minimum periods of fire resistance

Purpose group of building	Minimum periods of fire resistance[1] (minutes) in a:						
	Basement storey* including floor over		Ground or upper storey				
	Depth (m) of the lowest basement		Height (m) of top floor above ground, in a building or separated part of a building				
	More than 10	Up to 10	Up to 5	Up to 11	Up to 18	Up to 30	More than 30

Capacity (Table 3.2) [1]

Overall, there are six staircases, all that can be used for safe escape. But there are, however, two escape staircases located within more confined areas of the structure. Considering approximately 120 people are situated within the building and up to two floors, it would be suitable to ensure the minimum width of stair required to be 1 meter, which ensures the safety of occupants throughout the building during an evacuation.

Table 3.2 Capacity of stairs for basements and for simultaneous evacuation of the building

No. of floors served	Maximum number of people served by a stair of width:								
	1000mm	1100mm	1200mm	1300mm	1400mm	1500mm	1600mm	1700mm	1800mm
1	150	220	240	260	280	300	320	340	360
2	190	260	285	310	335	360	385	410	435

Maximum number of people served by 2 emergency stair cases:
*2*60 = 120*

∴ 1000mm is considerably the best width to ensure saftey during the evacuation process

Table 2.1 Limitations on travel distance

Purpose group	Use of the premises or part of the premises	Maximum travel distance[1] where travel is possible in: One direction only (m)	More than one direction (m)
3	Office	18	45
4	Shop and commercial	18	45
5	Assembly and recreation:		
	a. buildings primarily for disabled people	9	18
	b. areas with seating in rows	15	32
	c. elsewhere	18	45

Table 2.2 Minimum number of escape routes and exits from a room, tier or storey

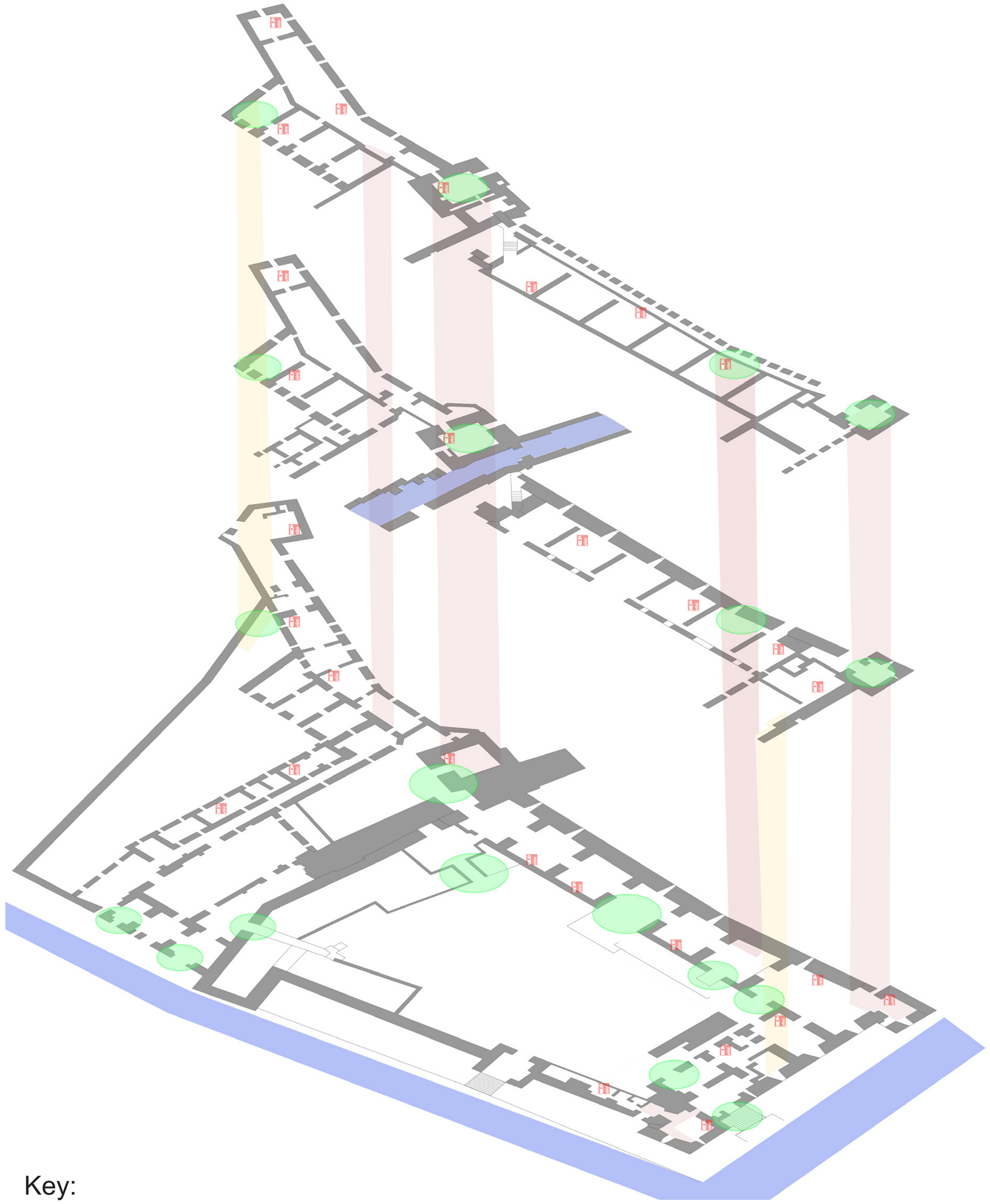
Maximum number of people	Minimum number of escape routes/exits
60	1
600	2
More than 600	3

(One group of tourists cannot exceed 20 and a maximum of 4 are allowed in per time)
Staff ≈ 20
Rouge Tourists 1 - 20
*Maximum Tourist groups ≈ (20 *4) 80*
20 + 20 + 80 = 120

∴ *Maximum Number of people ≈ 120*

Escape Routes and Travel Distance: (Table 2.1 and 2.2) [1]

The building is a substantial size and holds up to 20 staff members and only allows for a maximum of 4 tours at a time. It would be fair to assume that the maximum number of people in the building in the event of a fire would be around 120. Suggesting that the minimum number of escape routes be at 2. However, this is largely increased as seen in the floor plans, as there is an exit in almost every room.
The maximum travel distance would have to be 18m in one direction and 45m if there is more than one direction. Overall, the building is relatively safe to escape due to the vast number of directions one can take to the courtyard. However, the top left corner is over by 1m, which does not meet requirements, and therefore will need to be further analysed.



Key:

Exits | Stair cases | Emergency Stair case

Fire extinguisher | Optimal placement for Emergengy Veichles

The Castelvecchio building is mainly made up of its historic fortified stone walls. The stone and other non-combustible materials ensure fire resistance within the vicinity, helping contain fire and enduring the spread of one is reduced. But, if stone is subject to fire impact, the rapid change in temperature can affect the thermal mass, potentially resulting in fractures and weakened areas of the stone, making it a further hazard if not checked. Fire routes within the vicinity, although short, can still endanger occupants as thick stone and a lack of ventilation could easily trap toxic gases and smoke, posing a risk to escaping occupants and disadvantaging emergency responders. As a possible improvement, emergency windows could have a mechanical opening system in the result of fire, increasing ventilation to remove the smoke, ensuring the safety of the area.

1. Buildings Regulations Approved Document B- Fire Saftey. Volume 2; Buildings other than Dwellings
2.Museo, C.V. - (2014). Museo di Castelvecchio - Museo di Castelvecchio - Home page. [online] museodicastelvecchio.comune.verona.it. Available at: https://museodicastelvecchio.comune.verona.it/nqcontent.cfm?a_id=42545.

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Conclusion

Our technical analysis of Castelvecchio has allowed to us to understand Scarpa's approach to restoration, and assess how the building performs in its current configuration against modern standards. Analysis of the findings has allowed us to propose what we would do from a technological point-of-view in a contemporary restoration whilst remaining sensitive to the building's past and legacy as a pioneer.

Quantitative & Qualitative Analysis

Quantitative analysis has been vital for a technical evaluation of the building against the challenges posed by the climate crisis. By calculating load values, U-Values, ACPH values and lux values for example, we have mathematical evidence to support our technical report and provide guidance on the building's strengths, weaknesses and needs in the future.

We understand that the immense user experience of modern Castelvecchio within the rich historical context is what has made the building a pioneer of refurbishment. The qualitative understanding of implications of technical factors on this experience has been necessary to become respectful and sensitive in our suggestions for improvement, ensuring a sustainable future for the building.

Reference to Regulations

We have used an array of credible sources and sets of contemporary regulations to assess whether Castelvecchio meets contemporary standards and how to improve it if this isn't the case.

By using contemporary regulations which are designed to fight the climate crisis, we have aimed to bring Castelvecchio into that fight.

Structural Strategy

In our structural analysis, it is clear to see that Scarpa has embraced the old structure while introducing new contemporary additions that utilise the older aspects in creative ways.

As mentioned, the suspended flooring in the tower transfers load from the floor into the thick masonry wall of the tower. The steel girder that Scarpa introduced also works with the old structure, sitting on top of concrete walls that sit adjacent to the old masonry walls in the Napoleonic wing, which allows for a vast uninterrupted space, which is ideal for developing the spatial qualities of the museum.

Quantitative analysis of ultimate loads allows us to come to the conclusion that the additions that Scarpa added are reasonable and are structurally sound. Overall Scarpa's additions are very successful in terms of providing high-quality architectural space through a refined and measured structural intervention.

Construction Strategy

Analysing the details of the building envelope has allowed us to scrutinise the quality of intervention that occurred during Scarpa's renovation. In terms of wall, floor and ceiling details, analysis has exposed how at its core Castelvecchio is the product of ancient construction methods and respectful responses.
Analysis has shown that the historical conservationism of the building envelope creates modern compatibility issues such as energy efficiency and accessibility.
Whilst our proposed changes succeed in fixing localised issues incompatible with modern standards, the building's construction is too deeply rooted within the processes of a different age to become a model for contemporary sustainability.
Instead, it must be respected for what it is and where low-impact procedures can be used to add the next layer of the building's history they should be, cohabiting an appreciation for the past with an outlook for the future.

Building Performance

When evaluated against contemporary standards, the building shows significant flaws in its building envelope. The medieval construction which forms the core construction is dated, providing an unsustainable energy balance which creates a high usage carbon footprint. Scarpa's process of historical sympathy exposes the building's flaws, with precise additions creating a clinical atmosphere. Whilst modern renovation options exist, such as the introduction of mechanical ventilation and retrofitting improved insulation, they would risk eroding the atmosphere of historical appreciation which Scarpa has created.

Where low-impact changes can be made without disruption we support their addition. However, understanding the historic nature of the building and its technicalities contributes significantly to the appreciation of restoration work.

Building Services

The building in its current form doesn't meet contemporary building service regulation. Through the preservation of a historic form designed for military use, there are natural conflicts between the requirements for a museum. Windows designed for defence prevent adequate daylight, with a deliberately inaccessible fortification proving challenging for emergency evacuation.

The further implementation of modern building services into the structure through a renovation process would bring the structure in-line with contemporary standards. Whilst this would change the current experience, the process of continual evolution is what Scarpa exhibited through his work. A renovation of building services would signify the progression from Scarpa, adding the next natural layer to the building's story.

The Relationship between Architectural Technology and Sustainability in Renovations

Although Scarpa's Castelvecchio renovation pioneered a new typology of high-end building refurbishment, time has progressed since its development and there are new ways of thinking to ensure that historical buildings meet modern sustainability standards. Preserving historic buildings helps us to save unmeasurable quantities of carbon, helping to minimise the negative impact on the environment as long as they can be made efficient through their construction strategy, building performance and building services. We understand that deep-rooted structural strategies may be embedded within the DNA of historical structures; however, Scarpa has proved that substantial modern interventions within these structures can lead to exciting results and improved standards of use, leading to a more sustainable future.

Our Proposed Future for Castelvecchio

Castelvecchio is a building of layers. Scarpa was a pioneer of their understanding, evaluation and presentation which he displayed through his work on the museum. However, the story of Castelvecchio cannot end at Scarpa. It would be ironic to consider his work as the final layer, as it would contradict his very philosophy on building renovation.

Through our critical analysis and proposals we have devised a potential future for Castelvecchio moving into the fight against the climate crisis. Our layer of suggestions has been balanced between technical improvement and preservation of the layers we aim to support and 'improve' with our more modern understanding. Whilst we have not made the building a pioneer of carbon efficiency, we believe that our work showcases the potential of building sustainability. Our Castelvecchio is one that brings the past into the present and hopes to allow it to continue into the future.

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