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LIGHTING DESIGN FOR MONUMENTAL COMPLEX: A CASE STUDY

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Abstract

As part of the restoration of the Neptune Fountain in Bologna, research was carried out, and certain design proposals were formulated which offer food for thought and give new light to the monumental complex within the context in which it is located, in the system of squares Maggiore and Neptune. The activity was divided into two distinct phases, the first was concerned with surveying the current state of lighting of the fountain and the adjacent spaces; the second focused on drafting proposals for a new lighting system, based on new LED technologies, of the fountain of Neptune and the areas immediately surrounding which was presented by means of synthetic images derived from the digital reconstruction of the site. This article presents the working method applied and the results achieved.

Keywords

Cultural heritage, Lighting survey, Lighting design, Automatic photogrammetry, Digital reconstruction

1. *Introduction*

The theme for the lighting of statues that are part of monumental complexes in an outdoor cultural heritage context is not subject to the limitations of light exposure that are typically found in cultural heritage indoors. The degradation of artefacts is dependent essentially on the action of atmospheric and chemical agents due to the pollution of the city. Moreover, no specific rules are defining the requirements for the lighting of statues in the exterior. The main constraints of the project derive rather from requirements of energy sustainability, perceptual enhancement of the work and containment of upward dispersion of luminous flux (Regional council of Emilia-Romagna region, 2003, 2015). Today, thanks to solid-state lighting technologies, these objectives are easier to achieve than in the past, but their success requires careful design research, which is based on experimentation with Lighting CAD software. This is an open research area, in which the enhancement of the work cannot ignore a careful evaluation of the perceptive-visual aspects and the control of the annoying and disabling glare that all too often occurs in these contexts (Rossi, 2019). New technologies, together with careful design research using CAD tools, make it possible to direct lighting only where it is required, avoiding scattering the luminous flux upwards and towards the eyes of passers-by (Peña-García, Hurtado, & Aguilar-Luzón, 2015, 2016). In this article we present a methodological research in which we start from the survey of the state of photometric fact, the use of 3D models of the spaces considered made with different methodologies for the various parts, and the design experimentation through CAD simulation tools aimed at achieving the objectives set out above.

2. *Survey of the state of fact*

The survey phase is always very important in lighting design. In this case, in addition to providing essential quantitative data for the verification of the requirements to the normative references relating to the lighting of the square according to the regulations in force, it has also highlighted some qualitative characteristics on the technical solutions adopted to illuminate the squares and the buildings facing them, such as, for example, the extent of the lighting projected on the façades of historic buildings, the incorrect orientation or operation of some fixtures, or strong imbalances in the solutions adopted to illuminate the buildings with porticos.

During the survey phase, the weaknesses of the current lighting observed has proved to be fundamental for the formulation of design proposals. In addition to the needs expressed by the client, the survey has facilitated the identification of a series of interpretations aimed at enhancing the spaces and materials in the monumental complex of the fountain of Neptune and the surrounding buildings. The proposals developed provide static and dynamic lighting solutions, able to respond flexibly to needs that may change over time. Alongside the reduction in energy consumption, the design proposals are aimed at ensuring a proper enhancement of the shapes of the sculptural elements that characterise the fountain while ensuring the visual comfort of pedestrians.

2.1 State of the lighting system

For a correct evaluation of the current state of the lighting system, instrumental measurements, photographic surveys and inspections were carried out to characterise the luminous scenario of the statue and the immediate surrounding areas. The reference standards (Ente Italiano di Normazione, 2012; Comité européen de normalisation, 2004) for the measurements were UNI 11248:2012 (now replaced by UNI 11248:2016) and the European harmonised standard EN 13201_02:2004.

The results obtained (values, state of the installations and materials) refer to the conditions existing a few days before the start of the restoration work in which the entire monumental complex of Neptune was subjected.

The lighting system of the statue of Neptune consists of a single roto-symmetrical projector for metal halide lamp with opening (estimated by the relative position between the fixture and the statue) that concentrates the entire luminous flux (light emitted by the source) in a cone of 6°. The particularity of this single projector is given not only by the lateral lighting of the statue (which guarantees a good rendering of the forms) but also by the presence of a clear shadow, the shape of the statue, projected on the building that houses the offices of the municipality of Bologna.

The use of a single projector for the accent light on the statue probably derives from the desire to create a very well-defined projection of the shadow on the building. Other light sources directed at the statue would probably have made the projection less effective.

At the time of the survey, the fountain basin did not have any working lighting system but only the remains of a previous system, designed to illuminate the statue from below. Unfortunately, the structural conditions of the pool itself were such that it was expressly requested not to provide systems immersed in the water. At present, the pool, the water, the jets and the base of the statue do not receive direct lighting and are therefore visible only thanks to the light reflected from the adjacent façades. As a result, these elements are flat and uniform, and the differences between light and dark are exclusively due to the reflection factor of the material and the layer of oxide or deposits that covers most of the elements of the fountain (oxide also removed during restoration). In the future design proposal, however, the lighting of these elements will have to come from fixtures mounted on the surrounding buildings and at a certain distance from the complex.

However, it is not sufficient to pay attention to the fountain and statue alone; in order to define the contrast between the complex and the surrounding environment, it is necessary to investigate in detail the distribution of light in the immediate surrounding areas, both on the level of footsteps and the vertical surfaces of the buildings surrounding the complex. This is because excessive lighting of the context has the effect of losing the importance and centrality of the statue to the advantage of the surrounding buildings in the perception of a visitor who is crossing Piazza del Nettuno.

The measured quantities taken into consideration are illuminance (quantity of luminous flux per unit area) and luminance; photometric quantity correlated to the psychophysical sensation of luminance whose value depends on the position of the observer related to the surface itself (Fotios, & Gibbons, 2018). For this type of analysis we used the following measuring instruments: illuminance-meter (illuminance) used for the categorisation of the walking surface and various luminance maps for the vertical surfaces of buildings, generated by a luminance meter (LMT-L1009), a video photometer (Minolta CA2000) and a camera (Canon EOS 550D with 18-55 mm zoom lens) appropriately calibrated in our laboratory. Luminance maps are images taken from different points (and directions) of the square, which provide (thanks to a particular use of colours) information about the contrasts between the buildings and the statue or between different architectural elements of the façade: high values of contrast guarantee that details are more evident to users (Moeck, 2000).

2.2 Illuminance measurement

The illumination measurements on the street level were carried out during two different inspections: in the first series of measurements, the lighting system of the statue of Neptune was working, and the measured illumination values take into account this contribution (however, limited to the area immediately surrounding the statue). In the second series of measurements, the projector on the statue was off (Fig. 1).

From the examination of the results, it is observed that the illuminance values decrease as you move away from Via Rizzoli and approach the statue of Neptune, where you do not record the contribution of the luminaires that illuminate the road to vehicular traffic and its sidewalk.

The average illuminance value varies between 4 lux, on the side of Piazza Maggiore and 6 lux on the side of Via Rizzoli, with low level of uniformity (defined by the ratio between the minimum illuminance value and the average value); the explanation for this result is that the floor of the footsteps of Piazza del Nettuno is illuminated by the light reflected from the walls of the buildings.

The average illuminance values drop further, in the absence of accent light on the statue, with values between 2 lux on the side of Piazza Maggiore and 4 lux on the side of Via Rizzoli. It can be assumed that the choice of design was to create a very dark environment on which to allow the illuminated statue to stand out by the accent projector and the historic buildings of the square, whose façades are illuminated. It should also be noted that the levels are particularly low due to the failure of some of the luminaires, probably due to the lack of a maintenance program at regular intervals.

Despite the possible design intention, the measured values do not meet the requirements of EN 13201_02. The amount of light is in fact much lower with the result, due to transit safety.

2.3 Luminance measurement

Regarding the evaluation of the luminosity perceived by the observers (luminance), the Neptune fountain and the surrounding space were measured in all directions to evaluate the following aspects:

- The ability of the lighting system to make the three-dimensionality of the statue perceptible. The presence of luminance contrasts (the ratio between illuminated areas and shadows), in fact, enhances the perception of the shape of the statue (Nameda, 1990).
- The evaluation of the hierarchy of the different buildings for the monumental complex, considering the different directions of observation (Brandi, & Geissmar-Brandi, 2006). This evaluation served to evaluate which architectural elements attract the most attention by an observer looking in different directions within the square, assuming that buildings with higher luminance will capture his gaze more.

Fig. 1: Nocturnal photo of the statue and fountain of Neptune. On the right the projector dedicated to the statue is on, on the left it is off. However, normal photographs are not ideal for an evaluation of the real brightness of the environment

An evaluation of photographic material is generally not a good way to make considerations about a lighting system. It is often the case that photographs are used to criticise or endorse lighting design projects, but many factors can contribute to a distortion of the appearance of the scene.

The images in Fig. 1 may have an inadequate exposure time and appear sufficiently bright when in fact, the luminance values of the statue and most buildings, except for what appears in the background, are below 2 cd/m^2.

As an example, the maximum luminance of white in a common computer monitor can span from 150 to 300 cd/m^2, and the luminance of a white sheet placed on a desk illuminated with 500 lux (in compliance with the standards), has a value generally included around 120 cd/m^2.

As well in the case of the luminance measurements (Fig. 2), the two different operating conditions of the system were considered (in the presence and absence of the accent light). To better assess the visibility of the monumental complex, two privileged directions of observation were identified, reflecting the main routes followed by passers-by (Fig. 3).

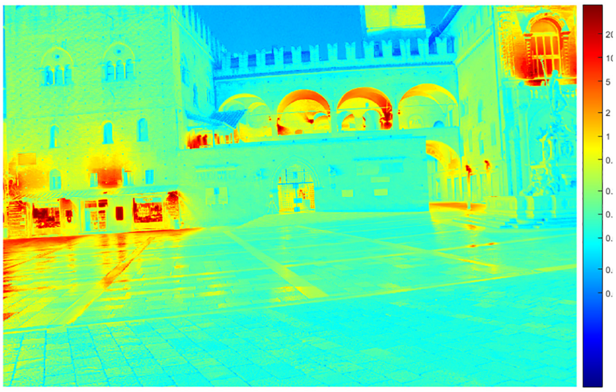

Fig. 2: Distribution of the Luminance in logarithmic scale of the area around the fountain and statue. Provides effective luminance values

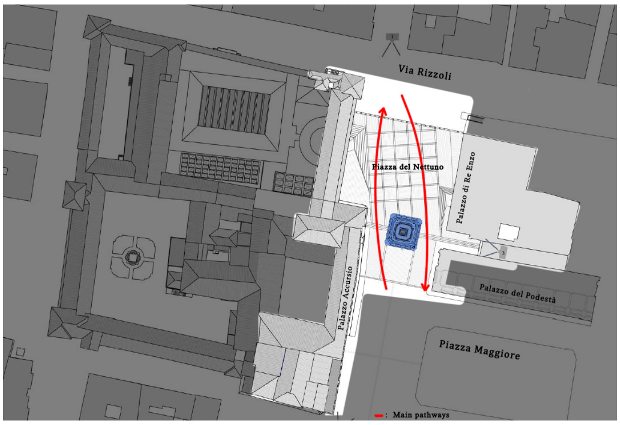

Fig. 3: Advantaged directions of passage chosen for the evaluation of the visibility of Neptune. From via Rizzoli to piazza Maggiore and vice versa

When a passer-by arrives from Piazza Maggiore in the direction of Via Rizzoli and observes the statue, his perception of it is barely sufficient when the projector on it is turned on. The base instead almost completely disappears, if we consider that its luminance is about 0.7 cd/m^2, against 2.1 cd/m^2 of the statue.

However, if we consider that the buildings in the direction of Via Rizzoli have an average luminance of about 4 cd/m^2, it is clear that the monumental complex is not adequately enhanced (Fig. 4, top left).

The situation worsens if we consider observing the complex from the opposite direction (from via Rizzoli to Piazza Maggiore). Except for a small portion of the left side of the statue (which, thanks to the direct contribution of the projector, has a luminance of about 5.8 cd/m^2), almost all of the complex (the statue, the pedestal and the basin of the fountain) has values between 0.2 and 0.5 cd/m^2. These levels are not adequate for a correct perception of the statue, even if the buildings in the background heading towards Piazza Maggiore have a reduced luminance (between 0.5 and 2 cd/m^2) compared to those of Via Rizzoli (Fig. 4, top right).

In the absence of accent lighting, this deteriorates even further, the luminance values of the statue oscillate between 0.1 and 0.2 cd/m^2, while those of the base is between 0.3 and 0.5 cd/m^2. It is clear (and it is also clearly visible in the left part of Fig. 1) that the buildings in the background (with luminances greater than 2 cd/m^2) are much brighter, while the Neptune complex is perceived as a dark silhouette of secondary importance.

In the two main directions of observation, the visibility of the statue and the fountain is not optimal.

Concerning the surrounding area of the statue, we made illuminance and, more extensively, luminance measurements. Following the elaboration of the results, it was possible to draw important considerations for the design concept phase.

Almost all the buildings overlooking the monumental complex and Piazza Maggiore are equipped with a façade lighting system that can produce luminance levels that are often higher than those of the statue, even though many of the projectors surveyed are poorly oriented, damaged or not working at all.

In the loggias, the voids are illuminated, while in the upper part of the buildings, almost always the solid surfaces are highlighted between the windows (here, too, we can see several non-functioning fixtures). Some projectors placed on the roofs (especially those on Palazzo dei Notai) and oriented to illuminate the floor are particularly dazzling; the eye of the observer is adapted to much lower luminance levels (around 1 cd/m^2) (Fig. 4, top right).

The Basilica of San Petronio, served by a frontal projector placed on the roof of the Palazzo del Podestà, is composed of two distinct sections with different materials (different reflection index) and therefore, although illuminated by a single luminaire, it is much brighter in the lower part than in the upper one (Fig. 4, bottom).

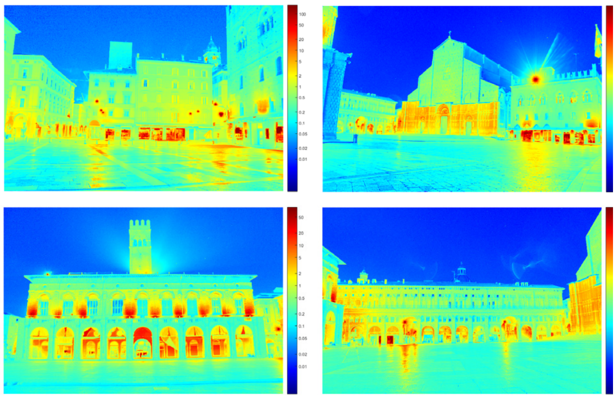

Fig. 4: Luminance maps of the buildings adjacent to the monumental complex and Piazza Maggiore. Starting from the top left and clockwise: buildings in via Rizzoli, Piazza Maggiore with the Basilica of San Petronio and the Palazzo dei Notai, the Palazzo dei Banchi and the Palazzo del Podestà.

2.4 Lighting sources present

After having carried out a census as accurate as possible of the lighting fixtures that made up the various systems, it was possible to see that, with the exception of two projectors located at the entrance of the Palazzo di Re Enzo, the light sources used are exclusively discharge lamps in traditional gases, of the two types (Rea, Bullough, & Akashi, 2009):

- High-Pressure Sodium Lamp – HPS
- Metal Halide Lamp - MH

The first type of lamp (HPS) is very efficient and is often used in urban lighting, where high colour rendering capacity is not required; in fact, this lamp emits a yellow-orange light (Fig. 5), which offers a limited ability to distinguish colours, but allows the emission of a considerable luminous flux with a modest electrical power consumption and consequently with reduced energy consumption.

Sodium lamps are mainly used to light the façades of buildings, i.e. in those parts of the space where yellow-green colours abound (part of the spectrum where this lamp is well-performing). In this way it is possible to obtain good results even if the Colour Rendering Index of the source is rather low. The colour rendering index (Ra) is a number between 0 and 100, used to express how much a light source is capable of rendering the colours of a predefined set of colour samples (Guo, & Houser, 2004); that of the HPS lamp is about 20÷23.

The Metal Halide Lamp, on the other hand, has a much higher colour rendering (Ra=65) but a lower efficiency than the HPS. Another factor is the colour temperature of the two sources, i.e. a parameter used to describe whether a white light source tends more towards a warm white shade (2000 K, typical of incandescent light sources) or a cool white shade (6500 K, typical of natural light with a clear sky). The MH lamps present are at a neutral colour temperature (about 4000 K) (Fig. 6). These two combined characteristics are plausibly the reason why the MHs were chosen to illuminate the statue and some of the marble elements.

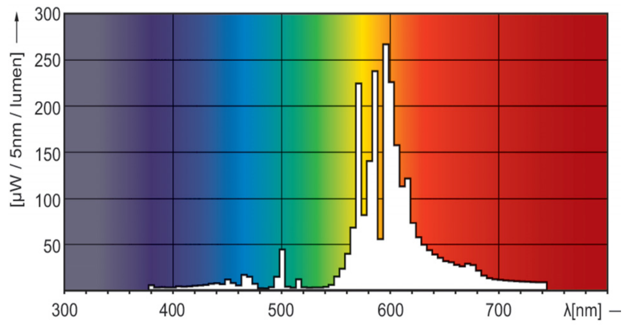

Fig. 5: Spectral power distribution of the light typically emitted by a High-Pressure Sodium Lamp (spectrum in the visible range 380-780 nm). Courtesy image of Philips

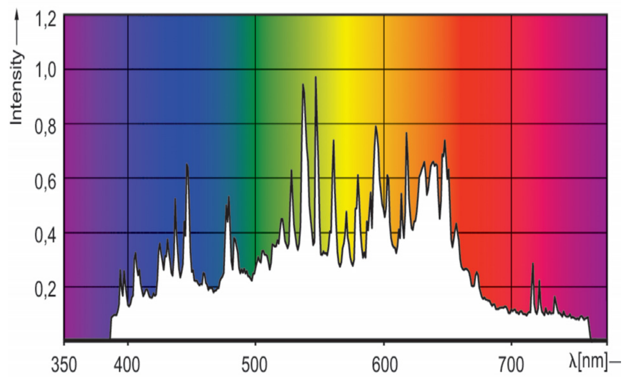

Fig. 6: Spectral power distribution of the light typically emitted by a Metal Halide Lamp (spectrum in the visible range 380-780 nm). Courtesy image of Philips

It should be noted that modern LED technology would allow great flexibility in the management of the "colour rendering" of surfaces and light tones, while maintaining a good luminous efficiency and also ensuring flexibility in the management and control of area lighting, as well as monitoring functions of the lighting system (Pierleoni, Belli, Palma, Valenti, Raggiunto, Incipini, & Ceregioli, 2018). For this reason, the solutions proposed use all luminaires with solid-state sources.

3. The proposed solution

After the lighting survey (Fig. 7), we moved on to the phase of formulating some preliminary proposals (in the form of a concept) for a new lighting of the monumental complex and the immediate surrounding area.

In formulating these proposals, a series of requests expressed by the client were taken into consideration, summarised in the following points:

- Minimise the consumption of electricity;
- Controlling diffused light;
- Contain the phenomena of discomfort glare towards passers-by;
- Enhance the monument of Neptune;
- Provide a clear legibility of the Fountain-Statue complex for the context, the surrounding buildings in the square, and its components;
- Use dynamic lighting solutions on special occasions, such as commemorations and anniversaries decided by the Municipality of Bologna;
- Lighting the Statue differently from the pedestal.

Initially, three concepts were formulated which, after several discussions with the client (who in turn interfaced with the municipality), were merged into a single preliminary proposal. The produced concept is not only intended to meet regulatory requirements, but also to interpret and enhance the space by mediating with communicative and functional requirements.

Already identified in the survey phase, the two privileged directions of observation coincide with the routes that tourists and users of the square usually follow: the first route is the one that goes from Piazza Maggiore to Via Rizzoli, while the second is the one that goes from Via Rizzoli to Piazza Maggiore (Fig. 3). The identification of these routes is essential both for the design of significant and visible lighting effects for most users, and for the evaluation of the parameters of quality of the system, such as containment of glare for the main directions of view of the observers.

3.1 The lighting of the statue and the pedestal

The new proposal for the illumination of the statue is based on a three-point illumination (instead of one like the one currently installed). Special shielding systems are also planned to limit the beam opening, eliminating the projection of shadow on the buildings, as requested by the client (Figg. 8, 10, 11, 13).

Fig. 7: Digital reworking of a daytime photograph of the square to simulate the lighting of the complex in one of the three concepts

Four warm-light projectors (colour temperature 3000 K) have also been proposed, which will be aimed at the pedestal (the Castellum); three of these projectors are mounted on the same structures that support the projectors of the statue, while the fourth will be positioned on the wall of the entrance courtyard of Palazzo di Re Enzo. The three projectors used to light the statue will have a cooler colour temperature (5000 K), which will ensure greater prominence to the bronze structure even at the end of the restoration process that will see the removal of the oxide patina that covers the statue. In this way, the contrast with the Castellum (in marble) will be even more marked.

Three RGB projectors (red, green and blue) will also be installed in the same position as the white light projectors that make up the Neptune's accent light, to provide temporary coloured lighting for events such as events:

- Blue lighting for World Diabetes Day in mid-November.
- Blue lighting for the World Autism Awareness Day at the beginning of April.
- Pink lighting for Komen Italia breast cancer day at the end of September.
- Red lighting for World Blood Donor Day in mid-June.
- Purple lighting for World Epilepsy Day at the beginning of February.

For the coloured light fixtures as well, we planned the installation of adjustable shielding systems for better control and definition of the beam related to the silhouette of the statue. Since some of the scenarios obtained with the coloured lights will lead the statue to have very low luminance levels compared to lighting with white light, it was decided that to make more visible the Neptune compared to the context, when using RGB projectors, the fixtures that illuminate the Castellum will be kept off, as visible in Fig. 12.

3.2 Additional lighting of the spaces surrounding the fountain

In addition to restoring the functionality of the current lighting systems of buildings (projectors on the façades, light points on the windows, etc.) was also developed a proposal for the lighting of the spaces surrounding the fountain which consisted of a series of light signs placed on the floor in correspondence with the lines of white stone inserted in the flooring. These devices will

Fig. 8: Digital reworking of a photograph to simulate the accessory lighting of the walking surface. In the final version of the concept, the shadow of the statue on the wall has been eliminated, and the beams of the two luminaires south of Neptune have been harmonised with those to the north

emit a very controlled luminous flux (narrow blades of light), a sign of light to channel the attention of passers-by. The colour temperature chosen is neutral (4000 K). Some of the initial concepts provided for a large number of these light elements (and an RGB version of them) but, although these would guarantee great flexibility of use, in the end, we opted for a system of light lines that created a sort of corridor that ideally directs pedestrians towards Neptune. The aim is to create a dynamic perceptual context aimed at placing the complex at the centre of the hierarchies of visual perception of the area.

In addition to the luminous signs on the walking surface, the windows of Palazzo D'Accursio (in correspondence with the Sala Borsa Library) and the battlements of Palazzo di Re Enzo will also be lit. These additional lighting fixtures (with narrow beam emission, to illuminate only the profiles of the elements) will also, have a colour temperature of 4000 K.

2.3 Lighting Management System

For the entire system, we hypothesised the installation of a management system capable of ensuring the achievement of the following objectives:

- Possibility of creating predefined lighting scenes that can be selected by the operator for events/recurrence;
- Dimming and partial shutdown of the system in the late hours of the night to contain operating costs;
- Possibility to create new light scenes in case of special needs, through the composition and regulation of the lighting of the individual elements of the fountain, statue or square.

For this application, the choice of the protocol for the management system leads to some possible options: DALI, DMX or a hybrid solution. A control system with a simplified interface (to make the programming of the scenes accessible) would guarantee additional and innovative functions for dynamic lighting, which would allow the Municipality to assign new and changing perceptual values to the context, depending on particular situations (Di Salvo, 2014).

4. Digital reconstruction of the statue and spaces

To present the model to the Municipality of Bologna, the client requested the production of three videos able to show the concepts formulated during the first phase. These videos were obtained by a simple movement of a camera to imitate the night walk that an hypothetical tourist takes, moving from Via Rizzoli to Piazza Maggiore and lingering on the Monumental complex of Neptune. It was, therefore, a matter of digitally reconstructing a portion of considerable space, composed of several historic buildings whose façades are composed of distinctive architectural elements. Fortunately, in this phase of the work, the collaboration with the team of the Department of Architecture of the Alma Mater Studiorum of Bologna University, proved to be fundamental.

The Bologna group was already working on the digitisation of spaces to obtain great detail three-dimensional models to simplify some of the restoration operations. The early material was produced with automatic photogrammetry thanks to the vast amount of imagery acquired.

These models were very important for the documentation of the underground chambers that bring power and water to the complex. Another very important function of the models was related to the very delicate and also irreversible cleaning process of the surfaces. Dirt and coatings accumulated over the years must be removed; the chemical analysis of surfaces produces results not immediately available while the visual analysis (also assisted by the microscope), may not be precise (it is difficult to find correspondence between the points in multiple cleaning sessions). For these reasons, the Bologna team, in addition to the three-dimensional models, has developed tools that allow to see in detail the state of the surfaces being restored in various stages (Apollonio, Ballabeni, Bertacchi, Fallavollita, Foschi, & Gaiani, 2017, 2018).

Therefore, there was already digital material that could be used to reconstruct the spaces. The production of each video involved the creation of about 2700 frames 1080x720 (full HD). The software used was 3D Studio Max (ver. 2017) by Autodesk, and the method of rendering was a global illumination calculated with Photon-Mapping algorithm (Wann Jensen, 2001). The light sources were not many, but the scene was geometrically quite complex.

The Bologna group, however, produced a model of the monumental complex at reduced resolution (about 2 million triangles, compared to the 30 million of the final model), which was however sufficiently detailed for the camera distances used in the videos (Fig. 9, top).

Numerous models of the surrounding buildings were also available, well detailed and textured.

The process of colour optimisation on textures is particularly important because the images being captured are taken during the day, in natural light conditions that may vary depending on the time of day and weather conditions (Cheung, & Westland, 2006). On the acquired models, an accurate pre-production work of the images had already been carried out to obtain a correct photogrammetric process (Gaiani, Apollonio, Ballabeni, & Remondino, 2017).

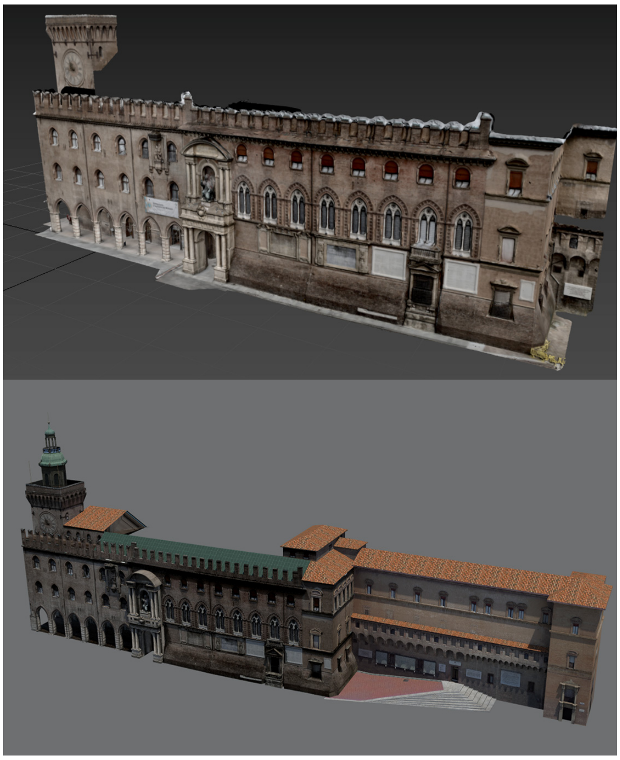

Fig. 9: Comparison between the model of Palazzo d'Accursio obtained with automatic photogrammetry (top, about 1,400,000 polygons, partial geometry) and that of its remodelled low-poly version (about 88,000 polygons, complete geometry**)**

However, the production of the videos took place on computers that were not optimised to handle such high complexity models; the use of geometries of millions of triangles would have greatly increased the modelling process and calculation times of the images. The choice was therefore to maintain the model obtained by photogrammetry of the monumental complex, and to model from scratch the buildings, which in the videos would be visible in the background, for which there was also a blur given by the depth of field.

Starting from the geometric models provided, books (Tuttle, 2015), from the photographs taken on-site, websites (Tuttle, 2016), and from the material available on the site of sharing of the restoration project (which involved the sharing of material between physicists, chemists, biologists, hydraulic and structural engineers, geomatics experts, restorers, architects, art and architecture historians), following an appropriate work of colour correction, a simplified 3D model (Fig. 9, bottom) of the environment was reconstructed that allowed a less intensive management for the machines used to render the more than 10,000 frames produced.

5. *Conclusion*

The lighting work carried out in the area of the monumental complex of Neptune in Bologna is part of a broader framework of restoration and enhancement. A process of great importance still in progress. The working groups share material and have synergies that make the overall picture even richer although more complex, given the multitude of skills involved.

The proposed design research was aimed at enhancing the monumental complex of the Neptune Fountain thanks to new solid-state lighting technologies and reducing energy consumption. Another aspect that has been considered concerns the visual comfort of passers-by, trying to avoid direct and indirect sources of glare. It is well known that the discomfort glare that often occurs in urban centres, while not impeding vision, from a perceptual point of view generates a negative psycho-perceptual feeling by most of the subjects, which are not able to put it in close relation with the problem of glare instead attributing it to the entire context observed.

The use of digital technologies, such as generation of control systems can guarantee the space a flexibility of use that allows not only virtuous lighting from an energy point of view, but also attractive in public events, allowing visitors to enjoy the area to his fullest.

Fig. 10: Synthesis image of the monumental complex of Neptune standing out in front of the buildings in Via Rizzoli; it is possible to observe the difference in colour temperature of the white light used to light the statue (cooler, 5000 K) and the Castellum (warmer, 3000 K)

Fig. 11: Close-up rendering of the Statua-Castellum complex; in the background the Palazzo di Re Enzo, where some luminaires have been hypnotised to highlight the battlements

Fig. 12: In this image, it is possible to observe the use of RGB projectors to obtain coloured illumination. The luminaires that illuminate the Castellum are switched off to prevent the statue from being perceived as less bright

Fig. 13: Long shot of piazza del Nettuno; it is possible to notice the luminous signs produced by the narrow beam luminaires installed on the walking surface

REFERENCES

Apollonio, F. I., Ballabeni, M., Bertacchi, S., Fallavollita, F., Foschi, R., & Gaiani, M. (2017). From documentation images to restauration support tools: a path following the Neptune Fountain in Bologna design process. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-5/W1, 329–336.

Apollonio, F. I., Ballabeni, M., Bertacchi, S., Fallavollita, F., Foschi, R., & Gaiani, M. (2018). Digital documentation and restoration tools reusing existing imagery: A multipurpose model of the Neptune's Fountain in Bologna. *Applied Geomatics*, 10(4), 295–316.

Brandi, U., & Geissmar-Brandi, C. (2006). *Light for cities: Lighting design for urban spaces; a handbook* (1st ed.). Basel: Birkhäuser Architecture.

Comité européen de normalisation - CEN (2004). *EN 13201_02:2004. Road lighting - Part 2: Performance requirements.*

Cheung, V., & Westland, S. (2006). Methods for optimal color selection. *Journal of Imaging Science and Technology*, 50(5), 481-488.

Di Salvo, S. (2014). Innovation in lighting for enhancing the appreciation and preservation of archaeological heritage. *Journal of Cultural Heritage*, 15(2), 209–212.

Ente Italiano di Normazione - UNI (2012). *UNI 11248:2012. Illuminazione stradale - Selezione delle categorie illuminotecniche*.

Fotios, S., & Gibbons, R. (2018). Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations. *Lighting Research & Technology*, 50(1), 154–186.

Gaiani, M., Apollonio, F. I., Ballabeni, A., & Remondino, F. (2017). Securing color fidelity in 3D architectural heritage scenarios. *Sensors*, 17(11), 2437.

Guo, X., & Houser, K. (2004). A review of colour rendering indices and their application to commercial light sources. *Lighting Research & Technology*, 36(3), 183–197.

Moeck, M. (2000). Lighting design based on luminance contrast. *Lighting Research and Technology*, 32(2), 55–63.

Nameda, N. (1990). Modeling effect of shading: New approach. *Lighting Research & Technology*, 22(2), 95–101.

Peña-García, A., Hurtado, A., & Aguilar-Luzón, M. C. (2015). Impact of public lighting on pedestrians' perception of safety and well-being. *Safety Science*, 78, 142–148.

Peña-García, A., Hurtado, A., & Aguilar-Luzón, M. C. (2016). Considerations about the impact of public lighting on pedestrians' perception of safety and well-being. *Safety Science*, 89, 315–318.

Pierleoni, P., Belli, A., Palma, L., Valenti, S., Raggiunto, S., Incipini, L., & Ceregioli, P. (2018). The Scrovegni chapel moves into the future: An innovative internet of things solution brings new light to Giotto's masterpiece. *IEEE Sensors Journal*, 18(18), 7681–7696.

Rea, M., Bullough, J., & Akashi, Y. (2009). Several views of metal halide and high-pressure sodium lighting for outdoor applications. *Lighting Research & Technology*, 41(4), 297–320.

Regional council of Emilia-Romagna region - Italy (2003). *Law n.19, 29/09/2003. Norme in materia di riduzione dell'Inquinamento Luminoso e di risparmio energetico*. Retrieved from https://bur.regione.emilia-romagna.it/archivio/bollettino?anno=2003&num_boll=147

Regional council of Emilia-Romagna region - Italy (2015). *Terza Direttiva per l'applicazione dell'art. 2 della Legge Regionale 29 settembre 2003, n. 19 recante: "Norme in materia di riduzione dell'inquinamento luminoso e di risparmio energetico"*. Retrieved from https://bur.regione.emilia-romagna.it/dettaglio-inserzione?i=da45165157f44840a7c6310b83aa39b1

Rossi, M. (2019). Evaluation of Artificial Light with Respect to Human Health. In *Circadian Lighting Design in the LED Era*. *Research for Development* (pp. 57-100). Cham: Springer.

Tuttle R. J. (2015). *The Neptune Fountain in Bologna - Bronze, Marble, and Water in the Making of a Papal City*. Turnhout: Harvey Miller.

Tuttle, R. J. (2016). *The Neptune Fountain in Bologna.* Retrieved from http://vistasvisuals.org/

Wann Jensen, H. (2001). *Realistic image synthesis using photon mapping*. Natick, MA: A. K. Peters ltd.