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APPENDICES

THE MOTIVATION

In 2010 the number of people entering the Vatican Museums that year was around 4 million, 8 hundred thousand and was destined to grow[1]. The restoration of Michelangelo's paintings, which was started in 1980 and continued for almost 15 years, had been an event of historic importance: a happy moment for Italian restoration, making a name for itself in the world, and a sensational critical 'case' which led to the manuals of the history of Art being re-written because, after centuries, the colours of the frescoes – those of the first Florentine manner, that of Andrea del Sarto, of Pontormo, of Rosso – were brought back to light.
The combination of the two names, 'Michelangelo and Sistine', reinforced by the excitement of the restoration and the clamour of the arguments which characterized it, continued to be an irresistible attraction for an ever-increasing number of visitors coming from all parts of the globe, heterogeneous in age and education, I believe, but combining, in the eyes of the conservators, an alarming profile: they constituted a potential source of risk for the safeguarding of the pictures.

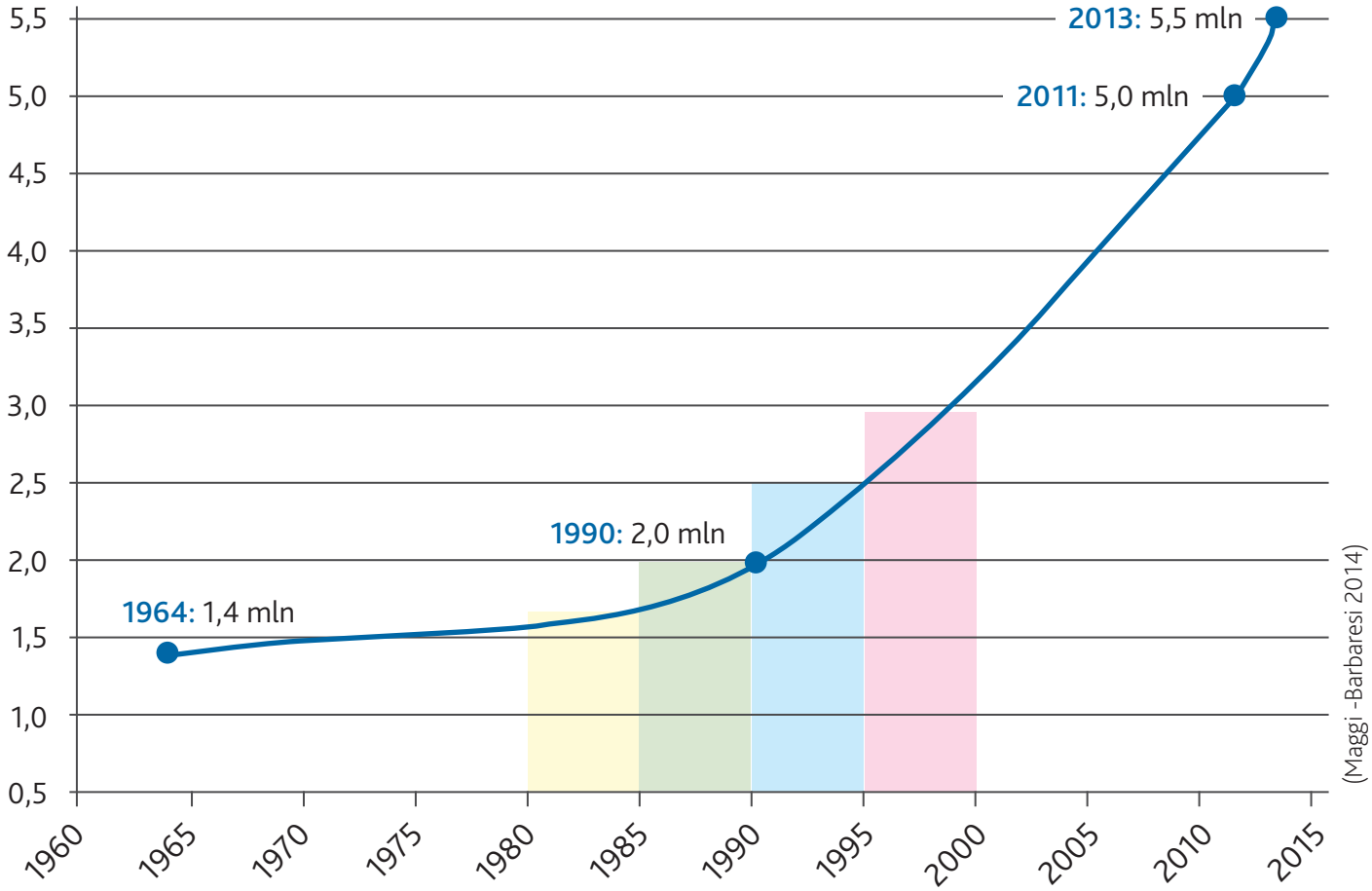
In 2010, on the threshold of the arrival of five million visitors annually, the recently established Direction of the Vatican Museums held it necessary to arrange a reconnaissance plan for the pictures and to give initiative to a series of careful checks. In particular, verification was sought as to whether or not the air treatment system, installed by Carrier in 1993, was still able to guarantee the maintenance of the environmental parameters set, in the face of the massively increased number of visitors.
At the time of the Colalucci-Mancinelli restoration the committee of experts preferred not to apply a layer of varnish to protect the newly-cleaned frescoes, entrusting their conservation to the effects of a controlled microclimate which rendered the air 'innocuous'. The choice was shown to be the right one: used elsewhere, protective varnishes have been found to deteriorate rapidly and the practice has fallen into disuse.
But in 2010, 16 years later, was the equation 'direct protection of the environment / indirect protection of the paintings' still valid? How many people were entering the Sistine Chapel every day? In the hours of the heaviest flows, were the crowds able to provoke enough environmental disturbance so as to trigger off the processes of degradation?

The first step was to organize a reconnaissance campaign and check all the painted surfaces.
In July 2010, restorers carried out integral dusting/brushing of the paintings, reviving an old usage of the Laboratory for the Restoration of Paintings of the Vatican Museums which during recent years had been relaxed because of new rules about safety at work which prohibited the use of moveable scaffolding and 'towers' over 16 m. high. Thus, during the nights of the summer of 2010, for the first time in its long history,

Left page: Photo Alessandro Bracchetti

1 In 2013 five and a half million visitors were recorded.

Calendar of restorations and consequent increase in the number of visitors*



(Maggi -Barbaresi 2014)

*The valuations are indicated in million

1980-1984:
Pontiffs and Lunettes

1985-1989:
Ceiling

1990-1994:
Last Judgement

1995-2000:
15th century artists, 'False curtains', Song Gallery, Marble Screen and marble (Pontifical) coat-of-arms

the Sistine Chapel saw the introduction of a 'spider platform': a mobile platform with a long, flexible arm which can rapidly be raised to up to 20 m. The photographs of restorers, intent on their work, suspended at that stellar height, went round the world. Worry and alarm provoked interviews with the Director of the Museums, Antonio Paolucci, in which he declared that inspections were being carried out, and that visits to the Sistine Chapel of an unlimited number of visitors, that is, without recourse to limiting the numbers of those allowed in, could continue only if it was certain that these numbers were not dangerous for the paintings.

In the meanwhile, without fuss, a strategy was outlined, the study set in motion, and the work continued.

The Vatican Museums and the Technical Services worked together in active collaboration. Carrier immediately declared itself available to start a study, draw up a project and donate, as it had done in 1993, an air treatment system in line with the most advanced technologies, which would treat and exchange the air and 'neutralize' every new risk. This was the birth of a collaboration at the highest professional level. Two years later, in 2012, came an analogous offer from Osram, promptly accepted, to study, draw up a project and then install a new lighting system using LED technology. The results, following opportune repeated simulations, were judged to be excellent.

Much time has passed since then. The work was undertaken with commitment and conviction in order to reach the set objectives, working also in the knowledge of having to intervene in a context which itself was deemed to be 'untouchable'.
With the arrival of two important anniversaries for the Sistine Chapel – the 450th anniversary of the death of Michelangelo, and the 20th anniversary of the conclusion of the restoration of the Michelangelo frescoes – the Vatican Museums is honouring its promise: organizing a grand international conference, open to all, in order to publicize the work carried out up till now. After an 'exemplary' restoration, the commitment for today and tomorrow is, and will continue to be, that of creating around these paintings, and in their service, a programme of constant checks and regular maintenance, to guarantee as far as possible their well-being in a carefully controlled environment, and their beauty in an efficiently illuminated context.

THE CONFERENCE

The Conference will take place over two working days, broken up into **five sessions.**

The first session will cover the recent history of the Sistine Chapel, beginning in 1980 with the restoration of the lunettes and the ceiling. By means of the memories and testimonies of those who were the main actors in the 'restoration of the century', the drama of that period and the atmosphere that accompanied the cleaning of the frescoes will be recreated. They will talk about the scientific work which accompanied all the phases of the restoration work, and the roles played by the *sponsors* who, with their economic support, made the whole thing possible.

The second session has the job of explaining the effects of the findings, the measurements, the environmental monitoring conducted in the Sistine Chapel, and the result of the complex diagnostic campaign. Thanks to the first session, it has been possible to reconstruct in a credible way the dynamics linked to the microclimate and establish the requirements of the new air treatment plant.
The results of the scientific tests carried out on the paintings will be made public. These tests were to determine whether or not the light, white inflorescences encountered in some areas could be considered initial phenomena of degradation, and to analyse them chemically. Interpretation of the mechanisms of formation will consider both the basic hypotheses and the specific correlations, given the Sistine Chapel environment.
The day-to-day maintenance plan followed since 2010 to safeguard the paintings and the entire Chapel will be explained in detail, together with its methodology and the results of work conducted by Vatican restorers in 2013 in collaboration with the scientific staff of the Museums. (See further pp. 15-18 and 19-28)

The third session is dedicated to the new air treatment system installed by Carrier. The project, the technical operations studied and later realized in order to guarantee effective control of the humidity, and the lowering of the pollutant levels during the peak crowded hours in the Chapel will be illustrated. The challenge taken up was that of planning to 'treat' a future volume of air that might well be three times greater with respect to that of the day. The innovative solutions will also be analysed from a thermodynamic point of view and rendered comprehensible even to non-experts by means of effective models, graphics and animated simulations.
Great attention will be paid to explaining little-known aspects, such as the structural calculations necessary in order to permit the installation, how the new apparatus was put into service, and even the precautions adopted to make possible the removal and correct disposal of the old system, whilst all the time giving the fullest respect to the Sistine Chapel building (from its decorated internal surfaces to its external walls); all the aspects, indeed, of 'opening a building site' within the Chapel which at first sight appeared to be a very complex problem. (See further pp. 29-31)

The fourth session concerns the new lighting system, carried out by Osram, the leader in a consortium of interdisciplinary studies supported at the European level.

The final project has accepted the limitations requested by the Museums' commission, made up of art historians, scientific experts and conservators who would have preferred more traditional profiles of illumination, to safeguard the sacredness and the dignity of the Chapel, the place where the Roman Pontiff is elected.
Some operations will illustrate the solutions adopted in order to attain this difficult objective: the realizing of a lighting system which is not too intense, but of the highest quality, capable of providing the best possible perception of the colours of the frescoes in their state of conservation and in their architectural space, and a unitary reading of a complex figurative text, crammed with signs and meanings. Others will underline the innovative technology of the system, a digital system which avails itself of the latest generation of LED, apparatus of extremely reduced dimensions, given particular optics, developed especially for the Sistine Chapel. (See further pp. 33-35)

The fifth and last session of the Conference will deal with the problem of mass tourism inevitably destined to increase in the near future. How can the anthropic pressure be resisted? How can the Sistine Chapel be saved from wear and tear whilst at the same time not turning away those who seek to enter this sanctuary of Christianity, to see the absolute masterpiece of Renaissance art? Is it ethical to deny what can be a most extraordinary experience? What alternatives are possible?

During the Conference there will be opportunity for discussion at the end of each session.

At the end of the first day conference attendees will be able to visit the Sistine Chapel and see for themselves the effects of the new air treatment and lighting systems.
On this occasion the Pauline Chapel will also remain open, Michelangelo's last work as a painter, and the subject of recent restoration.

STATE OF HEALTH OF THE FRESCOES

PREMISE

As the most authoritative manuals of chemical restoration report, the mural paintings are an integral part of the walls they cover. According to the technique and execution of the artist, the materials of which they are constituted become more or less stable aggregates over time.
Their condition also depends, to an extent that cannot be overlooked, on the thermodynamic 'exchanges' in which they are involved, that is, on the physical and chemical mechanisms which are established between the mural structure on which they are supported and the environmental conditions which surround them, and which in plaster favour at one moment the absorption of humidity and at the next its release.

For this reason, verifying the 'health' of the frescoes and painted surfaces of the Sistine Chapel required the study and control of the environment to which they are exposed.

THE ENVIRONMENTAL SITUATION
A STUDY OF THE MICROCLIMATIC CONDITIONS IN THE SISTINE CHAPEL

Since 2010 the Vatican Museums has put in place a strategy aimed at re-acquiring direct control of an understanding of the environmental conditions in the Sistine Chapel and activating improvements in the air treatment system in service since 1993, which, designed to 'treat' a maximum of 700 people present at one time, has had to work with ever increasing numbers.
To this end, the monitoring system in use was completely re-thought and a new **network of integrated monitoring** was installed, capable of recording environmental data continuously, 24/7. These figures were compared with the presence of visitors, monitored at various times by means of infra-red tele-cameras placed near the entrance and exit. In this way it was finally possible to prepare definite data about the number of people present at any one time in the Sistine Chapel and establish links and correlations with the microclimatic conditions registered.
A special Commission was set up, also open to external specialists, which, in a very short time, allowed the microclimatic and environmental conditions in force in the Sistine Chapel to be thoroughly described; the major risk factors identified; analyses of the critical aspects of the system provided; and a series of provisions proposed, subdivided into those which could be achieved in a very short time, and 'structural proposals'.
The Commission worked on this during 2011 and 2012, but already in the first six months of surveillance, using both extemporaneous and continuous monitoring, an important quantity of data was collected which was examined, discussed and gathered together in the paper, *Microclimatic conditions in the Sistine Chapel*, submitted to the *Direzione* of the Museums on 15 February 2012[2].

2 Results of the work of the Commission set up by the Director of the Vatican Museums (V. Cimino, P. Mandrioli, M. Matteini, U. Santamaria), Prot. 4037, 7A of 23 March 2012.

New reference sensor for T(°C) and RH(%)

Below is a list of the **principal measurements taken**:

Microclimatic parameters in the Chapel
Temperature, humidity relative to the air and surface temperatures recorded for the painted walls

External climatic parameters
Temperature and relative humidity recorded in the city of Rome

Number of visitors present at any one time
Total daily numbers present and numbers present at any one time at various times of day

Concentrations of carbon anhydride (CO2)
Measured at various heights and on the north and south walls

Concentrations and dimensions of atmospheric particles
Samples of dust, from up to 10 m high, and the concentration of particles contained by dimension

Circulation of the air
Measurements of direction and speed, taken at three different heights on two walls

Flows of air in the entrance and exit passages
Measurements of direction and speed

Flows of air through the ventilation grates in the floor
Measurements of direction and speed

Flows of visitors
People-counters in the three entrance and exit passages

Left page: The monitoring system used from December 2011 to January 2012

The environment control system installed in 1993 was designed to 'neutralize' the wide fluctuations of heat and humidity provoked by the crowds of pilgrims and tourists, to maintain an ambient temperature a little lower than that over the surface of the paintings, to avoid condensation of the humidity, and the migration of this within the porous structure and the activation of unwanted chemical reactions catalysed by pollutants in the air or in the dust. In order to do this, the air in the system was emitted after a series of treatment and purification.

With respect to what had been conjectured, the monitoring carried out showed some 'tranquillizing' and some critical aspects, which will be dealt with in depth in a specific session of this Conference.
Here the principal points are outlined.

Exclusion of any reaching of the dew point and formation of condensation on the walls

The air treatment system active in the complex was ensuring thermo-hygrometric levels (that is, temperature and relative humidity) which, when compared with the data for 'contact temperature' (temperature as measured directly on the surface of the paintings), were able to exclude any reaching of the *dew point* and consequent condensation of liquid water on the surfaces, a situation which potentially carries grave risk for the frescoes.
Even though there was a certain delay, the system was largely managing to counter-balance the variations produced by the impressive number of visitors (as much as 1500-1800 people present at the same time, with an average daily flow of around 18,000, and with peaks of 24,000 and over).

Insufficient replacement of air and persistence of high levels of carbon anhydride

Measurements and theoretical calculations demonstrated that part of the air emitted was not being expelled sufficiently rapidly and was stagnating in the Chapel. This was confirmed by the monitoring of the concentrations of carbon anhydride, a natural and unequivocal *marker* correlated to the presence of visitors, which showed very high levels during the hours with the heaviest number of visitors.

Circulation of the air and the speed of flow over the walls

The type of circulation that was verified, with formations of ascending and descending air currents, favoured a uniform distribution, without stratification of interest, of temperature, relative humidity and carbon anhydride produced by the respiration and transpiration of the visitors, right up to the highest levels near to the ceiling.
The speed of the currents along the walls, however, were found to be too high, influencing the equilibrium of the crystallization of soluble salts, and transport and deposit of dust.

High concentrations of dust suspended in the air, circulation and deposition

The circulatory system of the air was contributing to the continuing suspension of particles brought in or produced by visitors and to their later deposition on the surfaces of the frescoes. Apart from the aesthetic damage, this is a condition of risk for the conservation of the frescoes because the dust contains potentially harmful chemical and biological agents.

Scale model showing the position of the sensors which the control network in the Museums uses today

10 T sensors T (°C) and RH (%)

2 T surface sensors (°C)

2 CO2 sensors (ppm)

6 Anemometers on the upper windows of the south side

3 Infrared beam people counters

3 Anemometers at the openings (entrances/exits)

Wanting to eliminate the hypothesis that the problem should be solved by drastically reducing the number of visitors admitted, and considering the limits imposed by the architecture and the paintings, intervening in the Sistine-system posed a difficult challenge. Notwithstanding this, or, precisely because of it, analyses of the data from the 'integrated' monitoring, which, obviously, was continuing, gave rise to many proposals.
The conclusions elaborated under the form of 'guidelines' were submitted to the technical team, made up of representatives from the Museums, the Technical Services, and Carrier, and were largely accepted.
The arguments will be dealt with in depth over both days of the Conference.

THE CLINICAL SITUATION
Scientific investigations on the frescoes of the Sistine Chapel

In May 2010, during checks of the state of the false curtains painted on the south wall below the *Moses* cycle, certain zones affected by 'whitening' were noted.
In July the Vatican restorers intervened with a first campaign of dusting and a com-

plete overview of the paintings, while the scientific staff carried out a series of analyses and diagnostic investigations on the surfaces. These would be repeated in January-February 2013 and, later, during works of the Commission purposely set up by the Direction of the Vatican Museums, which had worked alongside from March to December 2013, the date of the submission of the paper entitled *Scientific investigations on the frescoes of the Sistine Chapel*[3].

From the acquisition of samples – mainly carried out on the fifteenth century painting, but not solely – much useful data were derived which gave direction to the complex study and an understanding of the chemical and physical mechanisms which had generated the alterations.
There have been, in the course of the work, integration of measurements and controls entrusted to experts in the most advanced scientific technologies, specific experiments, joint on-site sessions, archival research, and discussions with restorers who had worked in the past on the restoration of the paintings in the Sistine Chapel.

The investigations, carried out using different analytical techniques and exchanging of results, were not limited just to the study of the composition of the so-called 'whitening' or 'inflorescences', but trial tests had also been extended to the water-soluble components present in the plaster close to the surfaces.
During the Conference the protocols for the investigations and the interventions adopted will be illustrated, including the 'pilot intervention' carried out in a 'sample' area, the later **investigations** and the **controls** using **imaging techniques**.

The restoration work on the *Vocation of the Apostles* by Ghirlandaio, conducted in strict collaboration between the Painting Restoration Laboratory and the Diagnostic Laboratory of the Vatican Museums during the months of August and September 2013, has permitted a rapid removal of the various alterations that were causing aesthetic and potentially long-lasting damage, verifying the efficiency of reversible methods which are not too invasive.
This work was later extended to all the fifteenth-century scenes and was happily concluded in December 2013.

Besides defining the specifics of the whitening, obtained through analytical examination, and the search for the possible mechanisms of formation, the Commission also considered aspects of interaction with the microclimate and formulated some recommendations with a view to preventing future conditions favourable to the re-forming of white patches.

In the second session of the Conference the more strictly chemical part of the study will be discussed: the methods used and the results which emerged from the **analysis campaign** of the whitening, in particular the analyses conducted on the water extracted from the white material and the discovery, among the soluble salts, of a prevalence of **calcium bicarbonate.**

The **study of the phenomenon of whitening** and the conditions which cause the crystallization of such salts on painted walls will be discussed in the light of the specific case of the Sistine Chapel.

3 Results of the work of the Commission set up by the Director of the Vatican Museums (V. Cimino, P. Mandrioli, M. Matteini, U. Santamaria), Prot. 374, 7A of 10 January 2014.

The non-invasive techniques used to measure the water content sometimes present at different depths in the plaster support beneath the surface paintings will be illustrated, with the reconstruction of a distribution map which is useful for establishing eventual correlations with areas of white inflorescence.

CONSERVATION HISTORY AND LINKS BETWEEN WATER INFILTRATION AND WHITE INFLORESCENCE

As has been authoritatively reconstructed, the Sistine Chapel frescoes suffered damage very early on due to both subsidence and the infiltration of rainwater. Paolo Giovio, writing to Vasari in 1547, described the "chapel of Michelangelo, which is being eaten away by potassium nitrate and cracks"[4].

Systematic evidence for the poor state of conservation of the painting appears until the beginning of the 1700s in documents which describe the condition of the ceiling, the *Last Judgement* and the work of the artists of the 1400s as affected by problems of dust, humidity and whitening. The roof of the Chapel, poorly sealed, and the four descending perimeters often obstructed, allowed rainwater to pass through the flanking stones of the ceiling, where it meets the lunettes, and spread until it reached the surfaces of the frescoes. This situation was remedied only in 1975 when the roof and the sentry walk were resealed.

Since 1980, during the cleaning of the lunettes and the vaults, below the layers of adulterated glue earlier salification has resulted in white spots which scientific analysis has identified as patinas of sulphates, silicates and carbonates.

Old restoration documents also exist for the scenes painted by the artists of the 1400s which testify to the presence of salification which, according to the restorers' notes, was due to repeated infiltration of water coming through windows left open, or not properly closed, and arrived on the cornice and from there spread onto the murals below. Once again, the whitish spots were found to be sulphates, silicates and carbonates.

During the restorations concluded in 1999, the white areas were dissolved and removed in the cleaning operations.

CLASSIC CARBONATE FORMATION PROCESSES AND RESEARCH HYPOTHESES

The phenomenon of salification of carbonates is something which can be verified when persistent erosion by water leads to the plaster becoming saturated. If the contact with water is prolonged, the calcium carbonate, although highly insoluble, can begin to dissolve.

This leads to the formation of small quantities of calcium bicarbonate, which travel to the surface and are precipitated there, creating visible white patches. Most of it, however, doesn't reach the surface and is re-precipitated within the plaster itself, remaining invisible. This process, slowly and gradually results in the formation of very fine calcium carbonate crystals, subdivided, and with a high surface specifity, which can be further dissolved by future events of a different nature. Besides calcium carbonate, the whitish patinas often contain other soluble salts, such as chlorates, sulphates, etc.

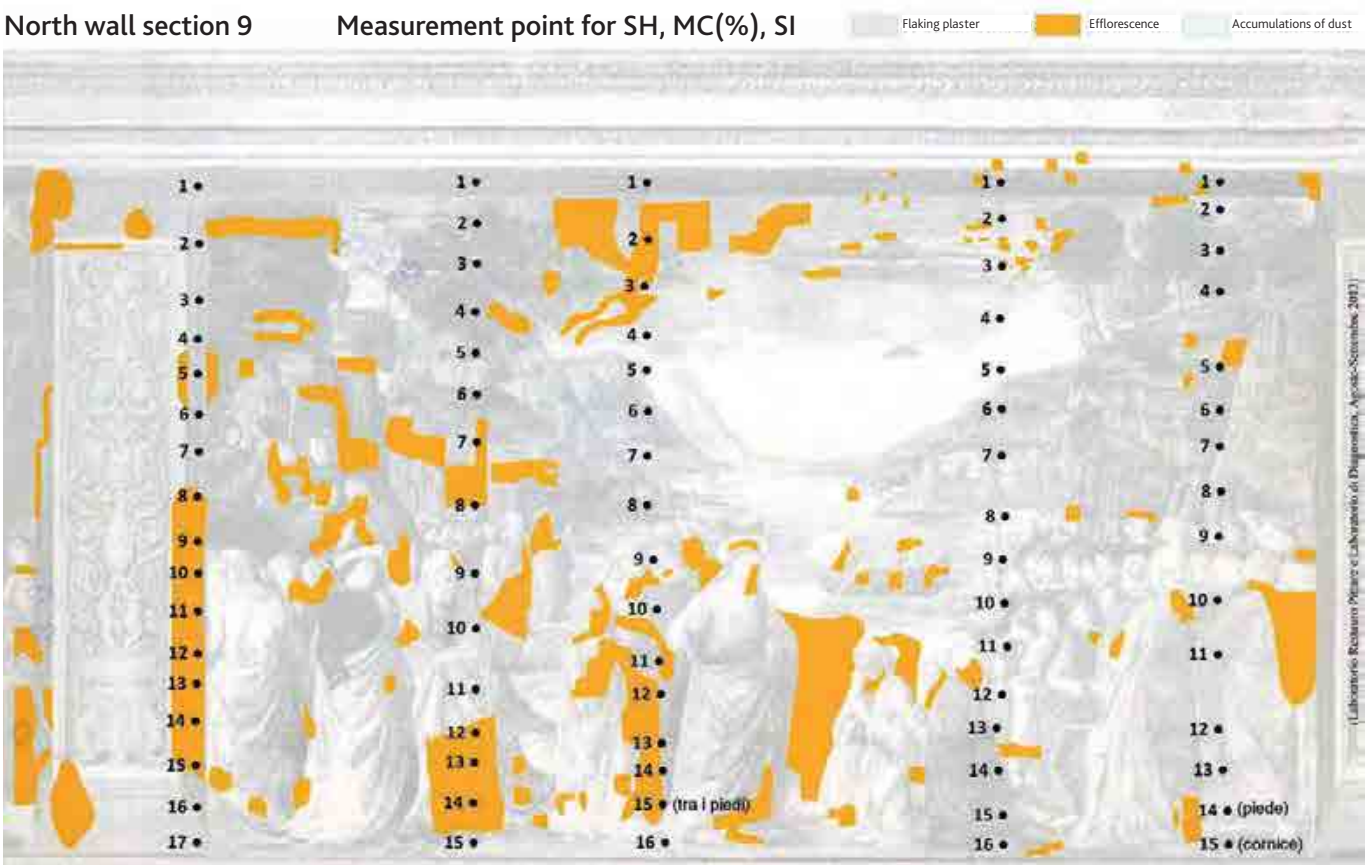
'RECENT' WHITENING: NEW CONJECTURES

The high concentration of CO2 present in the Sistine Chapel environment, combined with a certain quantity of water, most probably localized in layers within the plaster by phenomena of adsorption, not yet fully confirmed – partly because of the impossibility of carrying out investigations which would damage the painted plaster – would favour the formation of soluble calcium bicarbonate. The process would happen even

Left page: Photo Claudio Guaitoli

4 Archivio di Stato di Arezzo, Archivio Vasari, 10 (XLIV), cc18, 23.

Scene showing *The Calling of the Apostles*, the 'pilot' project for the 2013 work



Map showing the points of investigation where measurements of sub-surface humidity were taken

Restorers at work during the operation to extract the salts in 2013

more easily in the presence of very fine crystalline formations of earlier origin.
Later, in conditions favourable to drying, the calcium bicarbonate would travel through the surface giving place, in a relatively short space of time, to new patinas with a whitish aspect.

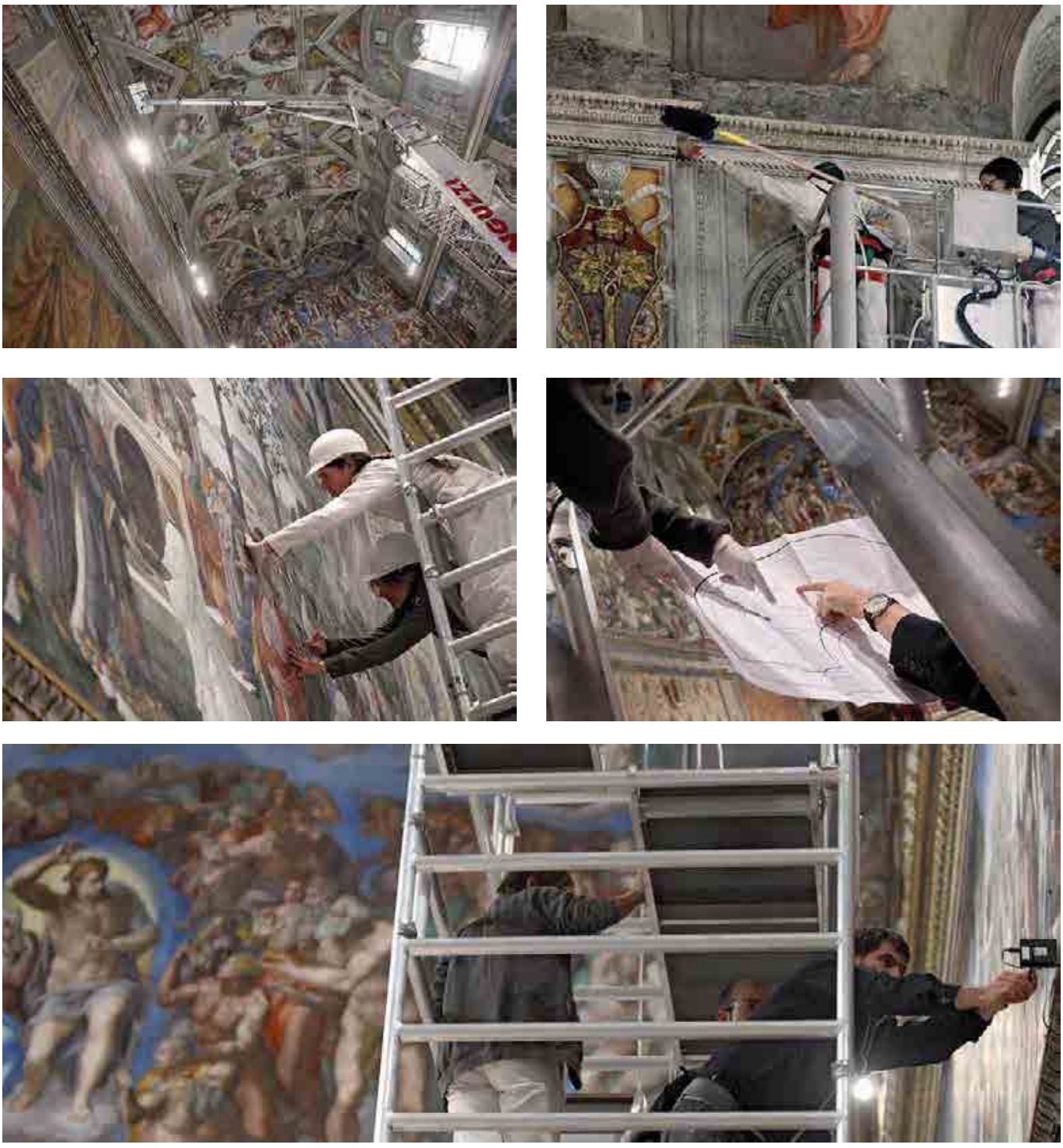
Other contributory causes

The speed of formation can be explained by the vertical currents of air whose routes are found close to the surface of the paintings. In fact, fast and turbulent air flows can contribute to the spreading of a quantity of CO2 over the porous structure of the paintings which is capable of giving rise, within that structure, to the phenomenon described. However, whatever the actual genesis of the whitening, one certain contributory cause is undoubtedly the high concentrations of CO2 present in the Sistine Chapel, produced by the enormous number of visitors and consequent upon insufficient recycling and treatment of the air.

Recommendations

In order to guarantee a correct conservation of the paintings, a significant lowering of the levels of CO2 was essential, and this needed to be pursued at the same time as a rigorous control of the humidity in the air. The speed and the directions of the flows of air over the walls had to be reduced in such a way as the phenomenon of turbulence and excessive movement of dust in proximity to the surfaces of the frescoes was avoided. This had to be guaranteed by the specifications of the new system for conditioning, dehumidifying and purifying the air.

Happily, thanks to the operation which saw the removal of modest veils of carbon deposits carried out in 2013, a correct aesthetic and conservation perception of the fifteenth-century paintings has been reacquired. To guarantee the future, a coordinated, programmed and convergent execution of levels of maintenance, preventive conservation, and control and monitoring of the painted surfaces had to be put in place.



Restorers and technicians at work during maintenance operations (photo: Claudio Guaitoli)

PLANS FOR MAINTENANCE AND CONTROL

Since the summer of 2010, the *Direction of Vatican Museums* has put in place a **global plan for the maintenance of the Sistine Chapel** which consists of a series of repeated and programmed operations, conducted with a view to **preventing and controlling effectively** the mechanisms which might possible lead to degradation of the painting.

These operations include:

- practicalities of cleaning the Chapel;
- control of environmental conditions within the Chapel;
- control of the efficiency of the air treatment system in use;
- control of the paintings;
- management of the visitor flows.

Practicalities of cleaning the Chapel

Daily cleaning of the floor has been introduced, in order to improve the hygienic conditions and to remove larger particles of dust, deposited on the ground during the night which, with the arrival of the visitors, would then be disturbed back into the air. This is carried out early in the morning with a machine which both washes and dries, fitted with soft brushes, so as to avoid damaging the marble of the floor (Frequency: daily).
Cleaning of the internal ventilation grills in the floor (Frequency: periodical).
The work is carried out by the **Cleaning firm** accredited to the Museums, co-ordinated by the **Contracting Service.**

Control of environmental conditions within the Chapel

By means of a network of sensors installed at various heights, internal ambient factors – temperature, relative humidity, surface temperature of the paintings, concentrations of CO2 – are continually monitored and compared with external readings.
At the same time the range, speed and direction of the air flow treated by the air treatment system as it enters and leaves the Chapel are monitored. Finally the number of visitors entering and leaving the area is counted (Continuous monitoring, 24h).
Development, graphic elaboration and filing of data, comparisons (Periodical delivery). In the hands of the **Conservator's Office**.

Control of the efficiency of the air treatment system in use

Verification of the working state of the various sections of the system and of the sensors is entrusted to the **Technical Services for the Governorate**[5].

Control of the paintings

The practice of regular 'dusting' of the paintings was re-introduced, carried out at the

5 And for a certain number of years, also to Carrier, according to new protocols for collaboration. Furthermore, in support of the monitoring of the Museums, Carrier guarantees to share the data registered by the sensors which govern the system.

same time as control and graphic recording of states of conservation. This work is carried out annually by the **Laboratory for the Restoration of Paintings**.
The **Diagnostic Laboratory** analyses the dust and diagnostic controls with a wide use of imaging techniques. Both laboratories are involved wherever extraordinary maintenance is required.

Management of the flow of visitors

The squad of **Custodians** has been re-organized and reinforced.
There are now always six carefully selected custodians working at the same time on each shift. Connected with the **Control Room,** which monitors the flow of visitors in the entrance hall and in the galleries, the custodians have the task of controlling each area and ensuring a regular flow of visitors, and impeding groups from staying in one place for any length of time.
A further presence is that of a **Priest** who invites visitors to maintain a behaviour consonant with the dignity of the sacred place.

PROJECT FOR AIR CONDITIONING AND PURIFICATION SYSTEM

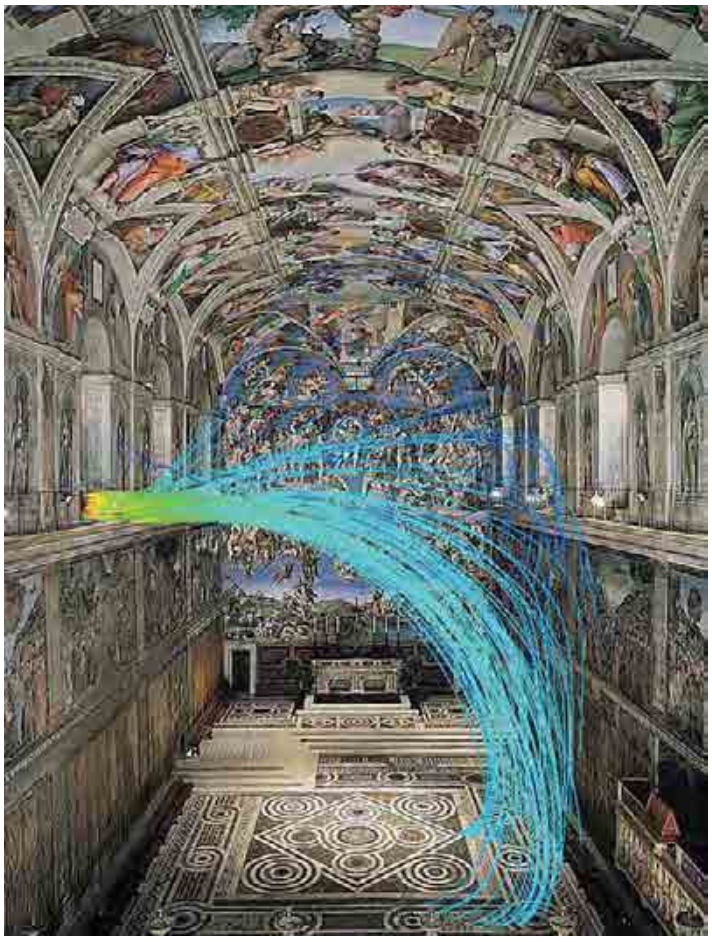
In June 2013, after about two years of preparation, the study for a new air treatment system, the 'HVAC Project' was approved. The Carrier team, part of the UTC group, led by a cosmopolitan engineer, in continually movement between Europe and the USA and made up of an efficient research and development group based in Milan, Lyon, and Syracuse, had managed to work out a technical proposal which would satisfy the many requests of the Vatican Museums.
The new air treatment system in the Sistine Chapel must guarantee a congruous and stable maintenance of the levels of air temperature, temperature on the surfaces of the frescoes, relative humidity, and concentrations of CO2 and fine dust, also in conditions of maximum flow of visitors (estimated, rounded up, at around 2000 people present at any one time).
The system must on no account present risks for the state of the paintings, nor require building work that would be invasive or potentially dangerous for the floors, walls, doors or windows.
These are the parameters required:

- An increase in the amount of air treated and emitted into the ambient space, but with a speed not to exceed 0,5 m/s over the surfaces of the frescoes;
- An ambient temperature (dry bulb) between 20 and 25°C (winter and summer);
- Relative humidity between 50% and 60% (55 ±5) and no higher. Guarantee of the effectiveness of the dehumidification treatment both when external humidity levels are high, and when internal levels rise because of an influx of visitors;
- CO2 concentrations below 800 ppm;
- Dust concentrations (PM 2,5) below 0,1µg/m^3;
- Low noise levels in the system itself.

During the Conference the technical details, and the theoretical studies which preceded them and rendered them possible, will be illustrated. These will include the calculation of an isothermal fluid dynamics model of the Chapel under the old system, projections and simulations of the changes which the modifications would bring, the laboratory experiments with the new technological solutions, including the **diffuser apparatus**, made expressly for the Chapel, capable of containing the speed of the increased airflow below the required limit of 0,5 m a second.
The project provides for a transformation from a system which used **external air**, with the stale air being expelled through the doors or the ventilation grills present in the floor, to one with a **filtration and partial re-circulation system**, with the possibility of a regulated increase in the capacity of the air flow.
While the old system was distributed with six openings for the emission of treated air placed in correspondence with the six windows in the south side wall, the new system uses two independent air treatment units (ATU), each using four emission and two return openings. The diffusion apparatus will be supported below these.
The possibility of exploiting **ways of filtering and re-releasing air**, according to es-


Piccali
ZSS

tablished calculations, and a new modification of the geometry of the release flow, produces a perceptible increase in the potential exchange of air, and a consequent lowering of CO2 and solid particle levels, which the project data promises will be reduced by half from those in the past.
In order to avoid dangerous stress on the walls from skimming air flows which 'dry' the painted surfaces, the system will work at full capacity only when absolutely necessary and, thus, only in conditions of maximum flow of people – counted and monitored by the appropriate appliances – and for a set time.
A **regulatory control system** using various types of sensors governs the efficiency and functioning of the system, including the various speeds.
In order to increase the efficiency of the expulsion of air, **special ventilation slits** have been installed on the north wall of the Chapel, opposite those which emit filtered air, and these begin to function whenever there are significant increases in air pressure within the Chapel.



Fluid-dynamic model of air flow

Left page: Phases in preparation of the site (photo: Biagio Tamarazzo)

Technical trials of illuminations at various colour temperatures (°K)

LIGHTING PROJECT

LED4Art is the name of the new lighting project for the Sistine Chapel and it is the fruit of a close collaboration between the Vatican Museums and Osram, the leader of a work group brought together specifically for this project, promoted by the European Community.
To better apply the potentiality of the new LED technology, the project was confronted at several levels: thus, the University of Pannonia, in Hungary, carried out studies on colour, the *Institut de Recerca en Energia de Catalunya*, in Spain, the research into energy saving, the *Fabertechnica* studio in Italy worked out the technical project for the illumination, and *Osram*, in Germany and in Italy, the development of the technologies and the production of new apparatus.

The Technical Services for the Governorate also took part in the project, taking care of aspects of the installation, the construction site and security, and the Vatican Museums which, assuming the artistic direction of the work, made available a committee made up of art historians, scientific experts and conservators, who traced the general principles of the new illumination, verified the congruity of the technical proposals and undertook a series of scientific tests and checks in their own laboratories.

In this way a stimulating dialogue was born between professionals from very different backgrounds, but sharing a common objective: to give the Sistine Chapel a lighting system of the highest quality, with innovative characteristics obtained from the technical application of the most advanced scientific studies in the sector, with respect for the strictest conservation requirements.

One talks about 'Technology in the service of art'. In the case of the Sistine Chapel this must be actually effected by a uniform illumination of high 'chromatic fidelity', but not too intense, capable of bringing out the colours of the paintings, without making them spectacular, but also capable of evoking a unitary reading of the whole cycle without any particular thing being specifically highlighted.

The project provides for the use of around 40 specially designed lighting strips, with a total of more than 7000 LED, installed on the cornices which run along the long sides of the Chapel (north and south walls) at a height of about 12 metres, which manage to recreate a **natural light effect** as if coming from the windows.
Thanks to very careful work integrating the mechanical and electronic components it has been possible to make small apparatus, which are quite invisible from the body of the Chapel.
The requirement for a **uniform illumination** was met by means of fine-tuning special optics, while reasoned photometric distribution profiles have allowed the ceiling, the walls with their frescoes from the 1400s and the wall with the *Last Judgement*, to be illuminated without any lighting or other interference on their surfaces, and without causing problems of dazzling for the visitors.

The guiding criterion that the **lighting throughout the Chapel must be uniform,** avoiding making distinctions between the paintings of Michelangelo and those of the

artists of the 1400s, or between the *Last Judgement* and the ceiling, led to the adoption of just two **lighting schemes**:
• *standard*, or *museum standard*, with an evenly diffused illumination over the walls and the ceiling, dedicated to the normal visitors to the Sistine Chapel;
• *gala lighting*, reserved for **religious functions**. On these occasions the first system will be integrated with a series of lights designed to increase the illumination in the body of the Chapel.

The *gala lighting* will be used in the case of particular events. Special moving apparatus which has been installed on the upper cornice, at the base of the pilasters, will be brought into use.
Powered from behind and controlled by a microprocessor, the system, once activated moves lights into position for the required length of time, returning after use to their rest positions, below the plane of visibility. Much attention has been paid here also to reducing dazzle.
Considerable trouble was also taken in the Sistine Chapel to avoid the effect of excessively 'cold' light, something frequently encountered with LED lighting. The lighting will recreate, as far as possible, the conditions of natural light filtering through the coloured glass of the windows, much as it had done in the era of the painting.

The new developed technology and the possibility of selecting and 'mixing' different monochromatic LED has made it possible to obtain sources of light at variable emissions.
Regulation of the system was carried out directly on site during the trial sessions of the examining commision and optimised wit the data obtained from the spectral study of the pigments.
The final effect has turned out to be completely satisfactory in terms of both the intensity and the quality of the light.
Thanks to the choice of monochromatic LED, in the on-site test sessions and during the patient evaluation of the best configurations, it has been possible to identify satisfactory levels of illumination, intensity, and colour temperature.
The spectral composition adopted allows the complete elimination of infrared and ultra-violet rays, control of the blue spectrum and to mantain and overall equalized spectrum, so as to show all colours to advantage.
The positive results obtained are duplicate: a softer and warmer light effect, cleansed of energy components potentially harmful for the particularly delicate painting materials, such as lacquers and materials used in restoration. The Commission also wanted to take into account recent alarms appearing in specialised journals concerning the presumed discolouring of some van Gogh's paintings, after they had been lit with LEDs, containing stronger light emissions.

There are many other interesting aspects of the new lighting design which will be dealt with during the course of the Conference. Among these will be:
• the studies about the phisical state of the colour and measurements of their spectral reflection of numerous pigments in conditions of natural and artificial light;
• chimical control test of the spectral compositions of the new especially on the colorants;
• the reduction of energy consumption, thanks to the efficiency of using LED and the integration of the control and plant management systems. The drastic reduction in wasted energy has been estimated to savings of around 60%;

• complete conformity of the new plant with Italian norms (DM, 10 Maggio 2001; UNI 10829) as regards maximum levels of illumination, levels of ultra-violet radiation and doses of maximum light annually. Adopting, in fact, a medium level of illumination in the interval between 40 and 80 lux, with a maximum limit of 100 lux and considering the predicted data and the Chapel's profile of use, the new lighting system develops a dose of annual maximum light of 374,400 (lux.h/anno), well below the figure contained in the Norm, which corresponds to 500,000 (lux.h/anno).

THE VIRTUAL VISIT

To understand the Sistine Chapel in its iconographic and iconological complexity, with the great number of artists and styles involved, is an arduous commitment. To help the public to understand is the primary ethic of a great museum.
For this reason the Vatican Museums are working on a multi-language educational service which will prepare visitors at the entrance and for the visit to the Sistine Chapel. A suitable environment will be arranged, provided with the latest video and digital tools in order to offer tourists the necessary information before their visit.

APPENDICES

THE SISTINE CHAPEL. A FEW FIGURES AND DATES

THE FABRIC

External space: length 43,90 m., width 17,80 m.
Internal space: length 40,23 m., width 13,41 m., height at the apex of the ceiling 20,70 m. When the two floors below and the floor above are included, the total height is ca. 38 m.
Surface covered: 780 sq. m., net 540 sq. m.
Total volume 30.000 m^3. of which 10.400 are di solid walls.
Lateral walls: average thickness 2,30 m.
Windows in the north and south walls: 6 each side measuring ca. 1,60 x 4,20 m.
Ceiling: thickness at the key 80 cm.
Weight of the building: ca. 20.000 tonnes; with foundations, 30.000 tonnes
Average weight distribution on the ground: 3,8 kg/cm^2.

INTERIOR. DECORATED SURFACES

Lunettes ca. 200 sq. m.

Popes ca. 264 sq. m.

Ceiling ca. 750 sq. m.

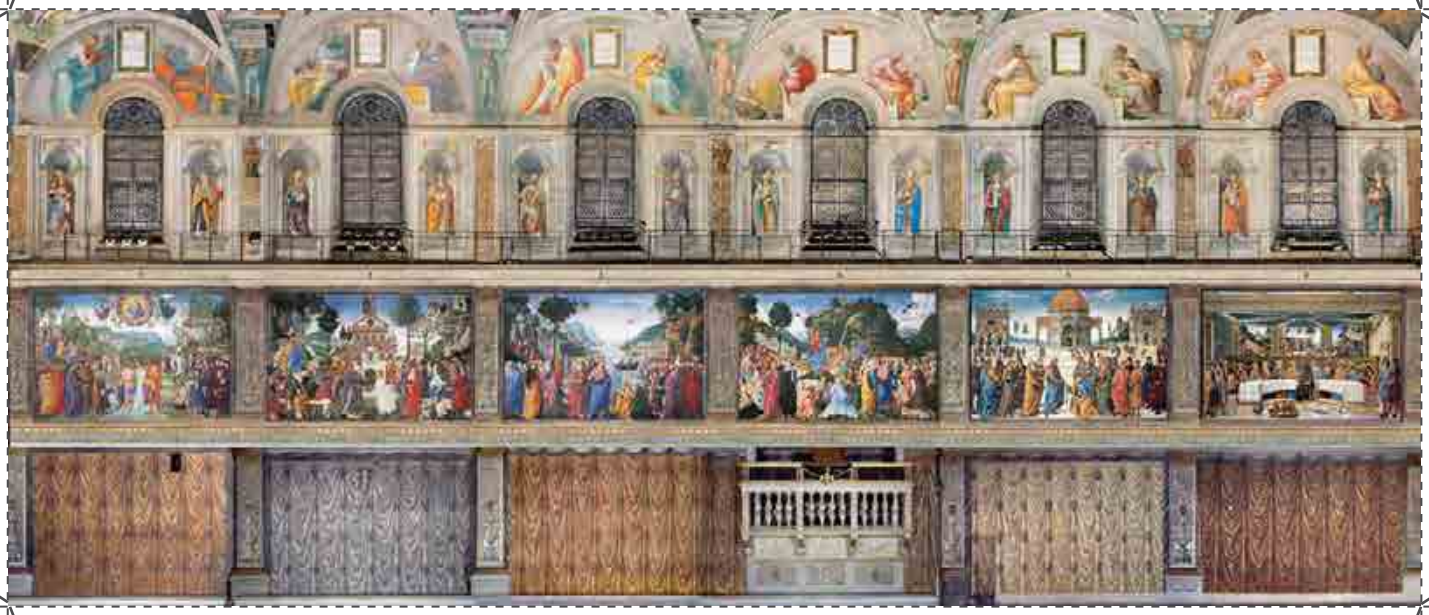
Judgement: ca. 180 sq. m.
The entire surface measures 16 x 13 m. and contain 366 figures, executed in 452 *giornate**.

Paintings from the 1400s: ca. 400 sq. m. with 14 scenes, 6 on each long side, 2 on the counter-facade.
Each picture measures ca. 5,5 x 3,5 m.

False curtains below: ca. 450 sq. m. in total.

Total interior surface (including doors, windows and marble cornices): ca. 2500 sq. m.
Total painted interior surface: ca. 2250 sq. m.

**Giornata*: the 'daily' portion of fresh plasters, decided by the artist, to be painted with colour dissolved in water.



1277-2014
SEVEN CENTURIES OF ACTIVITY IN THE SISTINE CHAPEL

1277

The *Palatium Novum* (the south and east wings of the Cortile del Pappagallo) was built during the pontificate of Nicholas III (1277-1280). At that time it possibly did not include the *Cappella Magna* which existed before the Sistine Chapel.

1278

The *Cappella Magna* or *Cappella Palatina* was possibly founded under the pontificate of Urban V (1362-1370).

1477-1480

Sixtus IV (1471-1484) commissioned the re-building of the *Cappella Magna*. The name Sistine Chapel derives from this initiative.

1480

Pier Matteo d'Amelia painted a starlit sky on the ceiling.

1481

27 October: Cosimo Rosselli, Botticelli, Ghirlandaio and Perugino are contracted to paint ten frescoes in the Chapel.
Work in marble carried out: the Papal coat-of-arms above the entrance, the marble screen and the singing gallery.

1483

9 August: Sixtus IV celebrates the anniversary of his election to the Papacy with a solemn High Mass in the Chapel;
15 August: the Chapel is inaugurated on the Feast of the Assumption.

1484-1492

During the pontificate of Innocent VIII the sacristy and the east end of the Chapel were restructured and decorated.
The decoration was completed under Alexander VI (1492-1503).

1504

June: the Chapel shows the first signs of instability.

1506

10 June: Pietro Rosselli, in a letter to Michelangelo, informs him that Julius II (1503-1513) wants Michelangelo to undertake the new decoration of the ceiling.

1508

10 May: contract and first payment of 700 gold ducats to Michelangelo for work in the Sistine Chapel. The scaffolding is erected and the work begins.

1510

August: Michelangelo finishes the fresco decoration of the first half the vault (from the entrance wall up to the *Creation of Eve*).

1512

31 OCTOBER: Michelangelo completes the decoration of the second half of the vault.

1 NOVEMBER: "(The vault was) uncovered on the morning of All Saints when the Pope entered the Chapel to say Mass to the great satisfaction and rejoicing of all" (Vasari).

1515

Leo X (1513-1521) commissions Raphael to prepare the cartoons for the tapestries to be hung in the Sistine Chapel.

1519

After two years in the workshop of Pieter van Aelst in Brussels, the tapestries are finished: they will be hung in the Sistine Chapel on 26 December 1519.

1522

25 December: the lintel above the entrance of the Chapel from the *Sala Regia* collapses, killing two Swiss Guards of Hadrian VI (1522-1523). The two frescoes above the entrance, by Domenico Ghirlandaio and Luca Signorelli, were so badly damaged that later they had to be completely remade by Matteo da Lecce and Hendrick van den Broeck.

1533

Clement VII (1523-1534) gives Michelangelo the task of painting the *Last Judgement* on the wall behind the altar.
This involves the destruction of the existing fifteenth century frescoes and the earlier Michelangelo frescoes in the two lunettes.

1535

16 June: after Paul III (1534-1549) confirmed the commission, Michelangelo began to build the scaffolding for executing the fresco.

1 NOVEMBER: Michelangelo was appointed "Supreme architect, sculptor and painter of our Apostolic Palace" with an annual stipend of one thousand two hundred ducats.

1536

In the late Spring Michelangelo begins to paint the *Last Judgement* on the altar wall.

1540

15 December: the scaffolding is lowered and the upper part of the fresco revealed.

1541

31 OCTOBER: Michelangelo finishes his work, which is subject to both admiration and scandal.
Paul III celebrates Vespers in front of the newly revealed *Last Judgement*.

1564

21 January: the Council of Trent condemns the paintings of Michelangelo in the Chapel.

1565

Daniele da Volterra carries out the first work of painting draperies on the nude figures in the *Last Judgement*.

1566-1585

Pontificates of Pius V (1566-1572) and Gregory XIII (1572-1582). Construction of external buttresses due to the precarious state into which the structure of the walls and foundations of the Chapel had fallen.
Domenico Carnevali restores the *Judgement* and the ceiling. Matteo da Lecce and Hendrick van den Broeck repaint the frescoes on the entrance wall.

1625

Under the pontificate of Urban VIII (1623-1644) Simone Lagi cleans the walls with the *Stories of Moses and Christ*.

1710-1712

Under the pontificate of Clement XI (1700-1721) Annibale Mazzuoli carries out a restoration of all the frescoes in the Chapel, with the probable exception of the *Last Judgement*.

1762

Probable restoration and covering of some nude figures in the *Last Judgement* and the ceiling by Stefano Pozzi, as referred to by Richard in 1766 (*Description historique et critique de l'Italie*, V, pag. 358).

1797

A gunpowder explosion in Castel Sant'Angelo causes a portion of the *Ignudo* on the left of the Delphic Sibyl to fall, together with a fragment of the *Flood* from the ceiling.

1825

Vincenzo Camuccini attempts unsuccessfully to clean the *Last Judgement*: the *Accademia di San Luca* prevents the continuation of the work.

1903

Under the Pontificate of Pius X (1903-1914) a consolidation of the ceiling and the *Last Judgement* begins, carried out by Cingolani and Cecconi-Principi, under the direction of Ludovico Seitz. This work was not completed until the following year.

1920-1922

Consolidation work on the ceiling by Biagetti.

1930-1936

New consolidation work on the ceiling. This time the Director of the *Laboratorio di Restauro*, Biagio Biagetti noted in his report the presence of altered material over the original painting, but did not carry out any cleaning.

1964-1974

During the IV CENTENARY OF THE DEATH OF MICHELANGELO, under the Pontificate of Paul VI (1963-1978), consolidation of the building structure was carried out and a limited cleaning of the *Stories of Moses and Christ*, under the direction of Dioclecio Redig de Campos (Director from 1971 until 1978).

1975-1979

Work on the cover: restoration of the roof, the sentry passage and the battlements of the building and the replacing of several windows.

1979-1980

Under the Pontificate of John Paul II (1978-2005) the late sixteenth century frescoes by Matteo da Lecce and Van den Broeck on the counter-façade are restored. Restorers: Maurizio Rossi and Pier Giorgio Bonetti.

1980-1984

16 June 1980 – 13 October 1984

Restoration of the fifteenth century series of *Pontiffs*. First cleaning test carried out on the *lunette of Mathan and Eleazar* by Gianluigi Colalucci, head of the Laboratory for the Restoration of Paintings as the start of a campaign to clean all the lunettes. The work is directed by Fabrizio Mancinelli, Curator of the ABMM Department and Carlo Pietrangeli, Director of the Vatican Museums.

1981

Beginning of the collaboration with Nippon Television Network of Tokyo who will make a documentary film of all the cleaning and restoration (this collaboration continued until 1994). NTV will ensure financial support for the restoration and participate in the editorial project for documenting the results of the restoration, having in exchange the use of all the images for commercial purposes for three years.

1983

Beginning of the study of the microclimate of the Sistine Chapel (the data will be published in 1986 and 1988).

1985-1989

7 November 1984 – 31 December 1989

Restoration of the frescoes of the vault. The restoration team was composed of:
Technical manager: Gianluigi Colalucci, Head Restorer of the Laboratory, assisted by Master restorers Maurizio Rossi, Pier Giorgio Bonetti, and then Giovanni Grossi and Bruno Baratti.
Director of Works: Fabrizio Mancinelli under the supervision of Carlo Pietrangeli
Analyses and laboratory investigations: Nazzareno Gabrielli and Fabio Morresi.
Technical consultant: Pasquale Rotondi, ex-director ICR.
The Director of the Vatican Museums is Carlo Pietrangeli.

1990

25 March: John Paul II opens the exhibition *Michelangelo and the Sistine Chapel: technicalities, restoration, myth* in the Carlo Magno wing, jointly organized by the Vatican Museums and the Vatican Apostolic Library, with a magnifi-

cent display of graphic, photographic and film material.

26 March: International Conference *Michelangelo, the Sistine Chapel* organized by Kathleen Weil-Garris Brandt and Fabrizio Mancinelli. Inaugurated in the *Sala dei Cento Giorni* in the *Palazzo della Cancelleria*, then later (from 27 to 31 March) in the *Biblioteca di Sisto IV*, *Aula del Vecchio Sinodo*.
During this conference the results of first tests for the cleaning of the *Last Judgement* were presented.

1990-1994

Spring 1990 – March 1994

Restoration of the *Last Judgement*.
Technical manager: Gianluigi Colalucci, head restorer, Laboratorio, assisted by Master restorers Maurizio Rossi, Pier Giorgio Bonetti and Bruno Baratti.
Director of Works: Fabrizio Mancinelli, under the supervision of Carlo Pietrangeli.
Analyses and laboratory investigations: Nazzareno Gabrielli and Fabio Morresi.
Technical consultant: Pasquale Rotondi, until 1991, then Giorgio Torraca.
The Director of the Vatican Museums is Carlo Pietrangeli.

1993

After several years of study reserved for planning the project and for the acquisition of data, a new system for controlling the microclimate is installed (air filtering and conditioning). It replaces an old heating system which used grates placed in the floor. The work was carried out by the Technical Services for the Governorate, in collaboration with Delchi-Carrier who offered technical and financial support (July 1992).

The old incandescent lighting system is replaced by a new system of illumination using cold light (metal- halide). The projectors are placed outside windows screened by glass light diffusers. The work was carried out by the Technical Services for the Governorate, in collaboration with Osram and Siemens, who offered technical and financial support.

1994

8 April: *International Conference* in the Aula Paolo VI and a *Press Conference* in the 'Aula della Benedizione' in order to present the conclusion of the restoration of the Michelangelo frescoes and the official publication by the Vatican Museums of the restoration of the vault and the Acts of the 1990 Conference, in three volumes and co-edited by Nippon Television:

Vol. I	Plates. The restored vault
Vol. II	Report on the restoration of the vault
Vol. III	Acts of the International Study Conference Michelangelo. La Cappella Sistina held in 1990.

This occasion heard the following presentations:

- the restoration of the Last Judgement;
- the new system for filtering and conditioning the air and controlling the microclimate;
- the new lighting system.

1995-1999

Restoration of the pictorial cycle of the *Stories of Moses and Christ*, of the false

'curtains' and of the works in marble: the Pontifical coat-of-arms, the marble screen and the singing gallery.
Technical manager: Maurizio De Luca, Head Restorer of the Laboratory, assisted by Maria Pustka and numerous restorers.
Director of Works: Arnold Nesselrath, Curator of the ABMM department
Scientific managers: Nazzareno Gabrielli, Fabio Morresi
Consultants: Giorgio Torraca, Gianluigi Colalucci
The Director of the Vatican Museums is Francesco Buranelli.

1999

11 December: John Paul II presides at the inauguration ceremony for the conclusion of the works of restoration in the Sistine Chapel.

2000

Presentation of the official publication by the Vatican Museum on the restoration of the *Last Judgement* entitled *Michelangelo – The Sistine Chapel. Documentation and interpretation,* in two volumes:

Vol. I Report on the restored Last Judgement
Vol. II Plates. The restored Last Judgement.

2010

Antonio Paolucci, Director of the Vatican Museums, brings back the practice of regularly dusting all the frescoes and institutes a programme of maintenance and control of the state of conservation of the paintings in their ambient context. He organizes the first of a long series of meetings involving both the Museums and the Technical Services for the Governorate, which is soon joined by Carrier. These meetings culminate in the report *Progetto Sistina – stato di salute degli affreschi, controllo ambientale, ipotesi di possibili interventi*. These works continue until 2014.

2011

Antonio Paolucci, Director of the Vatican Museums, sets up and presides over the Technical Committee which is charged with:
• carrying out an *environmental study* in the Chapel, furnishing indications relating to the suitability of the air treatment system in use and the consequent impact on the wall paintings murals;
• carrying out a *scientific study* on the state of health of the frescoes, and identifying any phenomena of alteration to be found on the paintings.
The Delegates present, for the Museums the works were undertaken by the Diagnostic Laboratory and the Conservator's Office and by Mauro Matteini and Paolo Mandrioli, brought in as external consultants by the Direction for the Vatican Museums. The reports were submitted in 2012 and 2013 respectively.

2012

The collaboration with Osram began, aimed at drawing up a plan for a new lighting system in the Sistine Chapel.

31 OCTOBER: Benedict XVI (2005-2013), on the occasion of the 500th anniversary of the inauguration of the vault of the Sistine Chapel, recalls the event with a celebration of the same religious function in the Chapel and delivers an important theological speech.

2013

June: The committee of Vatican Museums – Technical Services for the Governorate approves the project for the new HVAC System, a plant which will treat and change the air, designed by UTC-Carrier. The apparatus was then made and, the following year, the phases of executive design, the building site and the installation were projected.

2014

The committee of Vatican Museums – Technical Services for the Governorate approves the project design for the new lighting system proposed by the consortium LED4Art headed by Osram. The specially designed apparatus is then made and the installation begins.

30-31 OCTOBER: In commemorating the 'uncovering' of the vault and the *Last Judgement* 450 years after the death of Michelangelo, and 20 since the conclusion of the first real restoration of Michelangelo's frescoes, the Vatican Museums organizes a Conference entitled:

THE SISTINE CHAPEL TWENTY YEARS LATER NEW BREATH NEW LIGHT

Presenting:

- the comprehensive studies carried out on the state of conservation of the frescoes in their ambient context;
- the new air-treatment system, with dehumidification and purification of the air;
- the new lighting system.

May 1980: Sistine Chapel, general view, before restoration

January 2000: Sistine Chapel, general view, after restoration

Sistine Chapel, the Ceiling. The Masters Restorers Pier Giorgio Bonetti and Maurizio Rossi at work on the scene depicting *The Original Sin*

Sistine Chapel, the Ceiling. The Master Restorer Gianluigi Colalucci during the cleaning of the panel depicting *The Creation of Adam*

THE SISTINE CHAPEL
TWENTY YEARS LATER
NEW BREATH NEW LIGHT

30TH – 31ST OCTOBER 2014
AUDITORIUM CONCILIAZIONE
ROME

VATICAN MUSEUMS

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Mons. Paolo Nicolini, *Delegate for the Administrative-Management Sectors*
Roberto Romano, *Secretary*

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Fabio Morresi
Francesca Romana Cibin
Maurizio Delle Rose
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