The Harmonisation of Light and Architecture: A Case Study of the San Lorenzo Church, Florence.

by

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CONTENTS

Summary

This report details the findings of an investigation into the interior lighting conditions found within the San Lorenzo Church in Florence. It incorporates both quantative and subjective assessments and attempts to highlight the factors that contribute to visual harmony within interior spaces.

1.0 Introduction

"Architecture is the masterly, correct and magnificent play of masses brought together in light"

Le Corbusier

Man has always been interested in 'light', for without it he cannot see. The visual impression of what is seen depends upon a complex interaction of a number of parameters such as quantity and direction of light, qualities of the object (such as size, colour and texture), the spatial relationship between observer, object and surroundings and of course the complicated processes within the visual system.

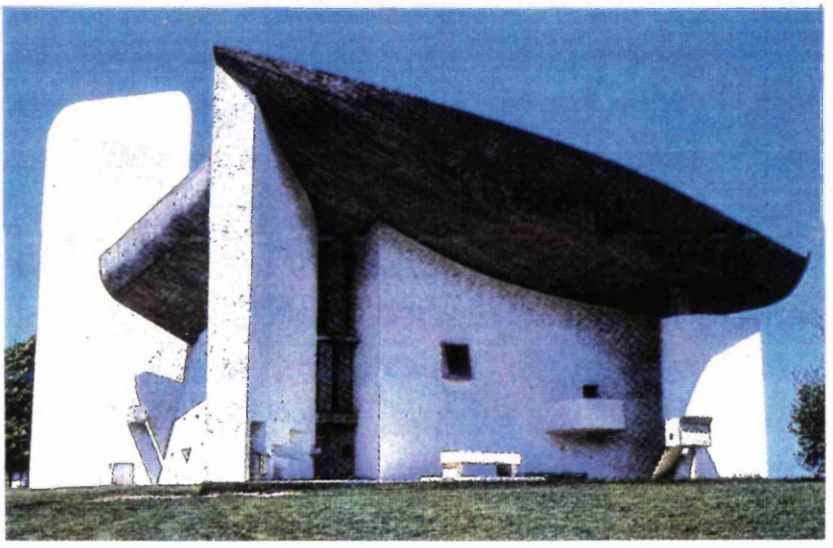


Plate 1. Le Corbusier's Chapel of Notre-Dame-Du-Haut

The way in which architecture is perceived, both internally and externally is determined by a number of considerations, the most important of which is surely the interplay between its form and its means of illumination. Light is unable to create architectural form, but can enhance it in a various ways, for example contrasting areas of light and shade can give depth and definition to a building facade and directional qualities can reveal both texture and shape of architectural components.

The qualities of light are not limited to physical enhancement, through the correct manipulation of space and light, human emotions, awareness and

appreciation for the given environment can also be influenced just as they are in theatrical productions. These feelings can be induced by a range of different lighting techniques such as varying 'strengths', directions and patterns of light and colour of both light sources and surfaces.

For centuries man had to rely on natural light as the primary means of interior illumination before the introduction of viable artificial sources. The utilisation of natural light for lighting internal spaces being governed by man's ability to build structures with the appropriate openings for daylight admission that are also structurally sound, and also the local climatic conditions.

Innovations in lamp and lighting technology, construction materials and design aids (e.g computers) should have squashed the 'limitations' of past centuries, in terms of the interior visual environment and there should have also been an increased awareness in how to manipulate space with respect to physical and psychological perception. Sadly this does not seem to be the case.

The pathway to modern lighting design practise has been in the main through visual performance and functionality requirements usually interpreted as horizontal illumination levels. W. Lam writing in 1977 [1] extends the argument by saying " Lacking an understanding of the basic principles involved, the technicians who now control our luminous environments have reduced the criteria for illumination to simple numbers, which are basically unrelated to vision, perception, comfort or pleasure".

An alternative approach was developed by J.M.Waldram in the 1950s which he called "Designed Appearance Lighting". (Appendix 1). This design procedure is a reversal of normal lighting design and involves the determination of a 'preconceived appearance' for an interior by the realisation of a number of parameters such as the 'impact view', experiences of people within the space as well as the decoration and the architecture. Having decided on the appearance of the interior, the lighting hardware needed to produce the required effects is then chosen accordingly.

The method then attempts to quantify the designed appearance, which is perhaps its failing and explains why it has not been more widely adopted. However the concept of visualising the appearance of an interior in three dimensions before beginning to specify the luminaires required should be the logical process for a lighting designer.

Unfortunately the way in which lighting design is performed today it is unlikely that both appearance and functionality will be given due consideration; on perhaps the majority of commercial projects the lighting design is the responsibility of an electrical services engineer, who although may be adept in the quantative calculations will most likely never have received any training in terms of visual appearance and the concepts of 3 dimensional space. Conversely, it may be the Architect who is responsible for the lighting design, who through formal training will understand the manipulation of form and space, but will not be familiar with the 'mechanics' of lighting that are needed to create the desired effect.

The objective of this report is to analyse the interaction between an interior and the way in which it is lit, by studying a specific example from both subjective and quantative viewpoints.

A suitable building had to be found in which to make such a study that had the required practical criteria, e.g. accessibility etc but more important, one which is of interest architecturally. Consequently the Author embarked on a search through numerous texts detailing the 'History' of Architecture to firstly narrow the search to a particular 'Architectural period or style'.

Within Murray's [2] text on the Italian Renaissance, exists the following quotation " I shall define beauty to be a Harmony of all the parts, in whatsoever subject it appears, fitted together with such proportion and connection, that nothing could be added, diminished or altered but for the worse...." [Alberti, De re aedificatoria.]

The Renaissance style was a return to classical ideals (Roman), where the architecture is based upon a 'modular system of proportion', symmetry and a relationship to the human scale. Thus the fundamentals of the

architectural principles reflect the essence of lighting design, which should be in harmony with the architecture in both functional and aesthetic terms.

The 'survey site' was finally selected to be the Church of San Lorenzo in Florence, which was designed by Filippo Brunelleschi, the man often referred to as 'The Inventor of Florentine Renaissance Architecture'. The Church of San Lorenzo has been discussed by a number of Architectural writers who have touched briefly upon the interior lighting, as the following quotation illustrates which hopefully justifies the choice of location.

"The effect is of an extraordinary harmony and serenity, a clarity of idiom without equal, sustained by an intellectual and rational inner force above all conflict. The light spreads calmly and uniformly over the interior, thanks to the intelligent spacing of the windows high up and the 'eyes' in the middle zone; the columns and arches are aligned in solemn and harmonious cadences; the chapels, a fundamental element in Brunelleschi's conception of architectural form, create pauses of shade in the luminous whole without producing a dramatic effect." [3]

Before discussing the development of the church of San Lorenzo and the survey itself, there follows a brief resume on the life and works of Filippo Brunelleschi so that at the completion of this report the reader has been provided with an insight into the Architect, the church and its lighting.

2.0 Filippo Brunelleschi

Documentation on life and works of Brunelleschi only becomes coherent from the age of around forty when he began his major works as an architect. He was born in Florence in 1377, the son of a diplomat, and thus through the opportunity of travel in his younger years was able to absorb the styles and designs of different areas that were exhibited in his later works.

Brunelleschi began his working life as a goldsmith and watchmaker and officially matriculated as a master goldsmith in 1404 having served the art for six years. Some of his early work reveals his personal conception of the relationship between figures and space that can be identified in his architectural designs. His more important works are, parts of the silver altar of St James in the Cathedral at Pistoia, the crucifix that hangs in the church of Santa Maria Novella and the panel relief of 1401.

Since he became a well known public figure in Florence, Brunelleschi was involved in the production of religious drama, the 'sacre rappresentazioni', and in particular as the creator of 'theatrical effects'. His work as a watchmaker and from later experiences of transporting materials and men on building sites gave him a good understanding of machinery and in particular hoists.

The results produced by Brunelleschi were marvelled at by the crowds of the day, as 'characters were made to fly through the air in the midst of spectacular explosions of lights and fireworks'.[4]

The complexity of the apparatus design did not only apply to the movement of components from one space to another. Brunelleschi also demonstrated the art of light control as typified by the arrangement within the copper mandorla at S.Felice, where the lights, by a spring mechanism, could be eliminated from view and when required instantly reinstated. Vasari's [5] much romanticised writing of the production at S.Felice talks of garlands of light above the angels heads that shone like stars and the mandorla 'with its infinite lights' along with the production itself 'all conspired to make a veritable representation of paradise'.

Brunelleschi had been appointed to advise on the construction of the buttresses of the tribunes of the apse of the cathedral before 1420 when along with Ghiberti and Battista d'Antonio was nominated to supervise the construction of the dome. He gained 'overall control' when Ghiberti's involvement diminished in 1425, having been given the important commission for the second Baptistry doors.

Brunelleschi adopted a new approach to building where he alone was responsible for the design and supervision of the project and the labourers were given a more 'subordinate' role.

The concept for a dome over the crossing of the Cathedral has been put forward as early as 1357, but since its dimensions were to make it one of the largest domes in the western world its execution was unprecedented in its complexity. A decree in 1367 defined the dimensions and form of the dome and these had to be respected. However following great consultations, it was Brunelleschi's 'original' and 'unforeseen' [4] double shell design that was finally accepted, and has since been described as 'a work of genius' [2].

In the early 1420's Brunelleschi was commissioned to design two further works, the Foundling Hospital and the Old Sacristy of San Lorenzo, which was intended to be the family chapel of the Medici.

A few years later, in around 1425 he became involved in the main project at San Lorenzo, the reconstruction of the church that was previously a romanesque structure and more will be said about the history and construction in the following section.

Whilst the aforementioned projects were still in construction, in 1428 Brunelleschi embarked on the design for a second basilical church, that of Santo Spirito situated on the southern side of the Arno.

It has been suggested that "In the years 1420 - 1446 Brunelleschi single-handedly created a new architecture, proceeding from his experience of Classical, Romanesque and Gothic architecture and utilising his own personal solution of the problem of perspective, conceived as knowledge 'per comparatione' (Alberti)" [5].

His architectural objective was to design a structure that was logical in every part and in which order and harmony would be achieved through the proportional relationships between the various elements both internally and externally.

However Brunelleschi's 'spatial ideals' were not restricted to the 'building scale', but his works were conceived as part of an overall urban context, based on rational geometric order.

Although Brunelleschi's proposals for urban restructuring remain incomplete (and some, such as the reversal of orientation of the Basilica of Santo Spirito were rejected), it was his approach and those that followed him that dictated the urban form of Florence for the following centuries.

3.0 San Lorenzo

The basilica of San Lorenzo is situated a few hundred metres to the north west of the Cathedral of Santa Maria del Fiore in the centre of Florence, in what was the parish of the powerful Medici family. The church itself forms part of a larger complex, which in addition houses the Medici Chapels and the Laurentian Library.

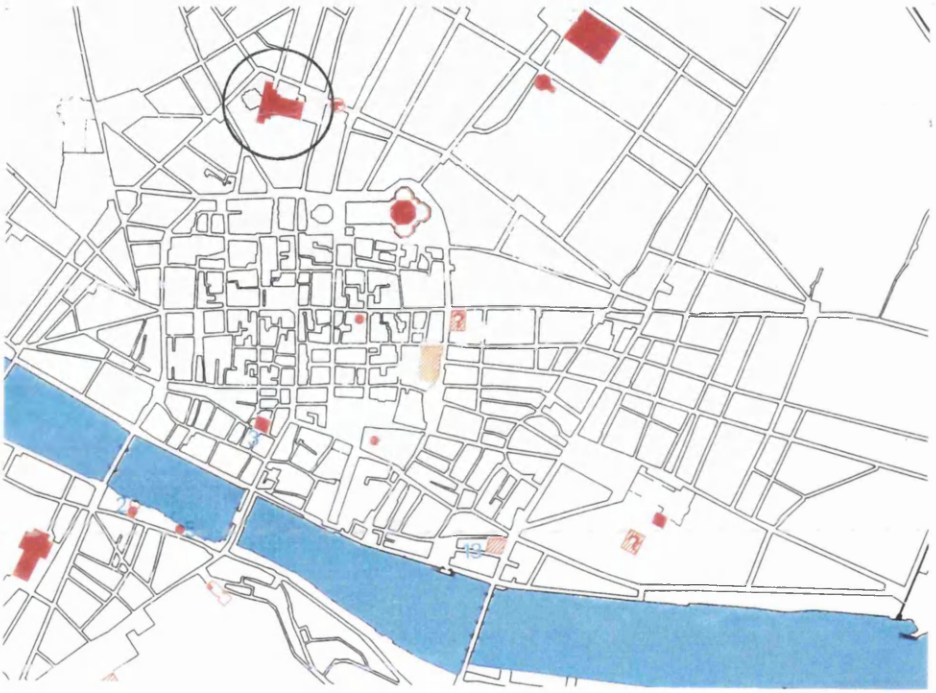


Plate 2. Location of San Lorenzo

3.1 The History

A church had existed on the site since its consecration by St Ambrose in 393 A.D and was dedicated to St Lawrence. Renovation had taken place in the eleventh century, before permission was granted in 1418 to redevelop the site as a centre of worship and learning, and it is essentially the resultant structure which stands today.

The first part of San Lorenzo to be rebuilt was the 'Old sacristy', which was intended to be the family chapel of the Medici family and commissioned by Giovanni di Bicci in 1419, it was Brunelleschi's first ecclesiastical building. This was originally a stand-alone structure that was not connected to the existing church nor to the monastic buildings.

The history of the reconstruction of the main church, due to contradicting and incomplete documentation is complex and those that have tried to unravel the true history have put forward their own theories. The main point of contention is the date of Brunelleschi's involvement and his degree of design input.

It would appear that the work on the main church was initiated by Matteo Dolfini on August 10th 1421, in cooperation with the Vicar, the Operai and the Masters, and progress continued under Dolfini until his death in 1424.

It was most likely at this stage that Brunelleschi was consulted, having made an impression on the building of both the Old Sacristy and also the dome of the Cathedral that were under construction at this time. Having adopted Brunelleschi's proposals some of the walls already built under the guidance of Dolfini were demolished as the intended design was for a building more 'handsome and richer'.

The Medici family in addition to the Old Sacristy, 'sponsored' another chapel within the left arm of the transept of the main church that was completed (at least structurally) in 1431. Further chapels were planned along the nave of the church and private patronage was also sought for these.

The Medici chapel is important, since it is highlighted in a document of 1434 [6] as a blueprint for the oculi above each planned side chapel. However as Battista [4] points out there is an anomaly in this document since it calls for the chapels to have the same height as the transept. In order to allow the passage of light through the oculi the roofs over these chapels would need to be lower.

The building programme ceased for a number of years due to financial problems, but resumed in the 1440s, shortly before Brunelleschi's death in 1446.

The side chapels along the nave, having been designed in 1434 were eventually built on the cloister side in the 1460s whilst the chapels on the

right hand side were not completed until the 1480s. These newer chapels block the windows of the corner chapels of the Operai and Corsi family, which had previously been built when the idea of chapels opening off the aisles had been given up.

Leo X commissioned Michelangelo to work on the design of the facade of Brunelleschi's church in 1516, but this contract was annulled in 1530 and to this day remains unfinished.

Michelangelo then began work on the New Sacristy in March 1520, as a further monument to the glory of the Medici family, and the design was a long way from the simplicity of Brunelleschi's approach with regards to the interior. Shortly after Michelangelo was commissioned by the Pope Giulio to build what is known as the Laurentian Library to which access is gained from the cloisters.

The final main component of the San Lorenzo 'Complex' wasn't built until the 17th century, and that is the so-called Chapel of the Princes. This was built between 1604 and 1640 under the supervision of Matteo Nigetti. This octagonal chapel is situated behind the chancel and has a richly decorated interior intended to represent "something beyond all human limits" [3].

3.2 The Church Today

The shape of the church of San Lorenzo as it stands today is that of a basic Latin cross, produced by the combination of a transept added to a typical basilica with similarities to earlier classical and paleo-Christian examples, as illustrated in Plate {3}.

As Chiarelli [3] points out the church is the first 'practical application of Brunelleschi's brilliant and revolutionary conception of architectural space as defined by "linear perspective" '. Here Brunelleschi's design evolves around the basic geometric unit of the square to achieve a harmonious relationship between each of its interior components.

The interior reflects Brunelleschi's simplistic yet inspired approach to decoration with the walls painted white and the architectural components outlined in the grey 'Pietra Serena" stone.

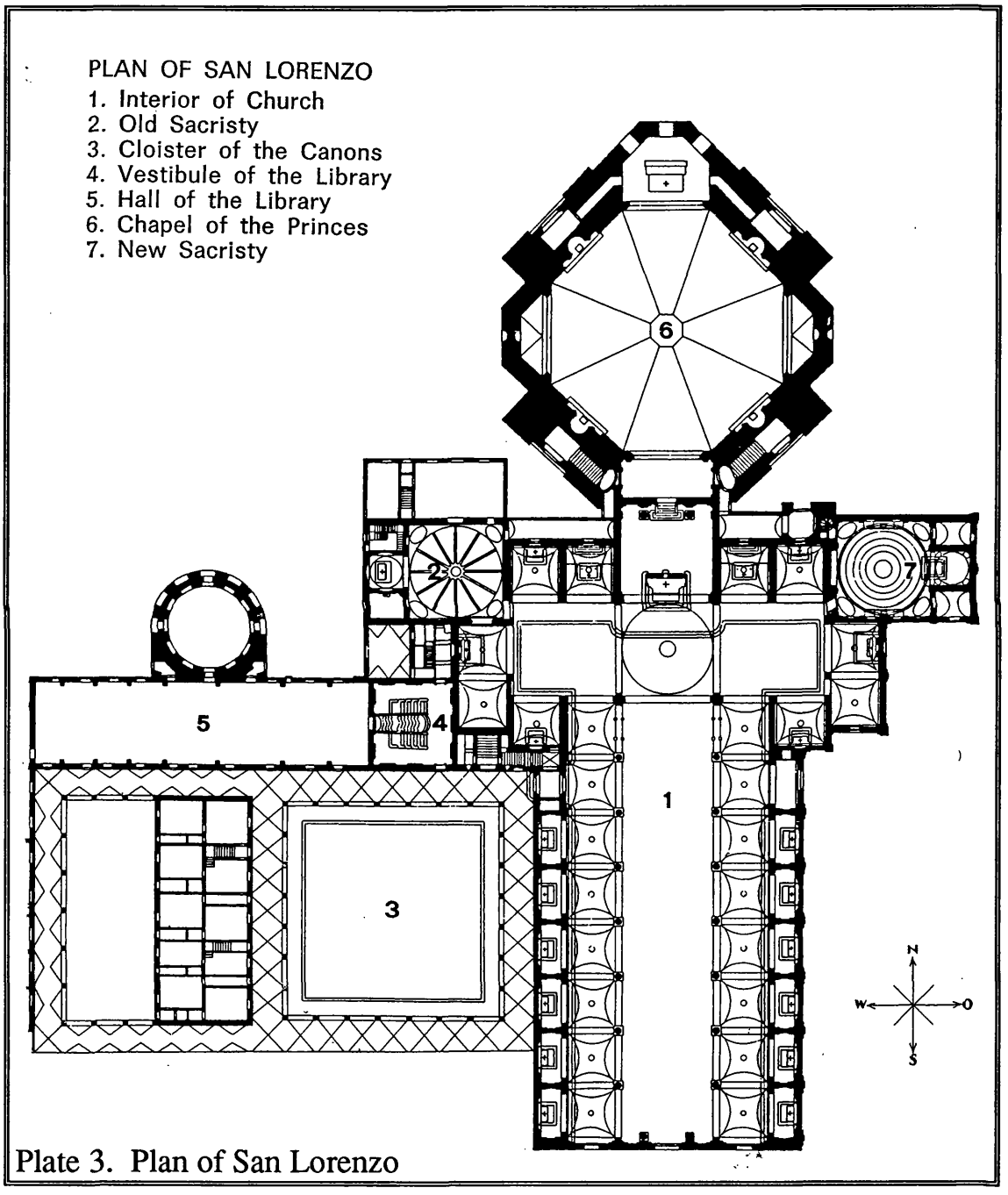


Plate 3. Plan of San Lorenzo

The nave is flanked by two aisles, along which are six chapels on either side with openings equal in width to the width of the side aisles. These side chapels are barrel vaulted and above each entrance there exists an oculus.

Plate 4 A side chapel along the nave

Along the nave the succession of arches add definition in both horizontal and vertical planes, emphasising the side chapels and the height of the nave, drawing the attention up into the upper zone.

There are arched windows at high level along each side of the nave that continue along three sides of each arm of the transept, these are spaced approximately 5.6 metres apart and as will be seen in a later section of the report play an important part in the ambiance of the interior.

The ceiling remains one of the more elaborate components of the church, finished in white and gold in a regimented squared pattern, although this

has undergone changes over the centuries having been described in 1459 as being "in fine gold, with ultramarine blue and full of roses gleaming like morning stars"[4].

The nave meets the transept at the crossing over which exists a hemispherical dome, with light entering through a lantern and supported by four piers, that also support the trabeation that runs around the entire perimeter of the transept and central nave. It is the square of the crossing that is Brunelleschi's basic unit, with the nave being four squares long and the transept arms each one square wide.

The transept has five chapels on the far side, of which the central and largest - the apse proper is also the same width as the nave. At either end of the transept there are two chapels, one of which is partially obscured by the two chapels on the near side in order that access can be gained to both the Old and New Sacristies.

Plate 3. Towards the Altar

Like many other Florentine Churches San Lorenzo houses many fine works of art, such as 'Annunciation' by Filippo Lippi hanging in the Martelli Chapel and a statue of the Virgin attributed to Alberto Arnoldi. In the cupola of the crossing is a fresco of the 'Glory of the Florentine Saints' by Vincenco Meucci.

Perhaps the most famous pieces are the two bronze pulpits, the last works of Donatello that have sat in their present locations at either side of the end of the nave since the first half of the seventeenth century.

Further works of high artistic merit can be found in the New Sacristy and the Chapel of the Princes but due to the pressures of tourism, access to both of these is gained from an external entrance and not from the main church as was originally intended and therefore will not be treated as part of the study. However access can still be gained to the Old Sacristy through the door in the left arm of the transept.

The walls of the Old Sacristy are equal in height to the length of its sides, thus forming a cube on which sits a hemispherical dome on pendentives. Decoration is kept simple, with the walls being divided into three equal horizontal zones, the two lower ones being the top and bottom halves of the square wall divided by the entablature.

In the centre of the Old Sacristy stands a marble table, beneath which Giovanni di Bicci, the patron and his wife are buried in the sarcophagus.

There are twelve oculi in the dome of the old sacristy and an arched window at high level above the altar that provide the illumination.

It has been suggested [3] that the design of the Old Sacristy has a symbolic function, with the 'triadic rhythm referring to the Trinity, whilst the twelve segments of the dome, each illuminated by a round opening, symbolise the light shed by the teachings of the apostles.

Plate 6 The Old Sacristy

4.0 The Survey

The objective of the survey was to try to provide a comprehensive picture of the interplay between the light and interior of the San Lorenzo church.

In order to achieve this, a multi facetted approach had to be adopted, combining subjective assessment, such as the author's descriptive accounts of the interior, quantative measurement of lighting parameters such as luminance, illuminance and reflectance and even a combination of the two, with the subjective brightness map.

In addition a survey was required of the sources of light both in natural and artificial terms which produce the resultant effects.

It is only when all these elements are brought together can one begin to seriously investigate their relationship in the overall context of building and 'lighting design'.

The survey took place between June 28th and July 12th 1991 and all measured data was recorded during this period on different days at approximately 11.00 am and then averaged to give the values quoted in this report. This was deemed acceptable since the illuminance at a certain location within the nave for example, varied by only 2 lux over all the measurements taken.

The subjective accounts within this report were noted at different times of the day and on different days and have been amalgamated. It should be noted that the overall visual appearance of the church remained apparently constant throughout the accessible hours (8.00am - 12.00pm) daily and for services on weekends and festivals. There was no perceptible change in luminance patterns throughout the day and in the main body of the church there was no direct sunlight visible.

The average daily temperature was approximately 82 F (26C) and with clear sky conditions. A sunpath diagram can be found in Appendix 2, showing the altitude and azimuth of the sun at various times of the year.

4.1 Subjective Assessment

As one enters the church of San Lorenzo on a summers morning, one has to pause to allow the eyes to adapt to the relatively low levels of illumination that one finds inside. This process was observed in the majority of both worshippers and visitors alike entering the church. Those visiting the church tended to pause longer for reflection, not purely due to the unfamiliarity of the surroundings, but also due to the serenity of the interior, a stark contrast to the bustling San Lorenzo market only metres away outside.

Having adapted to the interior, the eyes survey a scene which is predominantly grey and white, with the exception of an ornately squared white and gold ceiling, a glimpse of blues and red over the crossing and the orangey glow of burning candles in the side chapels.

There is evidence of artificial sources, more obvious within the side aisles of the nave which were switched off and about which more will be said later.

From the rear of the central nave , the optimum viewing position is found, looking towards the altar, the uniformity and homogeneity within the nave is somewhat unexpected. One would have thought that the interior of the church would have been governed by the clear sky conditions outside, with sharply contrasting areas of high brightness due to sun penetration and darker areas, but this is not the case.

The nave is illuminated naturally by two sets of windows, the oculi above the side chapels and eight arched windows at high level on each side. The resultant perceived effect enhances the structural composition of the nave, provides uniformity at floor level and in the vertical plane sets up a gradient where brightness increases with height.

Consequently attention is lifted upwards along the nave due to the increased brightness in the upper zone, to the elaborate white and gold ceiling. This is given greater depth by the contrasting luminance patterns arising from the spacing of the windows at high level as can be seen in Plate {7}.

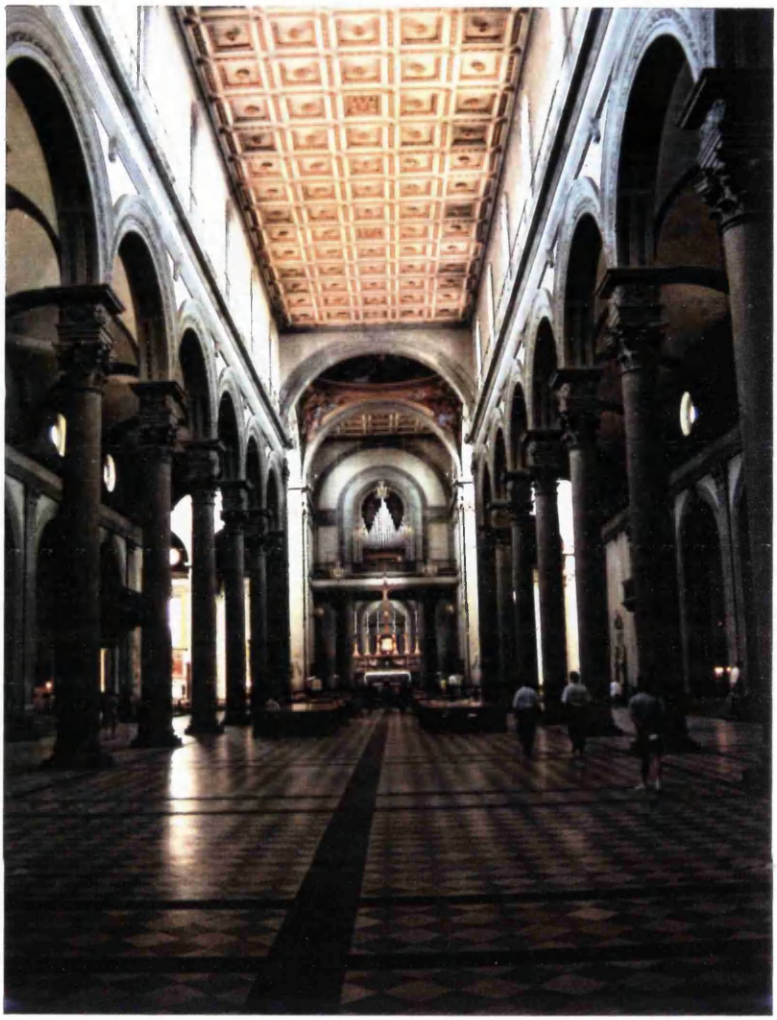


Plate 7. The Luminance Patterns on the Ceiling of the Nave

Remaining in the rear of the nave, as well as being drawn upwards, attention is drawn towards the altar, due to the increased brightness of the visible walls within the transept.

Within the centre of the field of view, at high level on the far wall of the chancel are the organ pipes, which are illuminated by windows at high level on either side wall. There is a prominence of light coming from the left hand windows providing directional lighting which through modelling, gives the pipes their tubular form. In addition the pipes are metallic which sparkle in the natural light contrasting with the predominantly matt grey interior.

Walking down the side aisles of the nave, the brightest part of the field of view can be found at the transept end, within the chapels flanking the chancel.

Perhaps the most interesting feature of the aisles is the way in which the oculi above the chapel entrances give rise to a changing luminance pattern on the white vaulted ceiling of the aisle. This luminance change is very subtle due to the fact that these round widows only admit diffuse light and no direct sunlight.

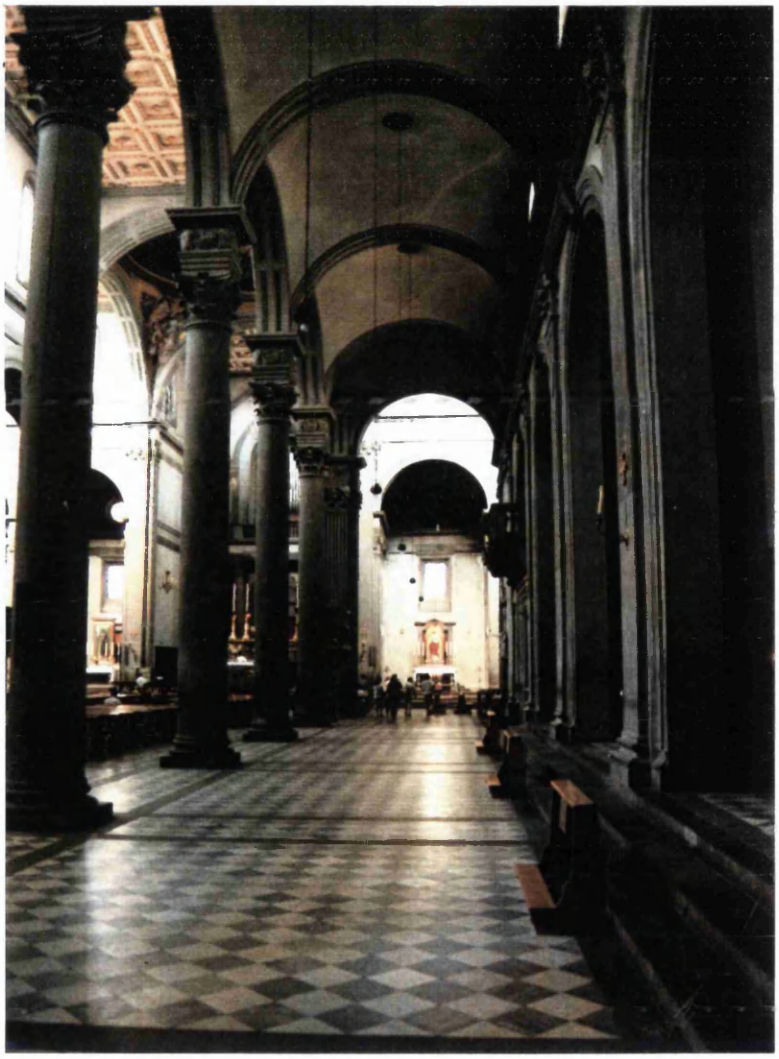


Plate 8 Along the right hand aisle

The columns of the arches along the nave appear dark since they are seen in contrast to the lighter surfaces across the church, which enhances their structural importance.

The side chapels along the nave are without fenestration and rely on the light coming through the arched windows at high level on the opposite side of the nave. Consequently it is the lower parts of the chapels that are relatively speaking the brightest, with the upper walls and barrel vaulted ceiling in darkness.

A number of these chapels glow by the light from candles of offering which brings a certain amount of life to the chapel, which in most cases is not enough to satisfactorily illuminate the heavy oil paintings which hang above the altar on the far wall of each.

However one piece of art which is marvellously lit is the fresco in the cupola of the crossing. Here daylight enters from the lantern above, and like a circular theatrical spotlight highlights part of the painting.

Plate 9 Fresco in the cupola

Within the transept, the main source of daylight enters through arched windows at high level, although the chapels, through being larger than those in the nave also contain round and rectangular windows. As stated earlier the transept appears brighter than the nave, again with a brightness gradient in the vertical plane.

Within the arm of the right transept there is a hidden chapel containing two windows, one circular and the other rectangular which provide fairly strong directional lighting within the chapel at the end of the transept. This results in strong modelling over the altar area giving the columns and portico a feeling of strength and protection of the crucifix which they house.

Sitting within the right arm of the transept, directional lighting continues, this time from above where the strength of the light perhaps extends from the physical sense to the spiritual. (The smaller services are held in this area throughout the week).

It is in the first chapel on the left hand side of the left transept, where there is evidence of modifications to the fenestration. The rectangular window has been blocked in order to locate a large crucifix which hangs over the altar. Incoming daylight is further restricted by the circular window above housing stained glass of lower transmittance, the only occurrence within the main church.

The chapel opposite the one just mentioned, although being the same dimensions, due to daylight passing through both windows is much 'brighter' and more inviting for those wishing to sit in private prayer.

Passing through a doorway in the corner of the left transept, one enters the Old Sacristy where one immediately feels that this is a separate entity from the main church space. Fanelli [7] says of the Old Sacristy, which supports the mood of independence "The Illumination comes from above, and there are no other openings which create a visual relationship to the exterior: the interior space is an absolute space, which excludes all others".

The incoming daylight enters at high level through the twelve oculi within the dome, the lantern above the dome, arched windows at high level on three sides and a further arched window over the altar. The light is of a diffuse nature due to the fact that within each oculus there is an iron-work disc and the lantern limits direct sunlight, and this light is again concentrated within the upper zone.

The consequences of the joining of the main church and the Old Sacristy (which was once an independent structure) has been to modify the daylight distribution since on two sides of the cubic room the arched windows face chapels within the transept. This has had a slightly derogatory effect on the interplay between Brunelleschi's two basic geometric components, the hemispherical dome and its cubic room beneath. The diffuse light in the upper zone emphasises the dome although the equilibrium of the cube and the representation of the Trinity would be enhanced by incoming daylight on three sides.

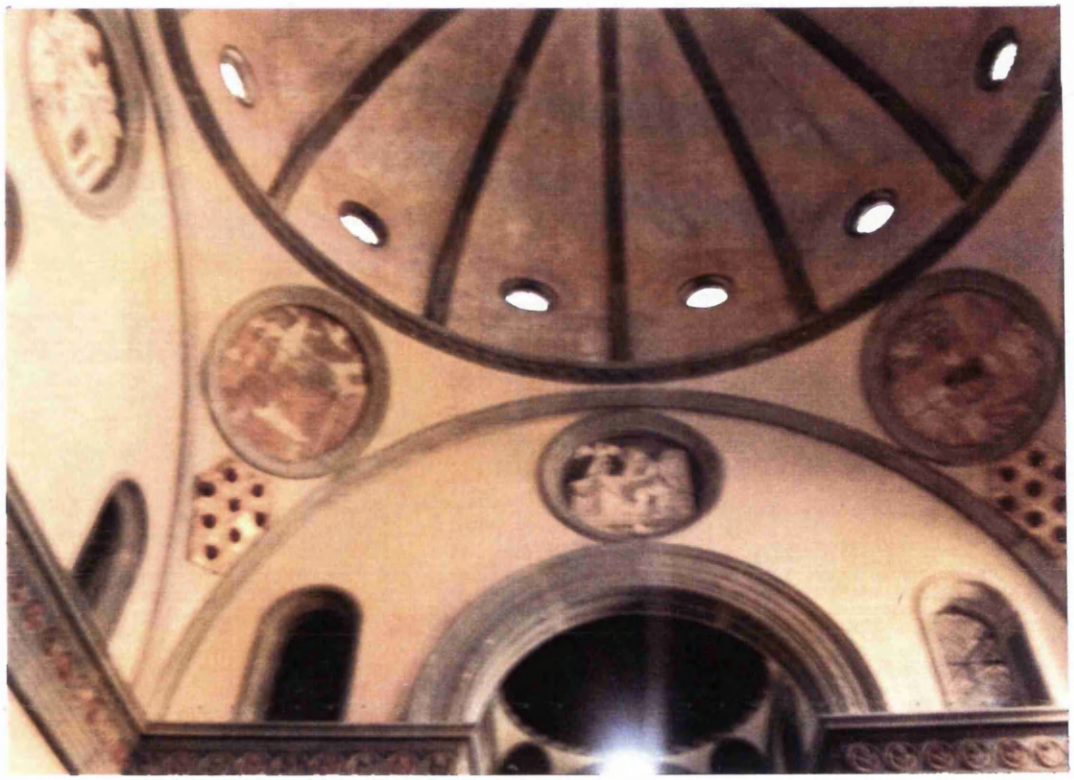


Plate 10 The oculi within the Old Sacristy

4.2 Quantative Assessment

4.2.1 Horizontal Illuminance Distribution

The illuminance measurements were taken with a Hagner Photometer, utilising the external cell and were measured at 1.5 metres above the floor level. The measurements were taken at approximately two metre grid spacings within the central body of the church. This was seen to be a practical spacing due to the size of the area and in order to be as discreet as possible for those in prayer. It is accepted however, that a more accurate measure of average illuminance and uniformity would have been calculated from a finer grid, but it is felt that the measured values taken fulfil their duty in providing an acceptable quantative assessment of the illuminance distribution.

It should be noted that the recorded illuminance levels are due in the main to natural light only, with a minimal contribution in some areas from candles of offering. Within the smaller chapels an artificial oil-lamp was switched on and served a symbolic rather than functional lighting purpose, light reaching the measurement plane was negligible.
Plate {11} shows the measured horizontal illuminance over the main church area, with Table {1} providing a summary for the different areas.

Illumination (lux)	nave	side chapel	transept	transept chapel
Average illuminance	30.5	15.4	44.4	54.5
Minimum Illuminance	17	10	39	49
Maximum Illuminance	41	22	51	60
Uniformity (Min/Ave)	0.55	0.65	0.87	0.89

Table 1 Summary of Illuminance Measurements

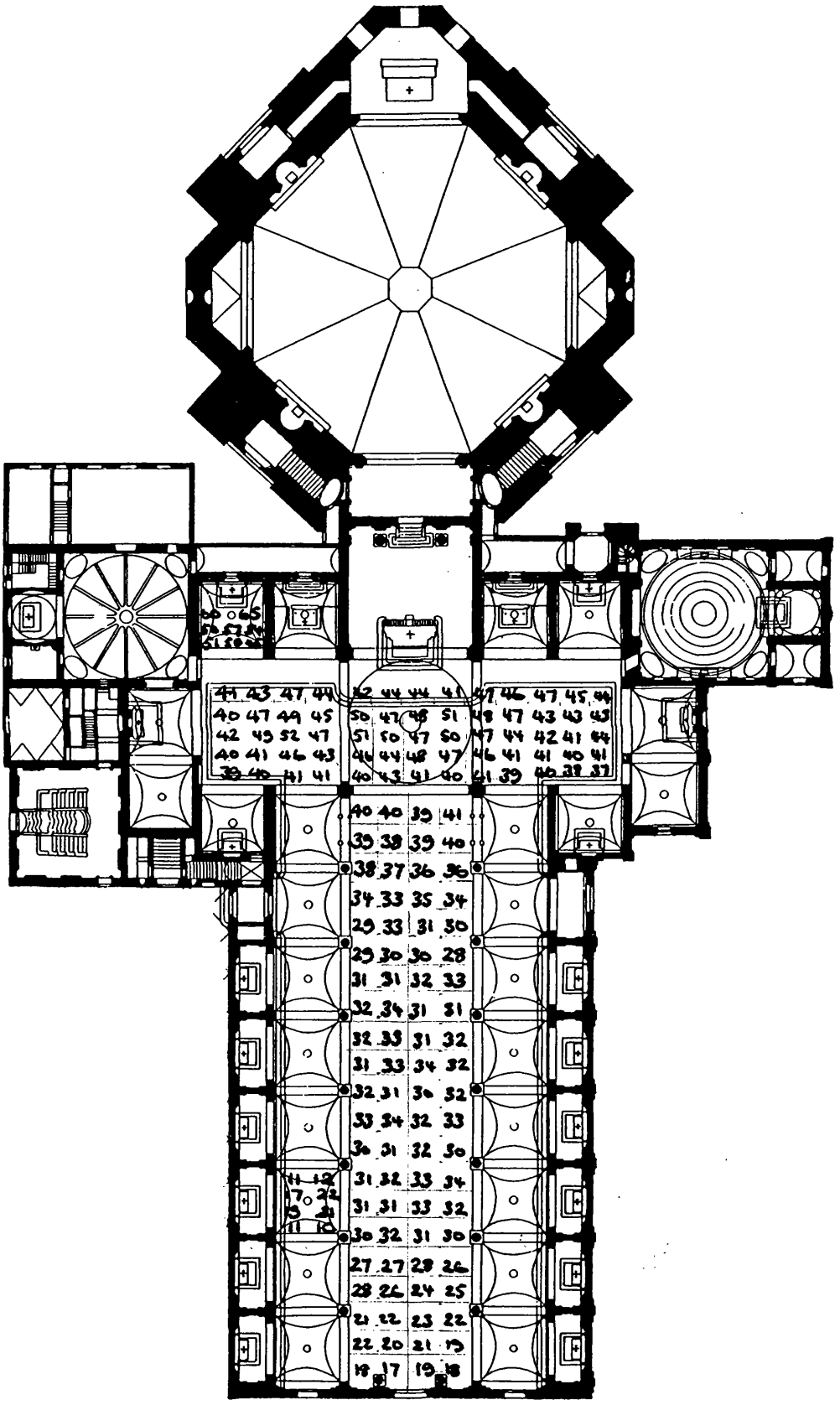


Plate 11 Horizontal Illuminance Distribution (Values in Lux)

The horizontal illumination measurements made within the church, as shown by Table {1}, ranged from 10 lux to 65 lux, which assuming an outdoor horizontal illumination level of 15.2kLux (excluding Direct sunlight) would give a daylight factor range of 0.065% to 0.42%. However it is inappropriate to discuss the illumination levels in terms of daylight factor, since the sky conditions over the study period were clear blue sky and thus cannot be related to the CIE standard overcast sky normally assumed in daylight factor calculations

There is a clearly defined increase in illuminance as one proceeds down the nave towards the altar, whereas in the transverse plane the values remain fairly constant..

At the far end of the church the illumination level falls below 20 lux due to the fact that the end oculus on either side of the nave has been blocked by masonry. It is these lower illumination levels that one encounters when entering through the main doors at the back of the church, and thus the adaption process from the illumination levels outside to those inside will take that bit longer.

The uniformity (minimum/average) within the central nave is fairly high (0.55), since the measurements were taken over such a large area, albeit on a course grid, with the diversity in illuminance (maximum/minimum) of only 2:1 (approximately).

Excluding the two far ends the illumination levels within the nave remain at a reasonably uniform level (around low to mid 30s lux), which can be attributed to the spacing of the windows both at high level and at the lower level, and also due to the orientation of the building. (restriction of direct sunlight).

Within the side aisles of the nave, the pattern of increasing illumination level towards the altar end is consistent with that in the central nave. This gives the whole nave a sense of unity and direction in the axial plane along the nave, whilst creating a less 'forceful' sense of order in the transverse plane, towards the side chapels where people kneel in private prayer.

The illumination levels within the third chapel on the left hand side are typical for those found within the chapels along the nave, the data for which has been omitted for reasons of clarity. The recorded values reflect their spatial relationship with the windows on the opposite side of the nave as well as the way in which the arched entrance limits light to the chapel corners.

The fenestration within the transept promotes not only higher illumination levels than those found within the nave but also a higher uniformity (again from a course grid). These levels reach their highest in the crossing where there is a contribution from windows in both the nave and the transept and also from the lantern above the dome.

The transept chapel chosen for the illuminance measurements was the one adjoining the Old Sacristy which contained both circular and rectangular windows reflected in the highest measured illumination level within the church, 65 lux. A uniformity was calculated to be 0.89 but this is not a particularly good indication since it is only calculated from only eight points.

4.2.2 Vertical and Mean Cylindrical Illuminance

Two other measures of illuminance were recorded in addition to the horizontal plane readings, these were vertical illuminance and mean cylindrical illuminance.

The vertical illuminance readings were quite straightforward, taken at a height of 1.65 metres above floor level (eye height) on a number of different room surfaces in a number of locations, shown in Plate {12}.

The recorded measurements of vertical illuminance on the walls in between the side chapels illustrate values consistent with those on the horizontal measurement plane. This surface is the grey pietra serena stone which is of a lower reflectance than the white plaster of the far wall within the chapels, where the vertical illuminance is approximately half that on the front wall. The light falling on these surfaces is provided by the windows on the opposite side of the nave.

The measurement of mean cylindrical illuminance was only an approximate one since it is the averaged illuminance on the four vertical sides of a cube (as detailed in Appendix 11 of the CIBSE Code for Interior Lighting 1984). These values are also shown in Plate {12} and reflect the trends shown previously in the horizontal illumination distribution.

However what the vertical illumination measurements on the four sides of the cube give is a better indication of the directional qualities of the interior lighting provided by the fenestration. For example taking the cube position within the left transept, the illuminance on the right face of the cube is seven times that falling on the left hand face. This is due to the fact that the fenestration within the chapel to the left of the cube has restricted incoming daylight due to the position of the Old Sacristy.

The readings on the cube at the crossing are perhaps the most significant, since this point is just in front of the position where the Priest delivers his sermon and is obviously important that the vector/scalar ratio is moderate to provide pleasant human features for communication with the congregation. Although the vector/scalar ratio has not been directly

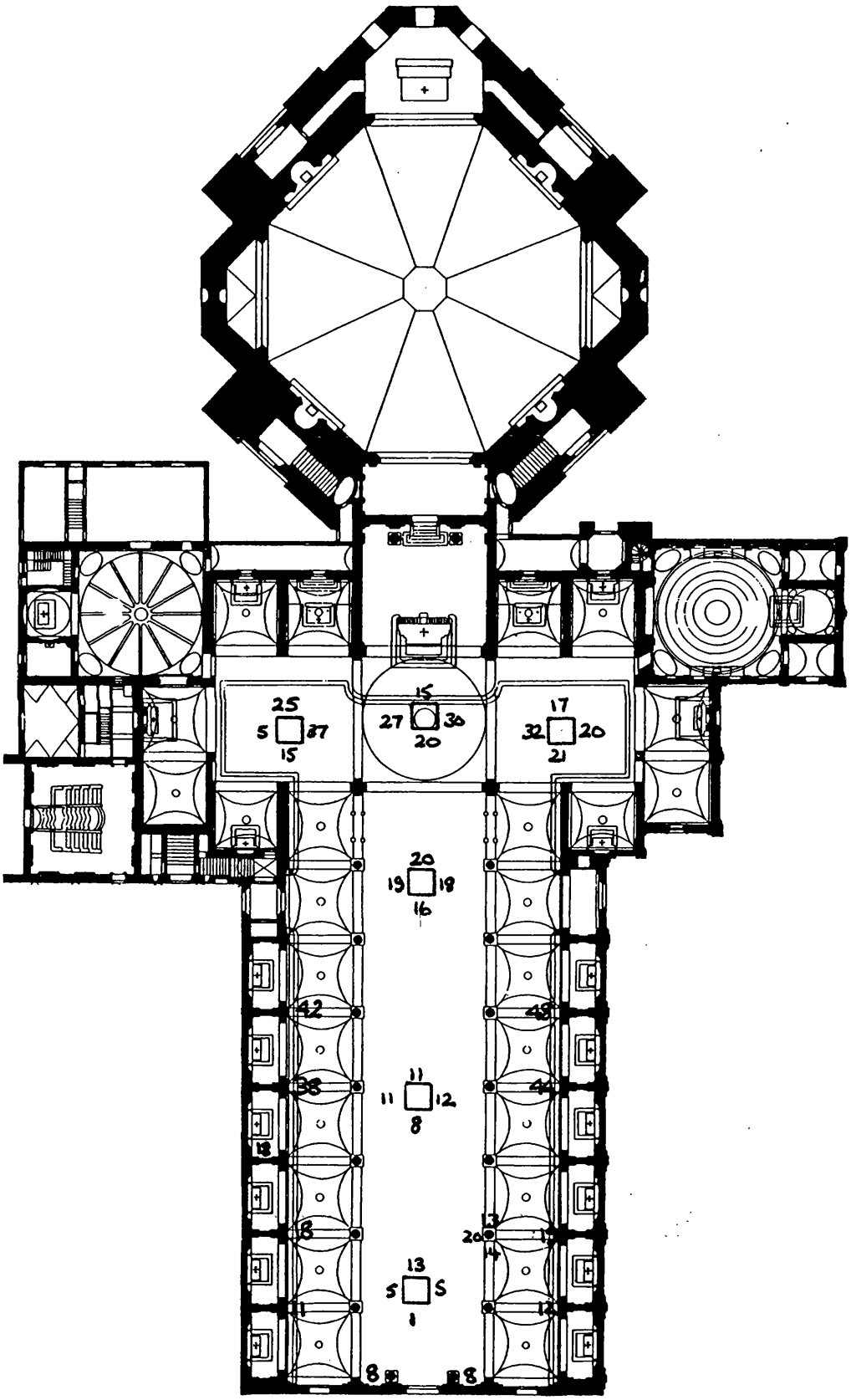


Plate 12 Vertical and Mean Cylindrical Illuminance (Values in Lux)

measured, the values with the exception of that on the back face are of the same order, as is the horizontal illuminance falling on the top face of the cube. This would suggest that the directional lighting provided by the windows in this area is acceptable for the Priest/congregation interaction, being of a moderate to soft nature.

4.2.3 Surface Reflectances

Before discussing the luminance distribution found within the main areas of the church, it is worth considering the reflectances of the surfaces.

These were measured with the use of a luminance meter and a sheet of white paper, which approximated to a 'standard reflectance surface', due to the Author not having a pressed barium sulphate or magnesium oxide disc available.

The luminance of the surface in question is measured followed by the luminance of the standard reflectance surface in the same location. The reflectance of the surface can then be calculated from the equation;

$$R = R_p.L_s / L_p$$

where R = reflectance of surface
R_p = reflectance of paper (assumed 90%)
L_s = luminance of surface
Lp = luminance of paper

(Assuming uniformly diffusing surfaces).

As mentioned earlier the church is predominantly grey and white and it is these two surface reflectances that were of principle interest.
Due to the variations in the grey Pietra Serena stone it was necessary to calculate the reflectance at a number of different locations and then find the mean average.

Surface	Reflectance
Grey stone	24.1%
White Plaster	89%

Table 2 Surface Reflectances

4.2.4 Luminance Distribution

Plates {13} - {15} detail the measured luminance distribution within the various areas of the church. The values quoted are in candelas/square metre and due to the fact that the values were low, great care had to be taken to ensure that the meter was correctly zeroed at each time of use. The luminance meter used had an acceptance angle of 1 degree.

Plate 13 Luminance Distribution looking towards the Altar (cd/m^2)

The distribution shown in Plate {13} may appear to reflect a particularly gloomy interior just by analysing the values, but this is not the case. There is no question of gloom due to the luminance range within the field of view being 40:1, with the luminance of the upper walls at 20 cd/m^2 and the luminance of the marble floor and lower columns at 0.5 cd/m^2 .

There is an obvious luminance gradient on the vertical surfaces within the nave which was highlighted within the subjective assessment. The vertical surfaces within the transept seen through the nave columns have a measured value of 21cd/m^2, this being the highest luminance value

within the field of view stimulates the visual system and becomes the focal point of the field of view.

The luminance values on each surface, apart from giving an order of magnitude do not express the feeling or mood within the space. What is important, is the fitting together of all the components into the visual scene.

Thus a more interesting parameter to discuss is the 'apparent brightness' of each surface, which depends upon the luminance of a surface, the luminance of its surroundings and on a number of complex visual parameters, such as the adaption state of the eye.

The luminance distribution along the right hand aisle, illustrated in Plate {14} can be used to demonstrate this concept.

Plate 14 Luminance Distribution along Aisle (figures in cd/m^2)

The columns which have a luminance of between 1 and 2 cd/m^2 are seen against surfaces of luminances of 9.5cd/m^2 in the transept and 6-7cd/m^2 on the ceiling. Hence the columns appear darker than their surroundings which enhances their weight and size emphasising their structural role.

The vaulted ceiling over the aisles also show differing luminance values, although it was felt that there would be a greater diversity in luminance than actually recorded.

The general luminance distributions are also found within the transept Plate {15}, with the highest values recorded at high level. These values also confirm the subjective assessment of strong directional light falling on the surfaces on the left hand side of the end chapel, and on the illuminated portion of the fresco in the cupola due to light from the lantern.

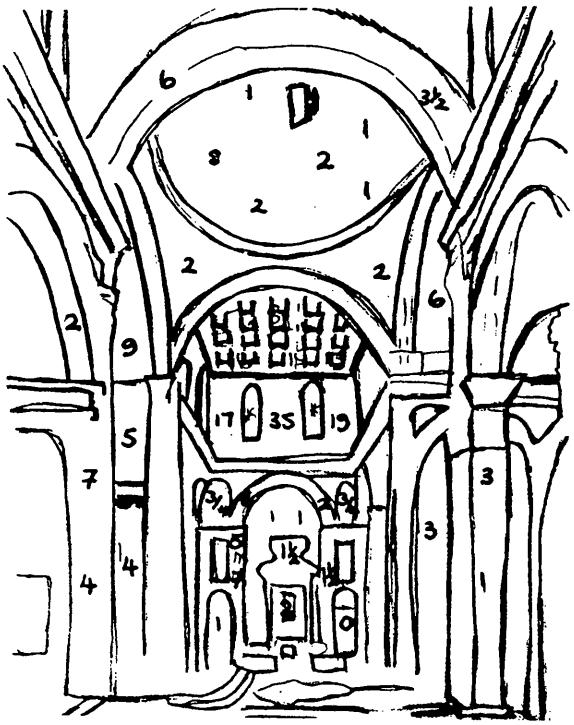


Plate 15 Luminance Distribution within the Transept (figures in cd/m^2)

4.2.5 Subjective Brightness Map

Perceived brightness is not related to luminance on a linear scale, thus the luminance distribution within a room is perhaps not the best method of assessing the eye's visual response to a particular scene.

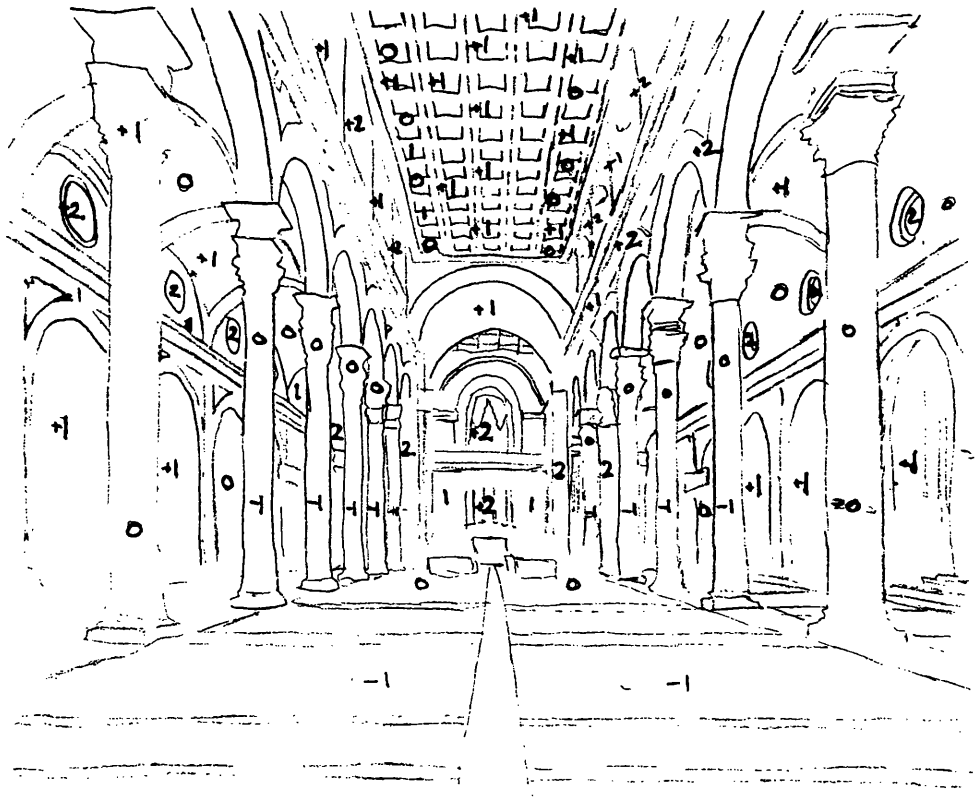


Plate 16 Subjective Brightness Map (arbitrary units)

Thus in Plate {16} the Author presents the perceived brightness distribution in a subjective map. The values were arrived at in the following way;

Firstly the view from the back of the nave was surveyed, and a point was found within the field of view that appeared as though it was the mid-point in terms of brightness. This was found to be the floor at the front of the nave which was then given the value of zero.

Using this as the reference value each part of the visual scene was then more closely analysed, those elements that appeared 'twice as bright' as the floor at the front of the nave were then given a value of '+1' and those appearing 'half as bright' were given a value of '-1'. Similarly those elements deemed twice as bright again were given the value of '+2' and likewise in the negative direction for those appearing half as bright.

The subjective brightness map becomes interesting when compared to the measured luminance distribution shown in Plate {13}. Here the mid-point luminance value is approximately 10 cd/m^2 which corresponds most closely to the luminance values found within the altar area and on the upper arches along the nave.

What appears to be the mid-point of brightness within the subjective map is in fact at the lowest end of the luminance range with a value of between 0.75 and 1.0 cd/m^2 .

4.3 Electric Lighting Installation

The survey period took place in the height of summer, where the only artificial lighting was provided by lit candles and electric imitation oil-lamps in the chapels, which provided next to no illumination on the measurement plane. This was true for 'visiting hours' during the morning as well as for the religious services in the early evening.

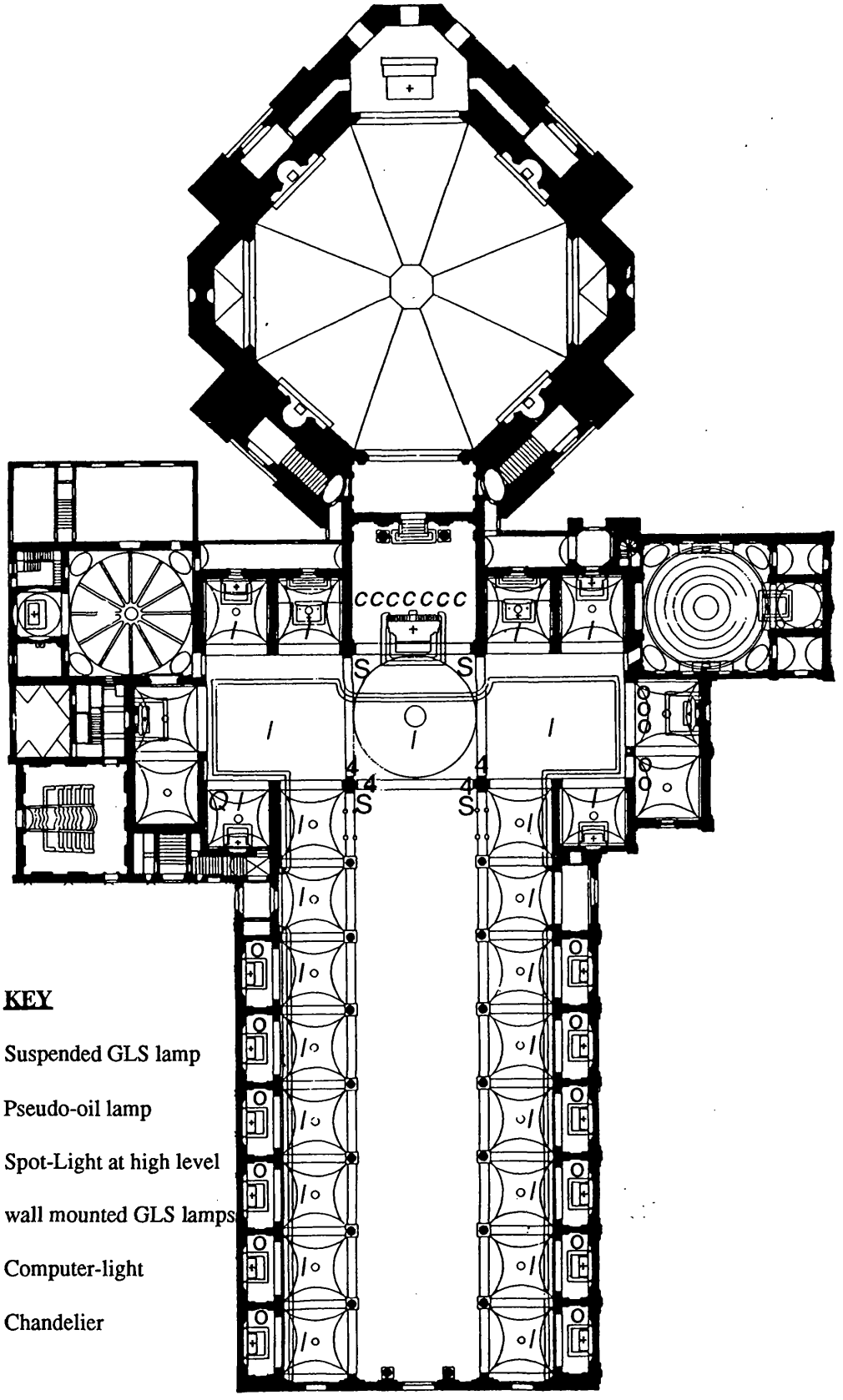
It was one of the original intentions of this report to study the development of the artificial lighting utilised within the church throughout the centuries, but this proved difficult due to lack of relevant documentation, and since the church is predominantly daylit today, it is not unreasonable to assume that this was true of the past centuries.

In addition to the candles of offering lit within the various chapels, on the wall between alternate chapels along the nave were mounted large white church candles on brass holders. There is no evidence on any of the wall surfaces of any additional or alternate fixing locations for candles or oil-lamps which existed in the past, and the candles which exist today are only lit on festival occasions. The locations of these, and the electrical installation are shown in Plate {17}.

The electric installation within the nave is restricted to the two side aisles where suspended from the ceiling outside each side chapel there exists an incandescent lamp (GLS). These are connected to the cable with the use of a simple lamp-holder and have no form of light control. On request these lamps were switched on, immediately violating the serenity and harmony of the interior with a fairground vulgarity, adding a row of 'glaring sparkle' along each side of the nave.

The simplicity of fitting continues within the transept with suspended incandescent lamps in either arm and also suspended from the dome at the crossing.

In addition at high level on the four corners of the crossing there sit simple luminaires each consisting of a GLS lamp and simple conical reflector that all point aimlessly to the apparent location of the congregation. Lower down the piers at a height of approximately 1.75



KEY

I	Suspended GLS lamp
o	Pseudo-oil lamp
S	Spot-Light at high level
4	wall mounted GLS lamps
Q	Computer-light
c	Chandelier

Plate 17 Electric Lighting installation

metres above floor level, there are four mounted 25 watt GLS lamps on each side facing the altar and those facing the central nave, which once again have no form of light control.

Over the altar area, the decorative nature of the electrical installation is improved, although the control of light is questionable. Seven suspended 'chandelier' fittings, each comprising a number of candle-shaped incandescent lamps, are arranged in a triangular formation such that the central fitting is at the highest point. Although switched off for the duration of the study period these luminaires were able to convey the importance of the altar area.

As mentioned in an earlier section, within each of the smaller chapels there are suspended imitation oil lamps, which contain a low wattage lamp that produce merely an orangey glow. These have absolutely no functional purpose in terms of illuminating the chapels but fulfil a symbolic role whilst preserving the feeling of antiquity.

Fixed to the suspension chain of these fittings within the side chapels along the nave, are primitive spot-lights housing incandescent lamps which are apparently focused onto the oil paintings and crucifixes which adorn the back wall of each chapel. It is a great shame that these remain switched off, since the works of art are of immense importance and thus warrant a higher degree of illumination.

One could argue that San Lorenzo is a place of worship and not an art gallery, and it is felt that this should be held in the highest regard. However, by correctly illuminating the far wall of each side chapel not only would worshippers and visitors be able to see the works of art but also the chapels themselves would be given greater 'depth'.

The forces of tourism can be seen in the left hand chapel within the left arm of the transept. This chapel was described in an earlier section, being of lower illumination levels due to the fact that one of the windows has been blocked by masonry. Within this chapel the church authorities have installed a 'computer-light', which can be seen elsewhere in a number of historical locations. Essentially this is a commercial proposition whereby the interested party pays for an area (or object) to be illuminated for a set

period of time, usually a minute or two. In the case of this chapel, the 'main attraction' is the painting 'Annunciation' by Filippo Lippi, which is an important piece of Renaissance art.

These computer-lights do have a serious advantage in terms of conservation of artwork, which degrade due to light falling on them on a lux/hour basis. Therefore when there are no people interested in viewing the subject matter, the main source of illumination is extinguished and the illumination levels are cut dramatically, thus aiding conservation.

However the Author would question the appropriateness of the use of the computer-light in its current position at San Lorenzo. When operated, the chapel is illuminated by three linear tungsten floodlights, which spill light into the transept area. When the time period expires the luminaires are switched off and the chapel is plunged into relative darkness, this can have a disturbing effect for those sitting in private prayer within the transept area.

A more satisfactory approach to illuminate the chapel, considering both conservation and annoyance factors, would be to illuminate the chapel and more importantly Lippi's painting to lower illumination levels than those provided by the computer-light but constantly. In this way by correct design and positioning of the luminaires one could illuminate the artwork to maximise peoples appreciation and spillage into the transept area could be kept to a minimum.

The viability of the existing artificial installation of San Lorenzo is highly questionable, although this statement cannot be quantified since access could not be gained to the church during the hours of darkness in order that the illuminance distribution provided by the installation could be measured.

The Standard Service Illuminance recommendation given within the CIBSE Code for Interior Lighting 1984 for the main body of the church is 150 lux. (The Church of England's publication "Lighting and Wiring of Churches" suggests the illuminance range of 100 - 200 lux).

This figure reflects the functional requirements of the lighting which should enable the reading of Bibles, Orders of Services etc, good communication between Priest and congregation and allow safe passage of people around the church.

It is not likely that this figure will be met within the central nave, by the luminous output from the sixteen suspended 100 watt GLS lamps positioned within the nave aisles

Even during the hours of daylight, the adequacy of the illuminance levels (10-65 lux) must be questioned, since although acceptable for the movement of people around the church, will not be adequate for the reading of small print found within religious texts by an elderly parishioner.

The question that needs to be answered, is why does the artificial installation remain in such a primitive state, since although there is a dependency upon natural light during the summer, within the winter there is certainly a demand for electric lighting.

It is unlikely that the reasons for not improving the 'lighting' are economic, since the church stands within an affluent area of Florence, but more likely due to the commonplace lethargy with regards to this form of improvement.

5.0 Discussion

It is hoped that through the subjective, quantative and photographic evidence, the reader has been provided with a vivid picture of the interior of the church of San Lorenzo, which stands as a monument to both the Christian Faith and the period known as the Italian Renaissance.

The interior of the church would seem to reflect Brunelleschi's ideals and objectives to create a balance between each architectural component and in so doing was able to "achieve control of a rational spatial structure" [5]. One of his main design principles was to use basic geometric forms such as the plain cube of the Old Sacristy, the domed cube of the Foundling Hospital and the crossing square within San Lorenzo, and to utilise these in the make up of the whole structure.

Two other factors contribute to the harmonisation within Brunelleschi's interiors; Firstly it is thought that Brunellechi was responsible for the first correct use of perspective on a monumental scale [Battisti], which illustrates his awareness of visual perception with regards to space and distance. Secondly he demonstrated his aptitude as a 'structural engineer' in the building of the cathedral dome and thus the composition of his buildings were not restricted to as many of the 'structural limitations' as those built by lesser architects before him. (The fact that the buildings of Brunelleschi still stand today, for over five centuries must be some indication of the quality of building!)

It would be a somewhat forced conclusion to suggest that Brunelleschi's design reflected his understanding of the interplay between the architecture and light in the resultant interior. However it is the opinion of the Author that the Old Sacristy and Church of San Lorenzo not only communicates the essence of Brunelleschi, the man and his architectural 'ideals' more than any of his other works that stand today, but also highlights some interesting lighting design considerations.

Over the study period the interior lighting of the church was principally natural light entering through windows at both mid and high level and

being of a diffuse nature 'spreads light calmly over the main body of the church at a human level'. This is reflected in the horizontal illuminance distribution, the relatively high levels of uniformity and also the fairly restrained luminance range.

This is not the case within Brunelleschi's second basilical church, that of Santo Spirito, where immensely strong shafts of direct sunlight penetrate the nave from the windows at high level on the right hand wall.

Plate 18 Direct Sunlight within the Nave Of Santo Spirito

The fenestration of San Lorenzo does provide fairly low levels of illumination (measured 10 - 65 lux), which does mean that the eyes need time to adapt when entering from the outside on a sunny day. Initially there is perhaps the slightest suggestion of gloom within the interior, but the concentration of light in the upper zones of the church and the attraction towards the altar and transept overcome this.

The degree of illuminance uniformity within the church provided by the equidistant spacing of the windows must be considered as one of its strengths, since the architecture with the aid of the subtleties of diffuse

light is able to define the different elements and areas. Plate {18} depicts the scene at Santo Spirito where the drama created by the pools of direct sunlight, and hence the effect on the visual system, take away the impact and strengths of the architecture.

The windows at high level within San Lorenzo give rise to a luminance gradient in the vertical plane, which emphasises the height of the nave. The columns and arches along the nave are given their shape and structural form due to the luminance patterns and directional lighting from the arched windows in the upper zone on the opposite side of the nave and from the oculi within the aisles on the same side.

The illumination vector (since provided mainly by the windows at high level) is vertically downwards, which contradicts peoples' preference for an illumination vector in the range 15 - 45 degrees from the horizontal [10]. This range is usually met during the daytime by side windows at 'human level'.

Strong directional lighting vertically downwards is not usually appreciated due to the casting of shadows upon the human face and the creation of a 'solemn' atmosphere within a space generally. However due to the diffuse nature of the incoming daylight and the high reflectance of the white plastered walls within the church, although the light is coming from above, the magnitude of the illumination is not unreasonably high for a building of this nature.

The colour characteristics of natural daylight furthers the consistency and visual calmness within the space determined by the simple white and grey decoration on the room surfaces.

There are a number of interesting comparisons to be made between the subjective assessment and the quantative measurements made within the church during the study period. The first, concerns the order of magnitude of both the illuminance and luminance measurements. Considering the illuminance values, on paper these appear fairly low, especially when compared to recommended illumination levels for offices (500 -750 lux) [10]. This is also true for the luminance values of the various room surfaces.

However in reality due to the adaptive processes of the visual system, the lighting levels on the floor and on the surfaces appeared higher than those measured. The 'brightness' of the organ pipes for example was perceived to be far greater than the measured 9cd/m^2, but this is due to its spatial relationship with the other surfaces of even lower luminance.

The recorded horizontal illuminance distribution and fairly high uniformity values reflect the feeling of homogeneity and unity within the interior of the church in general, which is further enhanced by the similar vertical illuminance values recorded falling on the walls and columns.

For a building of such architectural beauty and historical interest, let alone for its religious function, it is a great pity that the pleasures of the natural light have not been enhanced by a more suitable artificial lighting installation. Although this may not be utilised for many hours during the summer months, during the winter it would be essential for both the early morning and evening services.

The artificial lighting installation that currently exists within the church not only fails to meet its functional requirements but also has an extremely derogatory effect on the visual impression of the interior. The suspended bare lamps within the nave aisles reveal a slovenly and unpractical approach to the lighting of the area, with a lack of light control giving rise to, discomfort glare, detraction from the vaulted ceiling and a general impression not consistent with its religious purpose.

The luminaires at high level on the four corners of the crossing, although may provide adequate illumination for the congregation to read by, in terms of their directional qualities are poorly positioned since the light falls across the view of the congregation towards the altar area.

The design of an alternative artificial installation would need careful consideration, with regards to either 'preserving' the daytime appearance or for creating a different visual scene within the church at times when the natural light was not sufficient. Whatever choice was made, the lighting installation should fulfil the functional requirements of those

involved in worship, and illuminate the architecture in a 'non dramatic' way. By this it is meant that strong directional lighting should be avoided, as should areas of high contrast and strong concentrations of light.

Light should be pushed up into the upper reaches of the church, in order to provide its unity, since many church lighting installations seem to provide a 'black hole' effect above the congregation during the hours of darkness.

The lighting of the side chapels along the nave would add width to the central view towards the altar and would also have a secondary benefit of illuminating the art treasures that are housed within them. By careful light control, spillage from these chapels could be kept to a minimum to preserve the unanimity of the nave and its aisles.

The inclusion of the computer-light is a sad addition within the church and reflects the enterprising attitude of its governors. If the lighting installation of the church was improved, greater use could be made of the church during the evenings for recitals and classical concerts for example (as is done in other churches in Florence) and this could replace 'the need' for the computer-light in economic terms. This would allow those who use the church for private prayer during the day to do so without the existing visual disturbance.

It has been suggested[8] that there is too much 'drama' in today's lighting designs, a statement probably induced by the increased use of 'theatrical' lighting effects within new buildings. This is not to say that these effects are necessarily derogatory with respect to the architecture, but J.M Waldram's [9] words must be heeded; " The aesthetic aims must be those which will be deemed pleasing and suitable by the majority of users; not necessarily those which please the Architect. 'Avant-garde ideas are likely to please only their creator and are not likely to fulfil visual principles".

In order that an internal visual environment is pleasing to the people within that space, the designer must consider the scene as a whole.

Thought should be given to the lighting of each architectural element, surface and area but the important consideration is how these components fit together to ensure 'visual harmony'. (One must be careful not to interpret the word 'harmony' as 'uniformity', since it is the range of both illuminance and luminance within the field of view will govern the perception of the space in question).

The range of luminance on surfaces should be controlled such that there are no areas of high contrast that will stimulate the visual system at the expense of the rest of the visual scene. Luminance patterns and gradients on architectural elements are necessary since they give each component their form and characteristics (aiding our stereoscopic vision) and obviously create a more balanced and natural environment.

Investigations into preferred luminance ranges on room surfaces have in the main been concentrated within the office environment and often related to specific tasks, rather than to assess peoples reaction to a space in terms of visual appreciation.

When lighting large flat surfaces, the lighting designer is faced with a dilemma as to illuminate uniformly or to create some form of contrasting patterns and the decision will depend upon the given space and application. However, whatever the situation the creation of meaningless patterns and pools of light fail to compliment both the architecture and the appreciation of the space.

The positioning of the lighting hardware is another important aspect, since the directional qualities of the lighting will enhance form (modelling) and can also reveal the texture of the surface (which may not be required if the surface is cracked or uneven for example). The location of the luminaires will also have a direct impact on the perception of the space, since they are in fact part of the architecture. Long lines of linear fluorescent luminaires within an office space for example can look particularly unpleasing, for reasons of monotony and regimentation, and a space with many suspended chandelier fittings can appear too visually 'cluttered'.

Where possible the architecture and the lighting within it, should be developed simultaneously if the maximum potential of each are to be realised. One recent British project that has received much acclaim, and had adopted this approach, is the new terminal building at Stansted Airport designed by Sir Norman Foster Plate {19}.

Plate 19 The new terminal building at Stansted Airport

The lighting design was incorporated at a very early stage in the design of the building, in order to create a "calm, light and rational space" [11] having "an assertive but low profile, with a strong and recognisable presence" [12].

The main walls of the terminal are fully glazed, with light entering through triangular rooflights within the ceiling during the day. Located beneath these rooflights are perforated metal reflectors that allows a certain amount of diffuse light through, reflecting the light softly onto the ceiling 'square modules' whilst eliminating direct sunlight.

Within the terminal building the architecture and the lighting are inseparable, since even in the hours of darkness the illumination is provided by uplighters located within service 'trees'.

Although the building of the Church of San Lorenzo and the terminal building at Stansted are separated by a number of centuries and their functional purposes are completely detached, to make comparisons between their interior visual environments is not unreasonable.

In both buildings, the structure is emphasized very subtly by variations in luminance of particular surfaces, for example on the ceiling 'squares' within the terminal building and within the vaulted ceiling of the nave aisles at San Lorenzo. These luminance patterns are created by diffuse light with the exclusion of direct sunlight resulting in the architectural components being highlighted and accented in a more purposeful way with regards to the structure as a whole. (One could revert to the old analogy whereby the interior scene within the two buildings can be regarded more as a symphony than merely a collection of musical notes).

At 'human level' within either location, one appreciates the sense of order and composure of the space which in the case of the terminal building supports its functionality and at San Lorenzo provides the correct 'ambiance' for private prayer and worship.

In order to achieve visual harmony within an interior, the process of lighting design should encompass the three dimensional space. Quantative and subjective considerations should be given in particular to the room surfaces and not exclusively to a single horizontal measurement plane. A rational method of attaining the desired interior is by the determination of a preconceived appearance which can only be realised through the early involvement of Client, Architect and Lighting Designer.

Advancements in both lamp and lighting technology have created almost endless possibilities for the interior luminous environment and it is up to the Lighting Designer of today to utilise these to enhance the structural form provided by the Architect whilst meeting the functional requirements of the Client. Only through this process can one hope to achieve the harmonisation of light and architecture.

6.0 Acknowledgements

The Author wishes to express his sincere gratitude to the following;

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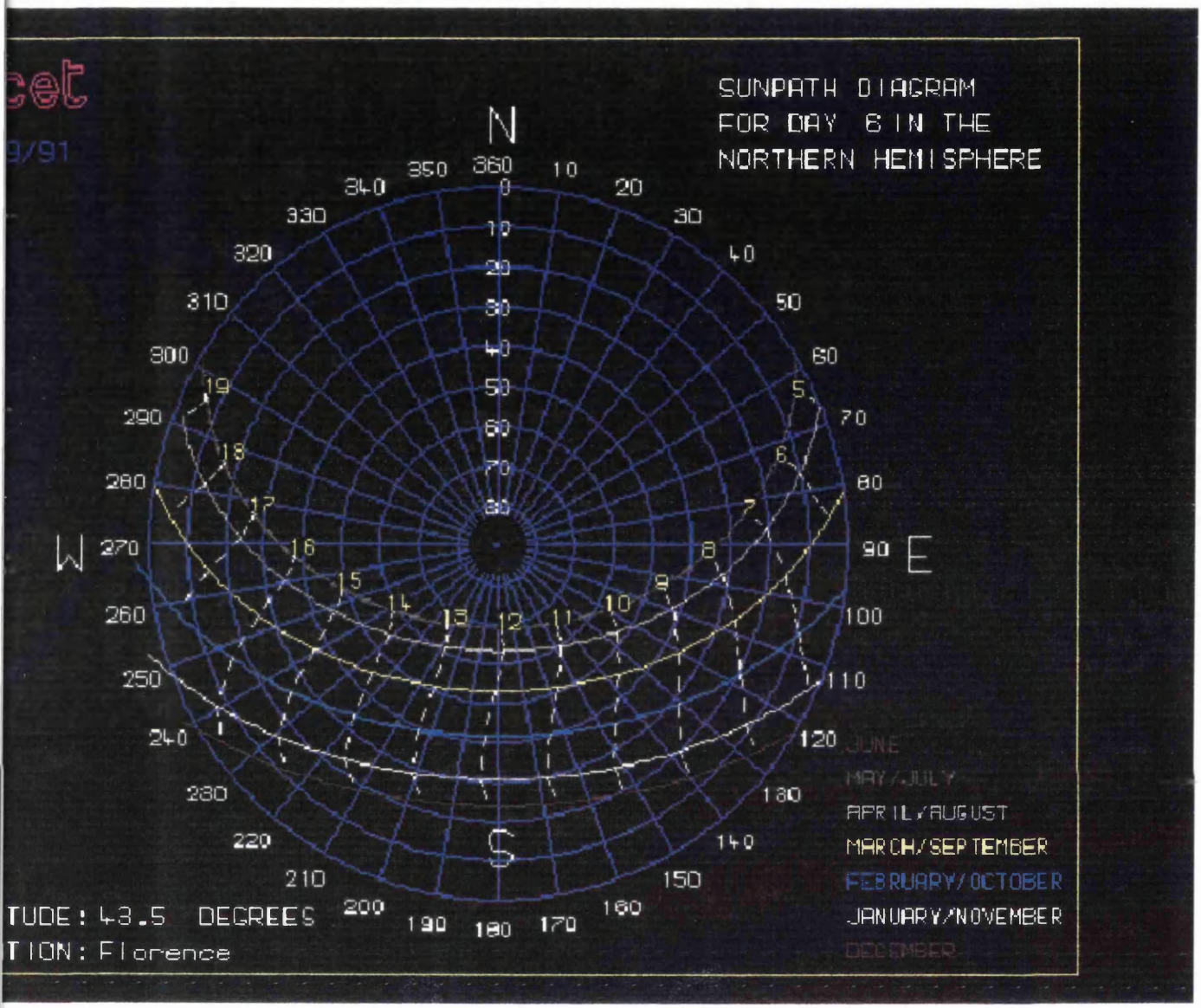
APPENDIX 1

Extract from 'Designed Appearance Lighting' by J. Waldram

APPENDIX 2

Solar Data for Florence


SUNPATH DIAGRAM
FOR DAY 6 IN THE
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MAY/JULY
APRIL/AUGUST
MARCH/SEPTEMBER
FEBRUARY/OCTOBER
JANUARY/NOVEMBER
DECEMBER
TUDE: 43.5 DEGREES
TION: Florence

LOCATION: Florence in the Northern hemisphere

Aug.	Jan. Sept.		Feb. Oct.		Mar. Nov.		Apr. Dec.		May		June		July		
Solar	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	AL
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7.00					5	102	15	95	23|	88|	26|	83|	25|	82|	2
1| 87	16	96	10	106	2	115		7.00						
8.00	3	126	7	120	15	113	25	106	33|	99|	37|	93|	36|	92|	3
2| 97	26	107	20	118	12	126	5	128	8.00						
9.00	12	137	16	131	24	126	35	119	44|	112|	48|	105|	47|	103|	4
3| 109	36	120	29	131	20	138	13	140	9.00						
10.00	18	150	23	145	32	140	44	135	53|	128|	58|	121|	57|	119|	5
2| 125	45	136	36	146	26	152	19	153	10.00						
11.00	22	164	28	160	38	157	50	155	60|	152|	66|	145|	65|	142|	6
0| 147	51	157	40	164	30	168	23	167	11.00						
12.00	24	179	31	176	41	176	53	179	63|	182|	69|	181|	69|	177|	6
3| 177	53	181	42	184	31	185	24	182	12.00						
13.00	23	194	30	193	40	196	51	203	60|	211|	66|	216|	66|	213|	6
1| 208	51	205	39	204	28	201	22	197	13.00						
14.00	19	208	26	209	35	213	45	223	52|	234|	57|	240|	58|	238|	5
4| 231	44	225	33	221	23	216	18	211	14.00						
15.00	13	221	20	223	28	229	36	239	43|	250|	47|	256|	48|	255|	4
5| 248	36	241	25	235	16	229	11	224	15.00						
16.00	5	232	12	235	19	242	26	253	32|	262|	37|	267|	38|	267|	3
4| 261	26	254	16	247	7	241	3	235	16.00						
17.00			2	246	9	253	16	264	21|	273|	26|	278|	27|	277|	2
3| 271	15	265	5	258					17.00						
18.00							5	274	11|	283|	15|	287|	16|	286|	1
3| 281	4	275							18.00						
19.00									|	|	5|	297|	6|	296|	
2| 291									19.00						
20.00									|	|	|	|	|	|	
|									20.00						
21.00									|	|	|	|	|	|	
|									21.00						
22.00									|	|	|	|	|	|	
|									22.00						
23.00									|	|	|	|	|	|	
|									23.00						
24.00									|	|	|	|	|	|	
|									24.00						
Solar	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	AL
T| AZM	ALT	AZM	ALT	AZM	ALT	AZM	ALT	AZM	Solar						
Time	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DE
G| DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	DEG	Time						