

The effects of spatial features on the luminous environment: the Ara Pacis Museum and the MAXXI of Rome

Selma Saraoui
Abdelghani Attar

Department of Architecture, Laboratory of Construction Engineering and Architecture (LGCA),
Abderrahmane Mira University. Bejaia, Algeria. E-mail: selma.saraoui@univ-bejaia.dz (corresponding author)

Azeddine Belakehal

Department of Architecture, Laboratory of Design and Modeling of Forms and Architectural and Urban Ambiances
"LACOMOFA", Mohamed Kheider University. Biskra, Algeria.

ABSTRACT

Spatial characterization of lighting ambiances is very important for museology and is usually done through sequencing of architectural space; however, in this work, we adopted a characterization based on the spatial configuration and fields of view presented to museum visitors. We examined two museums located in the same environment but with very distinct stylistic repertoires to explore how stylistic slant might affect this characterization.

We first assessed the properties of spatial visibility using space syntax, and then based on this analysis determined the most important isovists presented to visitors, i.e., fields of view, in the two museums.

We defined spaces from these, which we evaluated using HDR photos, which were processed by numerous applications and software, and we were able to deduce the spatial-light characteristics in each museum from the resulting pixels.

As a result, we were able to deduce the influence of stylistic trends on the selection of configurational and visual typologies of museum ambiances.

Key words:

luminous ambiance, space syntax, luminance, pixels, museum route, spatial configuration.

RIASSUNTO

Gli effetti delle caratteristiche spaziali sull'ambiente luminoso: il Museo dell'Ara Pacis e il MAXXI di Roma

La caratterizzazione spaziale degli ambienti luminosi è molto importante per la museologia e di solito viene fatta attraverso la sequenza dello spazio architettonico; tuttavia, in questo lavoro abbiamo adottato una caratterizzazione basata sulla configurazione spaziale e sui campi visivi presentati ai visitatori del museo. Abbiamo esaminato due musei situati nello stesso ambiente ma con repertori stilistici molto distinti per esplorare come il taglio stilistico possa influenzare questa caratterizzazione.

Abbiamo prima valutato le proprietà della visibilità spaziale usando la sintassi spaziale e poi abbiamo determinato, sulla base di questa analisi, le isovazioni più importanti che sono presentate ai visitatori, cioè i campi visivi, nei due musei. Da essi abbiamo definito gli spazi, che abbiamo valutato con foto HDR, elaborate da numerose applicazioni e software, e siamo stati in grado di dedurre le caratteristiche spazio-luce in ogni museo dai pixel risultanti.

Come risultato, siamo stati in grado di dedurre l'influenza delle tendenze stilistiche sulla selezione delle tipologie configurative e visive degli ambienti museali.

Parole chiave:

ambiente luminoso, sintassi dello spazio, luminanza, pixel, percorso museale, configurazione spaziale.

INTRODUCTION

The museum is one of the most built equipment in the world, in the current era, the new modes of conception linked to the exhibitions tend to give a new breath by the variation of the visitors' flows, making of the museum living equipment, and opened to the world. In front of this diversity of themes related to

museums, it is very difficult to establish a typology of museum architecture (Peressut, 1999).

Museum architecture has not ceased to evolve since the period when the museum became an autonomous building, we find those that are private or public, those that are fine arts, ancient art objects, or contemporary design... Museums nowadays also vary according to the stylistic tendency of the architects

who designed them (Fernández, 1999). This stylistic trend influences the spatial configuration of the museum and also its route, architects proceed in very different ways, the spatial configuration dictates in some cases the location of the route, sometimes the architect begins with the route and the spatial configuration will be reflected according to it. In this case, the route is not a simple way for the visitor, it becomes an adventure to discover the works, and an experience lived by the visitor when his body moves to create this movement that will allow him to get different sensations as he moves in the space.

The spatial configuration of the museum will be the result of a conception this conception could be seen as architectural anatomy of which the route will be the skeleton (Gregory, 2008), this conception should take into consideration three parameters: i) the exhibition space which must have sensory boundaries, we should design a space well occupied by the senses, whether it is light, sound or smell, we should think about controlling the physical signals preventing a physical signal from passing from one space to another; ii) the visitors or the exhibition audience, we should know what their numbers would be, their sensorialities, and above all think the route by putting ourselves in their place; iii) the mode of an exhibition and the use of technology and multimedia means to animate the body movement and make the space more dynamic; iv) the design should think sensoriality, concept, and form, we speak then of a reflection on the museum space and its content (Mattern, 2014).

The sensoriality in the museum is linked to the notion of ambiances, this recent notion has generated several reflections on the typology of ambiance that we must find in these spaces, there are generally two types of ambiance: i) situated ambiance: if we focus on the visitor, the atmosphere will exist in a specific space and/or it is perceived during the time of a visit; ii) the designed ambiance: if we focus on the intention of the designer to create this atmosphere, and his intuition during the realization, the ambiances then become mastered by the designer (Saraiva, 2001). The lighting ambiance is the most dominant in museums because it allows animation of the space while personalizing it, it is of such great importance, that many designers make it their priority during the development of their architectural work (Meyer, 1989).

This research is part of our previous research's new horizons; the goal is to move away from topology and verify the luminous ambiance from a different perspective, which will be the spatial configuration. Through this research, we will see to what degree the spatial configuration of the museum can influence the visitor's perception of the lighting environment, and to what degree the architect's stylistic tendency will influence the choice of the fields of vision in the route.

THE ROLE OF SPACE SYNTAX IN THE STUDY OF ARCHITECTURAL SPACE

Space syntax as a theory was initiated by B. Hillier and his colleagues at Bartlett, University College of London in the late 1970s (Hillier & Hanson, 1984). In the 1990s space syntax became an approach by which spatial configurations of architectural and urban objects were analyzed (Hillier, 1996). Space syntax is also concerned with the user of space and the space in which he lives, the spatial systems have a great influence on the distinctive characteristics of societies (Dursun, 2007).

In the architectural field, the spatial syntax questions the influence of the disposition of the different spaces that make up a building, and what difference can be made by one disposition compared to another. It is not just a matter of studying the different dispositions but also the behavior of the users in that space (Hillier & Tzortzi, 2006; Mazouz & Benhsain, 2009). The earliest research on space syntax in architecture dealt with museum cases, the studies took cases of already realized projects because of the lack of a language of museum space that could differentiate one spatial design from another (Hillier & Tzortzi, 2006). Most of them were aimed at studying extensions or simply functionalities of the museum space, such as the route and behavior of visitors (Nik Khah et al., 2021; Yuan et al., 2020), comparison between several museum typologies to understand the degree to which museum architecture affects our experience (Tzortzi, 2007), or the influence of local landmarks in the museum on the visitor's experience (Rohloff et al., 2009).

The tools inherent to the analysis by the space syntax can be used alone, for example, the technique of justified graphs (Reynoso C. & Reynoso N.P., 2012), the VGA, or the simulation of agents. We can also combine several maps or associate the results of space syntax with other types of analysis (Yuan et al., 2020).

The relationship between the isovist and the instantaneous photo

The isovists developed by the space syntax remains one of the best ways to understand the visual fields in a given space, and whatever the nature of the architectural or urban space, this notion had been popularized by Michael Benedikt at the University of Texas, and defined thereafter by Bill Hillier, as the field of vision from a particular point an axial space, a straight line of sight and a possible route (Yuan et al., 2020). Thus isovists whether at 90°, 180°, or 360° can be represented by a picture of what can be seen in a given direction in space.

The photo is the best vehicle of the ambiance that can characterize a given place, in our research, we will be

interested in the ambiance and the use of the photo, the simulations by software will remain just a virtual quantitative, which could have more realistic aspect if we make it accompanied by the photo. We mention for this purpose a study had been made on the influences of the configurational differences on the choices of the users, in the Centre Pompidou and the Tate Modern. It had revealed that the choice of visual fields in the projects analyzed in the form of isovist clearly shows if the spatial configuration offered visual accessibility to several spaces or just limits it to the exhibition space, from the results obtained, the choice of the centers of visual integration could be justified by photos snapshot of the visit (Tzortzi, 2017).

The pixel as a tool to define the ambiance through the photo

Measuring the ambiance in the architectural space would mean studying several parameters (Lam, 1977; Boubekri, 2008; Augoyard, 2020), two important aspects are quantitative and qualitative (Fedyeva, 2018), if the quantitative component is based on measurements and values (Ganguly et al., 2018), the qualitative component requires parameters more related to the user of the space, a survey (Kaya & Afacan, 2017), commented routes, or observation in situ (Beaudoin, 2016).

The ambiance in the architectural space had always been in relation with the user, his body, and the signals that characterize the space, it is the body of the user that once stimulated reacts to an ambiance by a behavior (Chelkoff, 2018).

Studying the ambiance through the photo can allow deducing a pattern related to the study of: i) the morphology of light and its dispersion on surfaces; ii) the levels of contrast on surfaces; iii) the relative

concentration of light; iv) the gradation or level of uniformity of light on a surface; v) the relative intensity of light. It is sufficient to take the photo study its histogram and developed an image of contrast to deduce the characteristics of the ambiance light (Demers, 1997, 1998).

It is also possible from the HDR images recorded under several exposure levels to obtain visual properties that will allow us to extract the ambient luminous properties (Cai & Chung, 2011; Cai et al., 2014). This will allow us to extract pixels for statistical and mathematical analysis, or use images by color range or iso-contour to understand the luminance distribution (Inanici, 2006).

This observation can be a post-occupancy evaluation (POE), which is often done on users who already have an idea about the field of vision of their space, and who will pass at some point to the sensational phase by reducing the eye movement in their spaces, thus demonstrating a certain equilibrium so they have adapted to the space. Therefore, the luminances do not have to be measured every time, we just have to put ourselves in the place of the user and measure the contrasts, and that will be enough (fig. 1a). To evaluate the luminance, we only need to choose a camera with a 22 mm lens, take a picture of the field of view and define the contrast, shadow, and light areas on the picture using pixelization. This photo-processing could be revealing of the internal ambiance for a long period as the external seasonal conditions are stable, and even if the condition changes the user will be able to adapt to the new conditions (Belakehal et al., 2003). The pixelation and the study of the luminous ambiance, by contrast, is a technique which was used in various research works, this technique had allowed the re-

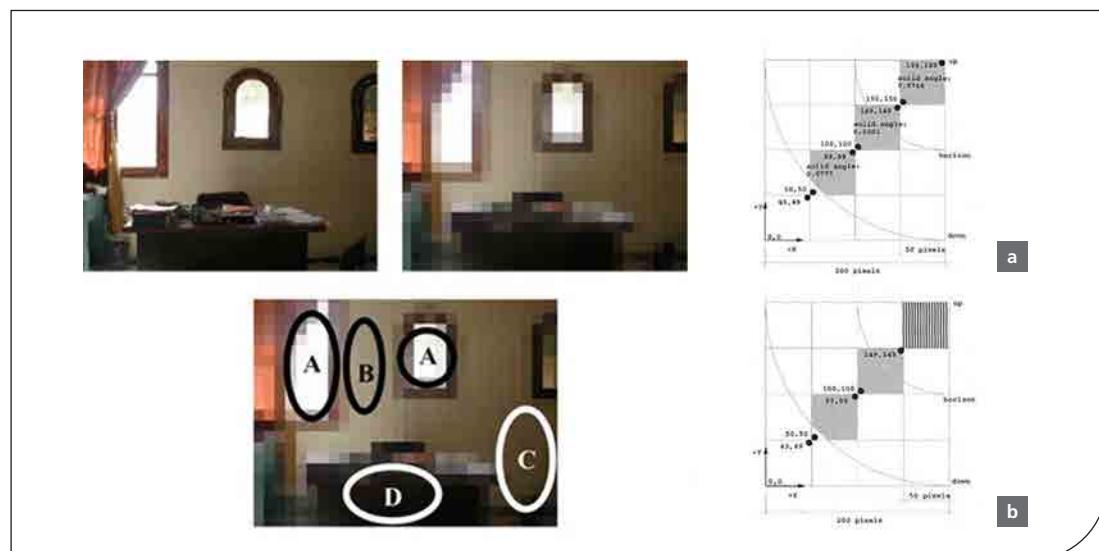


Fig. 1. Pixel processing in the search of Belakehal (a) and Moeck (b). The letters A, B, C, D identify areas with different light contrast. (© Belakehal).

searcher from simple map of luminance to describe a luminous environment, to reproduce it or to analyze it, and by the means of algorithmic filters we can on photos define the directional light with weak pixels (fig. 1b), diffuse with medium pixels, and finally sparkling with very large pixels (Moeck, 2001). Through work on the pixels of photos taken, the visualization of luminance became possible, the evaluation of lighting is by human vision (Cai, 2013).

If the characterization of the ambiances is done in several ways, the studies on the light were often accompanied by studies on the glare, this last can inform us on the luminous ambiance (Beckman et al., 1992; Pierson et al., 2017; Wilder et al., 2019).

THE AMBIANCE, THE ROUTE, AND THE EXHIBITION

The reflections around museology and sustainable development put the daylight in the center of all the debates around this question. The luminous ambiance remains one of the most important in the museum space (Armas, 2011; Saraoui et al., 2018, 2019), to exposing the objects had been since the creation of this establishment subjected to the scenography which requires the use of the daylight (Cuttle, 2007), either natural or artificial, the light put in values the exposed objects and makes the museum adventure pleasant.

Many are the techniques of lighting in the museum by daylight zenithal or lateral, the choice would be made by the architect, his style, and the type of ambiance required. The type and nature of the exhibition often dictate varied lighting typologies (Cuttle, 2007), the light in the exhibition space could have several impacts on the appreciation of the works, and each difference in the mode of exposure by light would communicate a different culture (Schielke, 2020).

The luminous ambiance in the museum is often studied in various forms, we cite for this reason some works that correspond to what we intend to do, the analysis of the luminous ambiance in The Kimbell Art Museum of Louis Kahn allows us to understand the work developed by the architect to compose the museum with light, whatever its type, creating a unique lighting environment, the evaluation of the luminous ambiance was done by radiance, first by simulating the average illumination and then luminances (Kacel & Lau, 2013). We can also take a part of the route and analyze it, it is often the most important part of the exhibition, passing through the entrance such as the work done on the Sharjah museum (Mushtaha & Shadid, 2015).

The study of the luminous ambiance in the museum is based on its route (Yuan et al., 2020; Yamu et al., 2021) and two other parameters: i) the luminance, which corresponds to the visual sensation of brightness, is calculated by measuring the luminous intensity in a given direction, on a given area and in a given angle of observation, its unit is the candela on the square meter (cd/m^2); ii) the illuminance corresponds to a luminous flux received per unit area, measuring the quotient of a total flux received on a given surface (Taillet et al., 2013: 235), in this paper, we will treat the luminance.

MATERIALS AND METHODOLOGY

The case studies about stylistic influence and configurational choice

Of all the European cities, the city of Rome is characterized by its history-laden past, in the city center Rome, we chose two museums located in the same context and obeying the same site characteristics, both in the classical context by excellence (fig. 2).

The first museum is the Ara pacis Museum by Richard Meier, and the second is the museum of Zaha Ha-

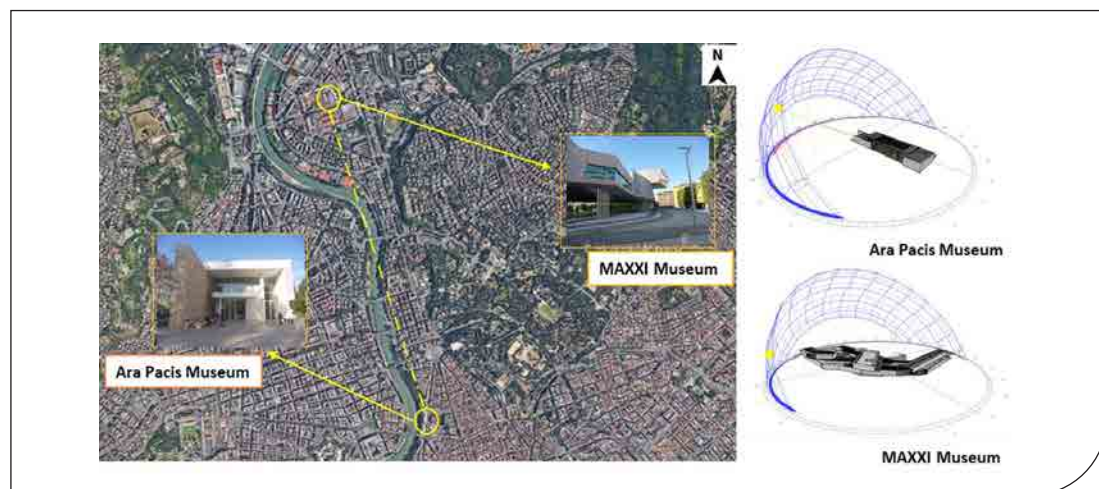


Fig. 2. Geographical location and climatic study of the two museums.

did MAXXI Museum, the choice was made because both museums had the same global orientation of the project, and are located on the same axis, and the climatic and environmental study, allowed us to find many points in common between the two museums. The common element in the spatial configuration of the museums is the use of mathematics. We've seen that the architect created a museum in the new avant-garde style for the Ara Pacis Museum, where we can see the application of the Cartesian spirit of mathematics in the basic geometric form and unambiguous route. The topological geometric form, based on continuous transformations, and the curve were used by the architect with a deconstructivist style for the MAXXI Museum. The route is linear if we choose a small sequence of the visit and labyrinthine if we analyze it in detail. We present the details of the architectural plans in figure 3.

It should be mentioned that for the Ara Pacis Museum, we will take the main display level, for the MAXXI Museum, the first two levels, and for the third, we will not take it because it is divided into two parts that do not communicate.

This paper aims to compare the characteristics of the ambiance in the museum route of the two museums,

we will first study the spatial configuration through the space syntax. The objective of this study is to evaluate the visual integration, connectivity, and movement of the visitors in the route of the two museums. In a second step, we will analyze the flow of visitors through the simulation of agents, and finally, the visual accessibility that will allow us to know if the view perspectives that are offered to visitors are those that will allow him to follow his visit in space or if the displays that dictate directions.

The second part will be devoted to the study of the luminous ambiance according to the photos taken during a visit, the first to evaluate the luminance according to the parts of the route, and finally by the luminance pixels (fig. 3).

Spatial configuration and space syntax

The spatial configuration is the composition that establishes a link between different spaces composing the global architectural space. In this research, we will explore the configurational properties to deduce the socio-spatial and visual characteristics of our space. The software we have chosen will be DEPTHMAP®. This analysis will be done by the VGA method we can obtain other more important parameters.

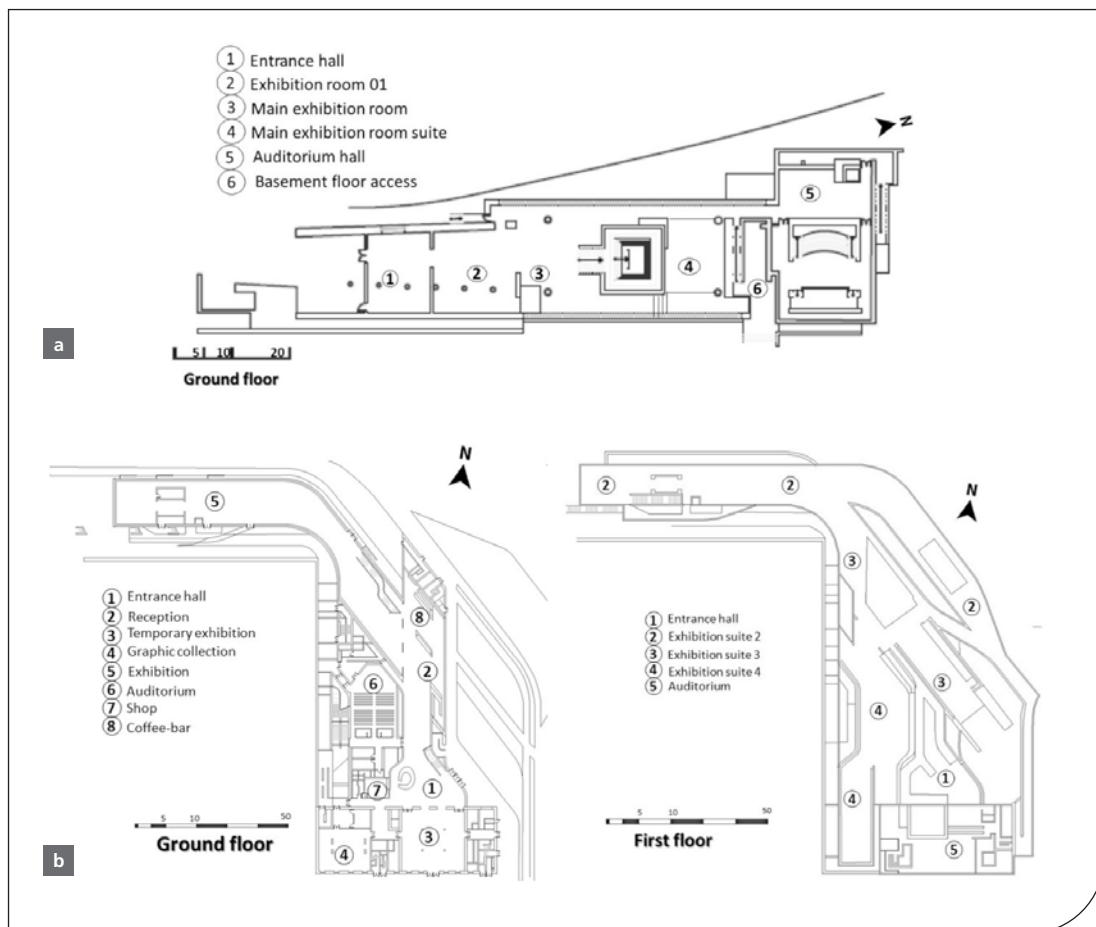


Fig. 3. The plans of the two museums: Ara Pacis Museum (a) and MAXXI Museum (b).

- Visual connectivity. This is the property of the connection between different spaces in the project, the higher the connectivity the more we have a strong spatial relationship between the spaces. The axes of connectivity offer good accessibility to the users of the space, it is noticed that these spaces are the spaces that cognitively mark the users of a given space (Hillier & Tzortzi, 2006).
- Visual integration. It is the capacity to move towards a space without passing by many other spaces, the more the space is integrated it has relations of fluidity more stated with the bordering spaces when the integration is important the space will be more coherent (Hillier & Tzortzi, 2006).

Study of the route and visual light fields

- Simulation of agents between proposed and adapted routes. This simulation is often used to evaluate the human flow in a building or to reorganize a given route. It is based on the principle that the behavior of users in a given space is subject to their perception and understanding of the spatial structure (Yuan et al., 2020). We compare our results with routes initially proposed by architects to see if there are disparities between the architect's proposal and the one resulting from the analysis of the spatial configuration.
- The isovist analysis and the visual field in the museum. From the results obtained in the first part we will choose the isovist that represents the most visual field that is offered to the visitor, according

to the values of the visual integration and the simulation of the agents.

Analysis of the lighting ambiance in museums

This technique will allow us to determine the most interesting visual fields from the point of view of spatial configuration to study, to define the ambiance. According to the resulting isovists, we will determine photographs that we will analyze through several techniques to define the types of lighting ambiance in the museum.

- Going from LDH to HDR. We will use a camera Fujifilm and Leica to take pictures in the museum route according to the isovists, we set the exposure to three values (2,0,2-), and using the free software Luminance HDR®, we superimposed them to obtain a photo of HDR version. This resulting photo had been processed by two software to compare the luminances in the Route, first RADIANCE® and Aftab application, the objective is to achieve to confirm the results of luminances recorded from the photos. We will be able to make a first reading on the type of luminous ambiance that exists depending on the spatial configuration by isolating the artificial light.
- Use of Matlab cluster script to extract the pixels. After a first reading of the ambiance according to the spatial configuration, we have thanks to a Matlab script been able to conclude the luminance from the selected photos, and we had calculated according to its images the percentage of the five dominant pixels in Grey image (fig. 4).

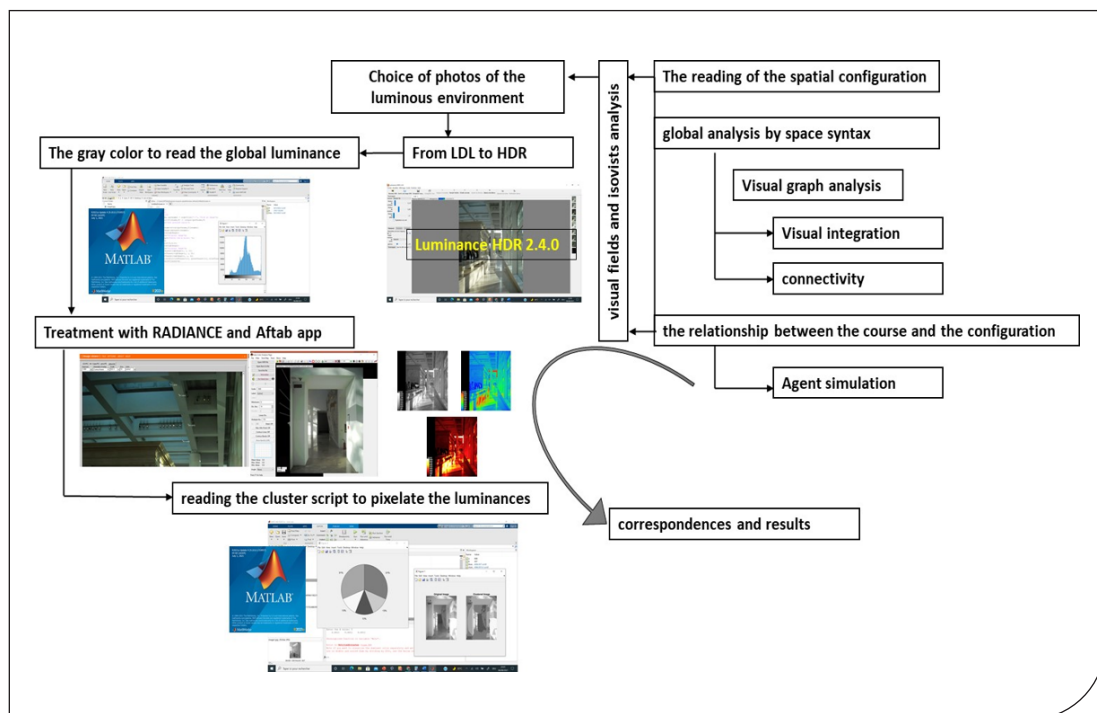


Fig. 4. Methodological framework.

RESULTS AND DISCUSSION

Visually integrated spaces

In the Ara Pacis Museum, the great value of visual integration is located at the South-East side of the plan, the least visually integrated part is the one located at the Northeast. We can also notice that the part behind the Ara Pacis and the reception area presents average values of visual integration (fig. 5a).

In the case of the Zaha Hadid Museum on the ground floor, the highest values of visual integration are located between the coffee bar and the reception area (fig. 5b), we can see that the spaces around this area are more or less visually integrated, the values

of integration decrease at the level of the entrance hall. For the second level (fig. 5c), the highest values of integration characterize the access to the 3rd exhibition space. We notice that, unlike the ground floor, some exhibition spaces are not visually integrated such as the third exhibition room, and the circulation spaces.

We can already make the first observation: for the Ara Pacis Museum, Richard Meier wanted the space to be exposed. In Zaha's work the aspects of visual integration are neglected except for the spaces where there is no exhibition, she sought to create an effect of surprise in her route which despite its linearity and these changes of direction makes it labyrinthine.

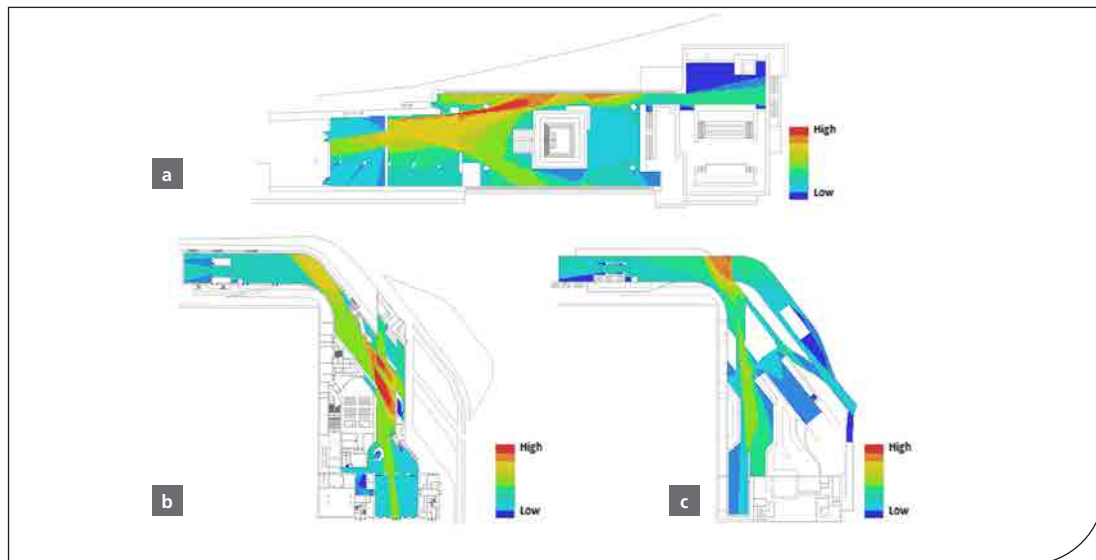


Fig. 5. Result of visual graph analysis (the visual integration): Ara Pacis Museum (a) and MAXXI Museum (b, c).

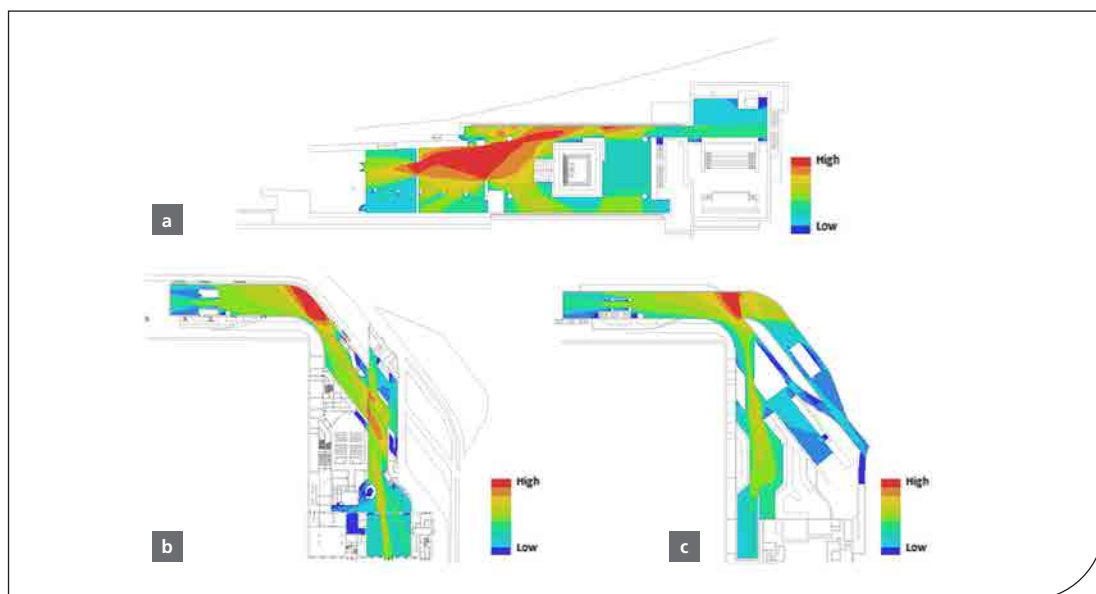


Fig. 6. Result of visual graph analysis (the connectivity): Ara Pacis Museum (a) and MAXXI Museum (b, c).

The visual connectivity of spaces


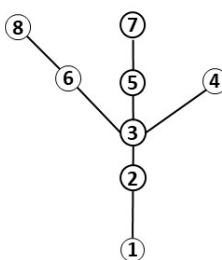
Richard Meier's museum offers great values of connectivity, its values characterize the very first part of the route from the entrance to the large exhibition hall. and being throughout the route on the west side. The eastern part is characterized by medium values. The exhibition area on the auditorium side has the lowest connectivity value (fig. 6a).

For the MAXXI museum, there are two visually connected parts, the hall between the coffee bar and the reception, and part of the first exhibition space on the ground floor, in the rest of the spaces the connectivity is average, we notice low values for the coffee bar and the circulation spaces (fig. 6b). For the case of the second floor, we notice that the value of connectivity is high in the exhibition space contin-

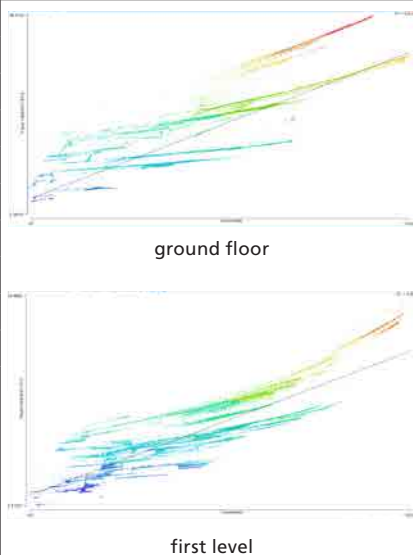
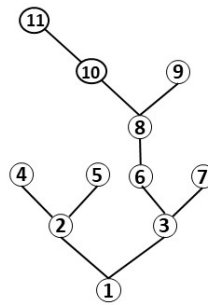
ued with the ground floor, for the fourth exhibition space it is average, and for the third exhibition room, the connectivity is low (fig. 6c).

The convex graph and global intelligibility

As a synthesis of this first reading, we calculated the values of visual integration for each space, the most integrated spaces in The Ara Pacis Museum are the first exhibition room and the western part of the main exhibition room. In the case of MAXXI Museum, we noticed that the most integrated space is the reception area on the first level, followed by the first exhibition room on the second floor, which is in direct relation with the reception area on the first level and the entrance hall on the second floor.

Space according to the number		Visual integration	Intelligibility graph	Exhibition convex spaces topology
1	Entrance hall	10.35		 R^2 ground floor = 0.86
2	Exhibition room 01	13.96		
3	Main Exhibition room 01	13.83		
4	Main Exhibition room suite	9.97		
5	Auditorium hall	8.44		
6	Basement floor access	Not def		
7	Auditorium	Not def		
8	Basement rooms	Not def		

Tab. 1. Summary of the characteristics of intelligibility in the Ara Pacis Museum.

Space according to the number		Visual integration	Intelligibility graph	Exhibition convex spaces topology
1	Entrance hall	8,87		 <p>R^2 ground floor = 0.63 R^2 first floor = 0.76</p>
2	Temporary exhibition	8.28		
3	Reception	13.78		
4	Graphic collection	Not def		
5	Auditorium	Not def		
6	Exhibition room 1	10.14		
7	Coffee-bar	10.06		
8	Entrance hall first floor	9.9		
9	Exhibition room 2	13.28		
10	Exhibition room 3	12.08		
11	Exhibition room 4	9.05		

Tab. 2. Summary of the characteristics of intelligibility in the MAXXI Museum.

The values of visual intelligibility are higher than 0.5 in all museums floors and the point clouds approach the 45° line which means that each space has good visual connectivity at the local level, and is well-integrated into the whole system, the space of the Ara Pacis Museum is the most intelligible with a value of 0.86, the MAXXI Museum spaces are a little less, for the first level we find a value of 0.63, and for the second level 0.76, so we can conclude that the spatial configurational system of the two museums is legible (tabs. 1, 2).

The comparison between the route and the agent simulation

In a second step, we compared the architects' route, as well as the visitors' experiences with their choices and the agents' simulation. We entered the biggest

number of visitors into the software according to attendance rates, to see their behavior inside, and we saw that the routes corresponded. This signifies that the current visit route is the same as the one suggested by the software globally.

For the Ara Pacis Museum and the first level of the MAXXI Museum, the routes match perfectly (fig. 7a), for the second level of the MAXXI Museum we have a slight discontinuity in the northeast part (fig. 7b, c).

Choice of the fields of ambient view to be studied in the route according to the isovists

The first results related to the configurational properties and the museum route will allow us to choose the location of the isovists related to the analysis

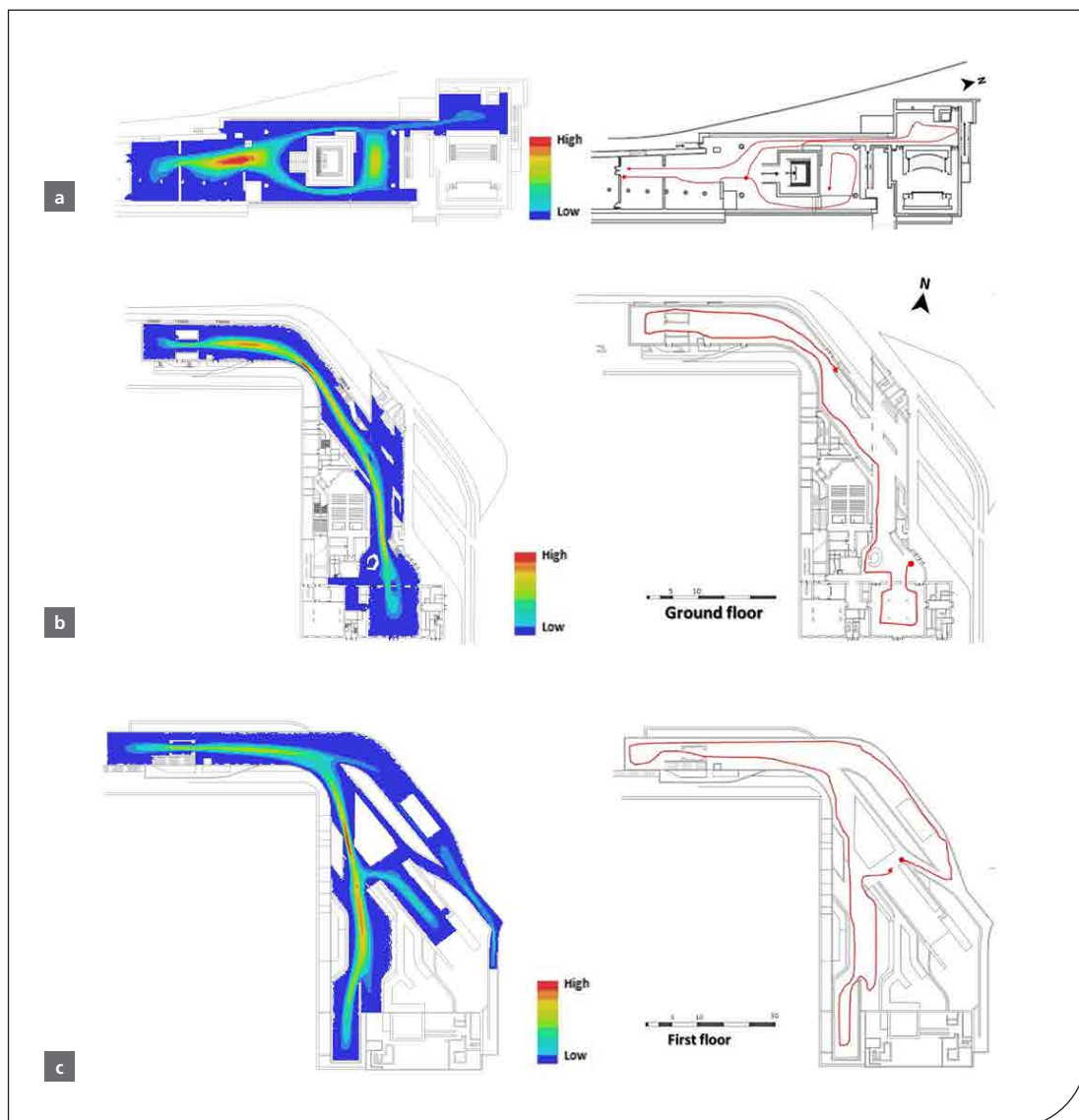


Fig. 7. Result of agent simulation compared to the museum's routes: Ara Pacis Museum (a) and MAXXI Museum (b, c).

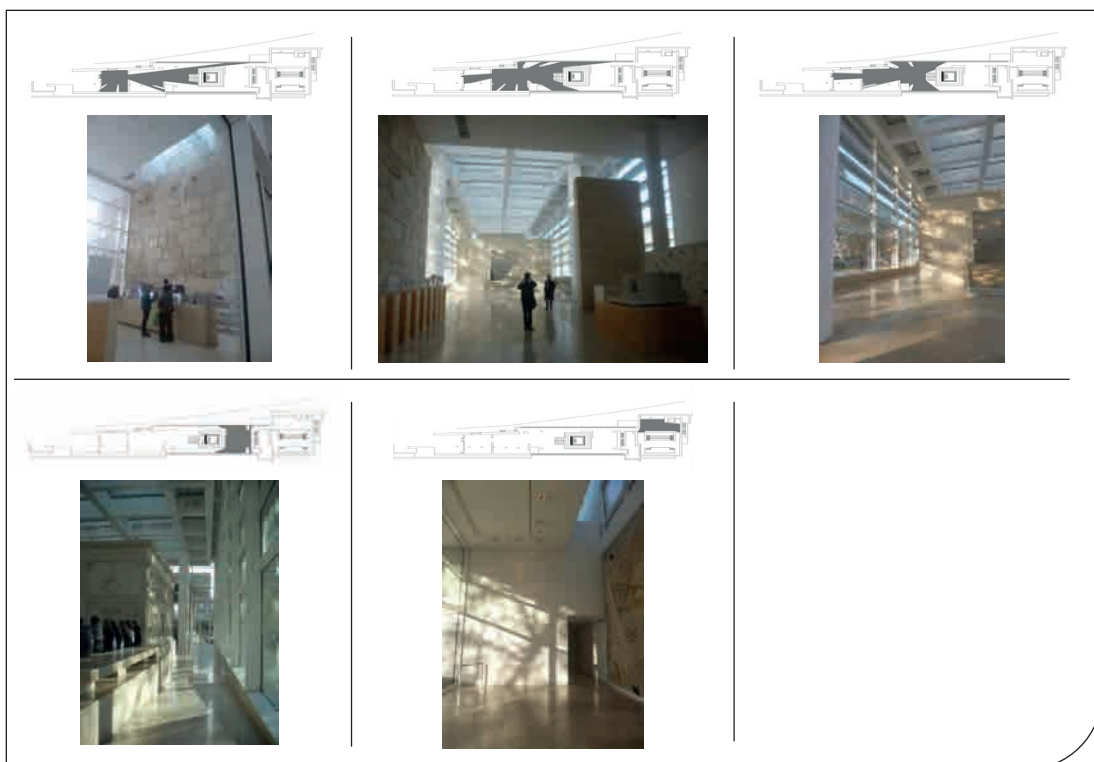


Fig. 8. Isovistes of the Ara Pacis Museum.

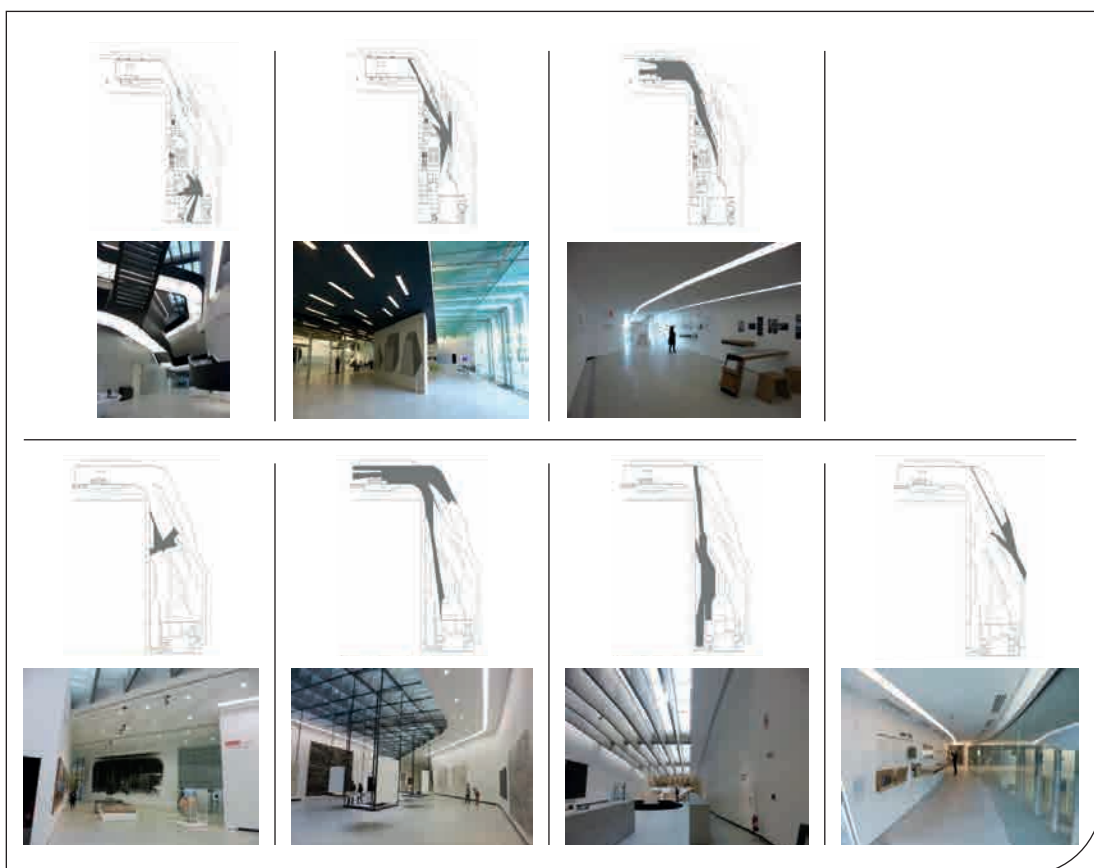


Fig. 9. Isovistes of the MAXXI Museum.

of the luminous ambiance in our study cases. The properties of the isovists chosen in the Ara Pacis Museum show that in the axis of the highest values of visual integration, the areas of the field of view and its perimeter are very important (fig. 8).

The isovists in the MAXXI Museum are very varied, first of all, that of the entrance hall foreground and background is low in surface compared to that of the reception area. For the rest of the isovists, the surface is important (fig. 9).

We will choose according to the isovists of the photo sequences and analyze the luminous ambiance in the museums according to the spatial configuration, first an isovist of the entrance hall, that of the most visually integrated part, that of the exhibition space, and finally the weakest.

The global luminance on the HDR image

We had initially analyzed the histograms of the colors of the parts or the values of the visual integration was average, with the program Matlab we compared the histograms RGB and those of the gray color (fig. 10). This comparison allowed us to conclude that in the end the shape of the graph and the highest and lowest values are the same. As a result, the gray color version would be the one we will use, we will reduce by RGB pixels in the museum and the evaluations will be on the same typology of pixels. From this conclusion we have made the photos through Radiance and Aftab app treatments to be able to read the luminance distributions in the two museums, we have noticed that the Ara Pacis museum has the highest values of maximum luminance. At the level of low values, the museums correspond. We have taken photos of the luminous ambiance chosen from the isovists to carry out this work, according to the route we have taken four sequences: i) entrance

hall; ii) a sequence of the most visually integrated route; iii) a sequence with medium visual integration; iv) a sequence with low integration (tab. 3).

For the entrance space, both museums present the same configurational characteristics regarding numerical values, however, the space of the Ara is a simple rectangle with an imposing volume, the space of the MAXXI Museum is much more suitable for human height.

The average luminance in this space for the Ara Pacis Museum is between 450 and 500 cd/m^2 , the maximum luminance is located at the zenithal opening reached a value of 1273.53 cd/m^2 , however, the zenithal opening at this level does not occupy, we have not found a significant rate of glare, given the advanced ceiling that constitutes horizontal protection of the entrance to the main facade, and the materials that compose the space and which are of texture rough that does not reflect solar radiation.

In the case of the MAXXI Museum, the values of luminance vary between 0.03 and 450 cd/m^2 , the east side lighting with its small surface area on the ground floor does not offer a large amount of luminance, and the skylights, although open, do not provide high levels of luminance, hence the use of artificial lighting in this part of the route, glare is non-existent.

In the sequence that represents the best configurational properties and for the case of the Ara Museum the values of luminance vary between 46.9 and 1703.18 cd/m^2 , the average values are close to 550 cd/m^2 , very homogeneously distributed over the whole of this part of the route, this distribution is explained by the stability of the zenithal lighting, which provides a good ambiance without contrast effect thanks to the skylights in the form of a perforated cube that characterize the ceiling, despite the

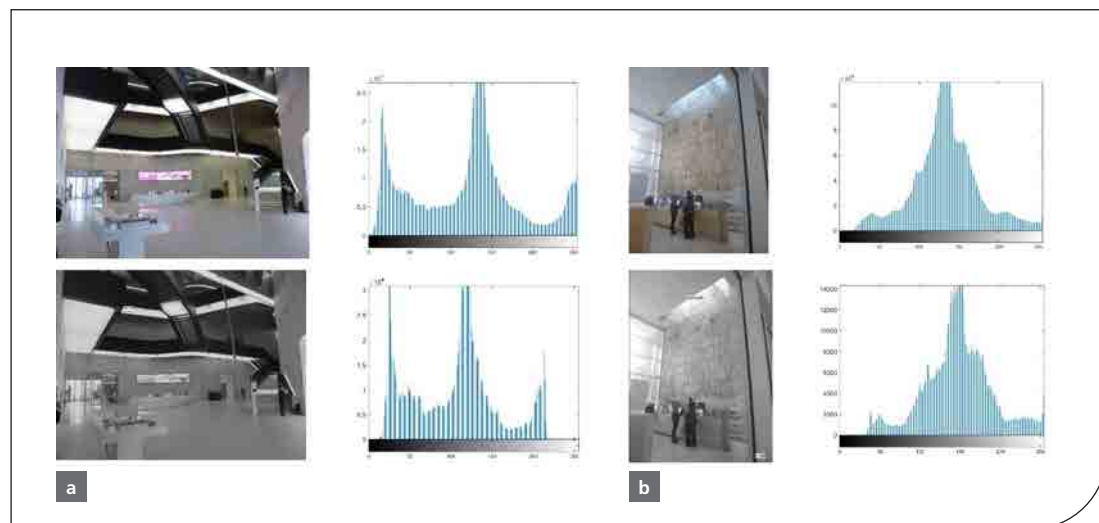


Fig. 10. Comparison between the photo histograms of the two museums MAXXI Museum (a) and Ara Pacis Museum (b).

contrast sought by the architect, and produced by the side window with removable curtains completely open for the most unfavorable day of December, we found the existence of a very low glare surface at ground level.

For the MAXXI Museum the values of luminance vary between 50 and 637 cd/m^2 , the average for this space located at the exit of the coffee bar and the reception and in front of the access to the exhibition space on the ground floor, the average luminance is 450 cd/m^2 , the highest values are found next to the side bays, the lowest is due to the black color of the roofing.

In the sequence where the visual integration is average, and for the case of the Ara Pacis Museum the values of luminance vary between 229.8 and 1056.26 cd/m^2 , the distribution of luminance is very homogeneous, this is due to the uniformity of natural light at the ceiling level seen when in this part also the zenithal lighting occupies all the surface of the ceiling, and this is also the case of the lateral lighting, for the most unfavorable period the glare is very low.

For the MAXXI Museum, in the spaces where the visual integration is average, and in general in this museum its spaces are mostly exhibition spaces, the luminance values vary between 0.08 and 507.04 cd/m^2 , the average luminance value is 280 cd/m^2 , often compensated by directed artificial lighting.

For the sequence where the values are low, we took two samples that revealed the same results, the one in






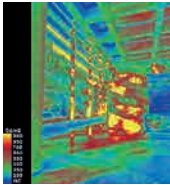



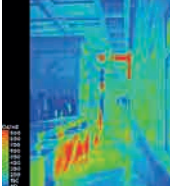


the table presents the corridor of the Auditorium part, the values of luminance varies between 18 and 697.08 cd/m^2 , the average of the values is 339.65 cd/m^2 , the glare is absent.

For the MAXXI Museum the luminances vary considerably in the less visually integrated parts, we found that for the most part, the use of artificial lighting is necessary, in the photo we have chosen, for the lateral lighting the values of luminances vary between 54 and 1014.23 cd/m^2 , the average value of luminances is 480 which is an imposing value compared to the other sequences chosen, we still constant that the artificial lighting is omnipresent despite the high values of luminances.

The image cluster and the pixel values

We have elaborated measures through the cluster technique on Matlab, these measures have allowed us to obtain the percentages of dominant pixels in each isovist chosen, we present in figure 11 an example of this operation, the results obtained for the entire route have allowed us to draw a graph of pixel values in each sequence chosen according to the museum analyzed. The analyzed clusters were recorded in three resolutions, first at 75×75 pixels, 150×150 pixels, 300×300 pixels, and finally 600×600 pixels. The solid angle increases as the pixels are increased.

There are for each pixelated photo a maximum of 6 shades, we have defined on the Matlab cluster script 5 pixels and for each photo, we will have a pixel more or less depending on the ambiance (fig. 11). We were

The museum	The Ara Pacis Museum		The MAXXI Museum	
Sequence entrance hall				
Most integrated route sequence				
Moderately integrated route sequence				

Tab. 3. Summary of grey and false-color luminance results.

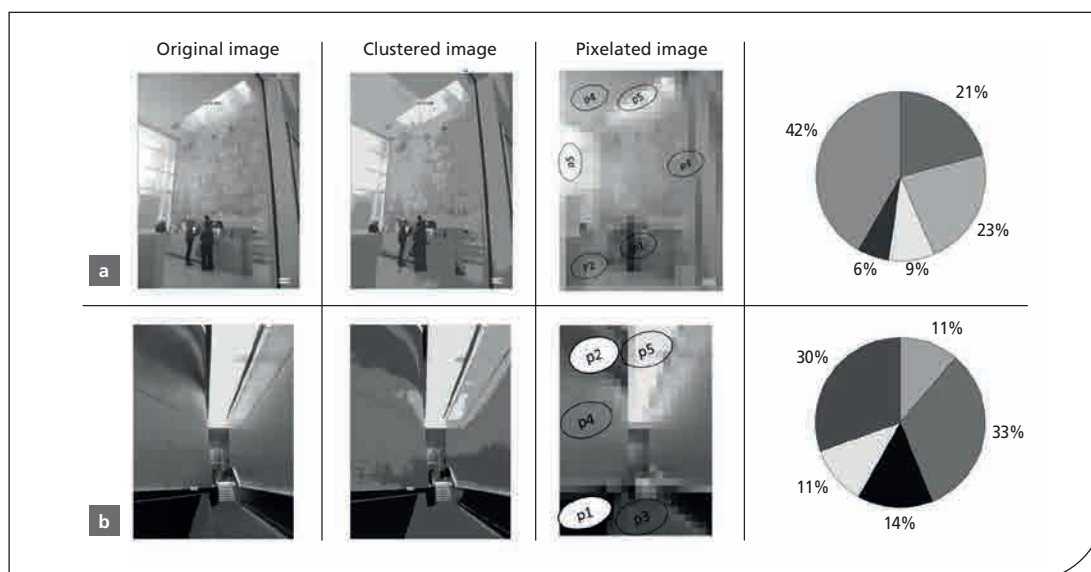


Fig. 11. Example of the application of the cluster script on a gray photo in the two museums: Ara Pacis Museum (a) and MAXXI Museum (b).

able to deduce the values of the solid angle depending on the photos, the values of the solid angle for the Ara Pacis Museum are between 0.6706/0.3143, for the MAXXI Museum the values are between 0.4501/0.087, which means that the second museum has a low surface exposure in the photos taken.

In the Ara Pacis Museum, the first part of the route (the entrance hall) and the last part at the floor level (the auditorium hall), represents high values of dark pixels, this is explained by the low luminances, the type of lighting in both halls is mixed (lateral, zenithal). For the main exhibition hall we see very high values of luminance, materialized by the dominance of light pixels, the lighting is zenithal and lateral type, for the first exhibition hall and the continuation of the main hall we notice that the graphs of pixels are almost symmetrical, which means the same ambiance with a field of vision reversed (fig. 12).

In the MAXXI Museum, the dark pixels seem to dominate in the route, this is due to the use of black color in the elements composing the route and the exhibition, despite the sobriety of the walls and floors and their clarity the overall component, the characteristics of the sequences of the visual field seems unstable the graph reveals that for the entrance hall, the reception, and the entrance hall to the floor the pixels are dark to more than 50%, despite the existence of some small percentage of bright pixels due especially to the areas on the photo of the lateral lighting. The dominance of this type of lighting also in the coffee bar makes the luminance clear. Regarding the exhibition spaces, we notice stability in the characteristics of luminances by approximately the same pixels, for the case of the first exhibition room the values of luminance

pixels tilt towards the dark because of the absence of zenithal lighting, on the other hand, the luminances of the exhibition room of the fourth exhibition room seems to have the brightest luminance pixels (fig. 13).

CONCLUSION

The analysis of the spatial configuration through space syntax reveals that beyond the stylistic differences between the architects Meier and Hadid, their museums reveal the existence of good integration and visual connectivity, which makes both museums intelligible and spatially legible for visitors, although both museums exceed the value of 0.5 in coefficient of intelligibility, the Meier museum remains the most intelligible with an overall value of 0.8.

for the two museums, the thought-out, lived, and reflected itinerary is perfectly superimposed on the ideal itinerary proposed by the simulation of the agents, this represents a great positive point regarding the management of the flows and the choice of the visitors about the spatial configuration.

The analysis of the visual fields reveals that the iso-vists have in both cases of study imposing surfaces and perimeters which offer to the visitors a good field of vision inciting him to follow his visit, the limited fields are not located in the main route of visit in the museum of Meier, but in that of Zaha Hadid, there is some part where the field is limited by the curvilinear of the lines, this is explained by the fact that Zaha who draws from the deconstructivist repertory seeks to create an effect of surprise. Considering the rough texture chosen by the architect, a global examination of luminance using

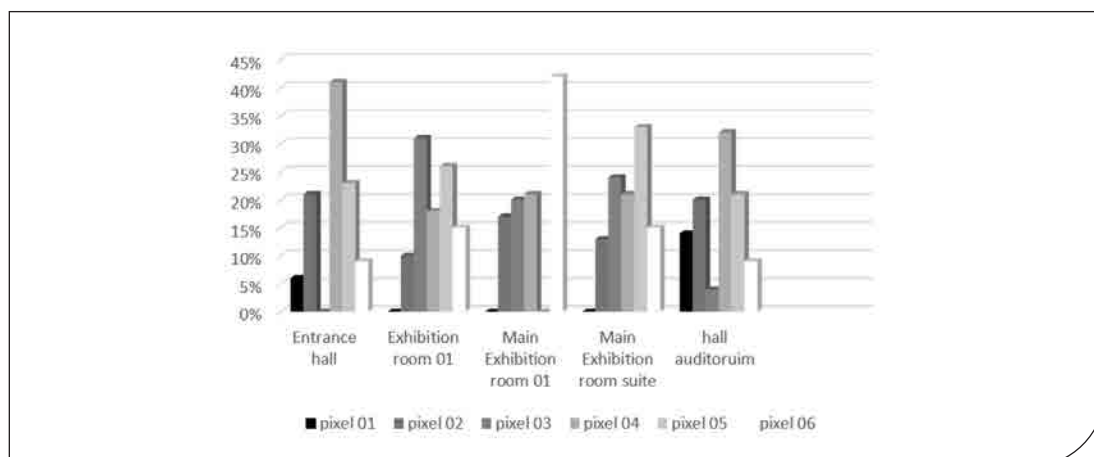


Fig. 12. Pixels in Ara Pacis museum.

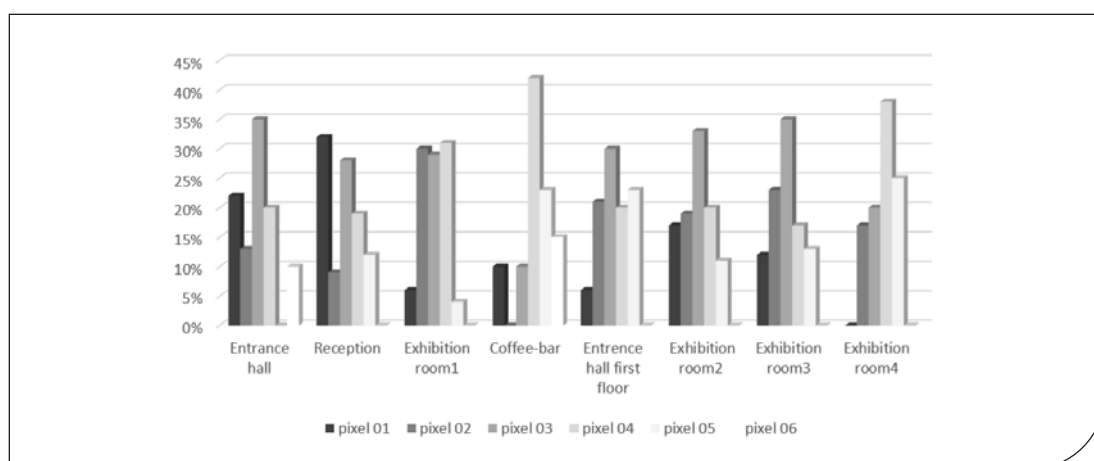


Fig. 13. Pixels of MAXXI Museum.

sequences photographed in gray color and false color and isolating artificial light reveals that the Ara Pacis Museum has the highest rate of luminance. Despite Zaha Hadid's choice of extreme contrast black or white in 70 percent of the route, the overall luminances of the museum are quite low, and indicating the existence of zenithal illumination with a retractable skylight, the artificial lighting is more than necessary.

The isolation of the luminance pixels according to the space revealed for the Ara Pacis Museum, stability when it comes to the characteristics of the luminous ambiance, we have a large percentage of luminous pixels in the main exhibition halls, the more we move away from this space towards the spaces that are not dedicated to the exhibition the percentages tend to decrease. In the case of the MAXXI museum, the characteristics of the isolation of the pixels reveal the instability of the luminous ambiance, we have a homogeneous ambiance within the exhibition space, but when compared to another

space of the same vocation the ambiance is no longer the same, and the percentage of dark pixels is important compared to the Ara Pacis Museum.

Finally, and despite the different stylistic registers of the two contemporary architects, the properties of luminance that characterize the ambiance are similar, in both museums the areas of high visual integration, often correspond to the place from which the visitor starts his visit, in these spaces the luminous pixels are the most important, The architects seek to use natural light at very high values to create stability in the spaces where there is a succession of the visual field, the only difference lies in the type of lighting, in Zaha's the route and rather a zenithal lighting, It is mixed for Meier, with a consistent zenithal and a very high contrast lateral; this contrast appears to be wanted by the architect, as the removable protection is not employed.

The distinctions are found in the spatial relationships between the exhibition spaces; in Meier's case, the linear route to the space is crossed without am-

biguity. Despite the high values, we find disparities between the values of visual integration on the same level in the case of Zaha; this difference is accompanied by a variety of exhibits, and even the type of lighting, which we found insignificant in the case of side lighting, as it allows for higher illumination values but has little impact on the interior ambience, we found insignificant in the case of side lighting, as it allows for higher illumination values but has little impact on the interior ambience, resulting in the overuse of artificial lighting, especially when combined with the path that follows the curvilinear shape of the walls and heightens the surprise effect.

REFERENCES

- ARMAS J., 2011. *Lighting for Museums*. In: Topical Problems in the Field of Electrical and Power Engineering, 10th International Symposium, Pärnu, Estonia, January 10-15, 2011.
- AUGOYARD J.-F., 2020. For an aesthetics of ambience. *Ambiances* (<https://doi.org/10.4000/ambiances.3136>).
- BEAUDOIN J.-M., 2016. Évaluation de parcours d'exposition: une approche par indicateurs spatiaux et temporels. *La Lettre de l'OCIM*, 165: 24-31 (DOI: <https://doi.org/10.4000/ocim.1658>).
- BECKMAN C., SCOTT R., GARNER L.F., 1992. Comparison of three methods of evaluating glare. *Acta Ophthalmologica*, 70(1): 53-59 (<https://doi.org/10.1111/j.1755-3768.1992.tb02091.x>).
- BELAKEHAL A., Tabet AOUL K., BENNADJI A., 2003. *An evaluation method for daylighting quality in buildings under clear sunny skies*. In: Craig, T. (ed.), Proceedings of the 3rd Conference of the Environmental Psychology in the UK (EPUK) Network, 23-25 June 2003, Aberdeen, UK. Aberdeen: Robert Gordon University, pp. 70-79.
- BOUBEKRI M., 2008. *Daylighting, architecture and health: building design strategies*. Routledge.
- CAI H., 2013. Luminance gradient for evaluating lighting. *Lighting Research & Technology*, 48(2): 155-175 (<https://doi.org/10.1177/1477153513512501>).
- CAI H., CHUNG T.M., 2011. Improving the quality of high dynamic range images. *Lighting Research & Technology*, 43(1): 87-102 (<https://doi.org/10.1177/1477153510371356>).
- CAI H., SAIFAN M.I., KILLEEN J.A., 2014. Case studies of a camera-aided imaging method for evaluation of interior luminous environments. *Indoor and Built Environment*, 24(5): 658-671 (<https://doi.org/10.1177/1420326x14534457>).
- CHELKOFF G., 2018. Expérimenter l'ambiance par l'architecture. *Ambiances*, 4 (DOI: <https://doi.org/10.4000/ambiances.1558>).
- CUTTLE C., 2007. *Light for Art's Sake. Lighting for Artworks and Museums Displays*. Elsevier, Oxford (UK).
- DEMERS C.M.H., 1997. *Light as a Generator of Space: images in the assessment and design of light in architecture*. Doctoral thesis, Department of Architecture, Martin Centre for Architectural and Urban Studies, University of Cambridge (UK).
- DEMERS C.M.H., 1998. *Qualities Of Light And Space: contrast as a global integrator*. First Simposium of the Quality of Light, 9-10 May 1998, Ottawa (https://www.researchgate.net/profile/Claude-Demers/publication/237810348_QUALITIES_OF_LIGHT_AND_SPACE_contrast_as_a_global_integrator/links/54452f700cf2f14fb80ef579/QUALITIES-OF-LIGHT-AND-SPACE-contrast-as-a-global-integrator.pdf).
- DURSUN P., 2007. *Space Syntax in Architectural Design Proceedings*. Proceedings, 6th International Space Syntax Symposium, Istanbul, 2007 (https://www.researchgate.net/profile/Pelin-Dursun/publication/228646158_Space_Syntax_in_Architectural_Design/links/54a696690cf257a6360a81b8/Space-Syntax-in-Architectural-Design.pdf).
- FEDYAEVA E.V., 2018. Quantity VS Quality: Logical-Philosophical and Cognitive Bases of Interaction. CILDIAH-2018. *SHS Web of Conferences*, 50, 01053 (<https://doi.org/10.1051/shsconf/20185001053>).
- FERNÁNDEZ L.A., 1999. *Museología y museografía*. Ediciones del Serbal.
- GANGULY S., WANG F., BROWNE M., 2018. Comparative methods to assess renovation impact on indoor hygrothermal quality in a historical art gallery. *Indoor and Built Environment*, 28(4): 492-505 (<https://doi.org/10.1177/1420326x18785791>).
- GREGORY R., 2008. *100 bâtiments majeurs du XXIe siècle. Plans, coupes et élévations*. Le Moniteur.
- HILLIER B., 1996. *Space is the Machine*. Cambridge University Press, Cambridge.
- HILLIER B., HANSON J., 1984. *The Social Logic of Space*. Cambridge University Press.
- HILLIER B., TZORTZI K., 2006. *Space Syntax: The Language of Museum Space*. In: MacDonald S. (ed.), *A Companion to Museum Studies*. Blackwell Publishing Ltd. Chapter 17. pp. 282-301.
- INANICI M.N., 2006. Evaluation of high dynamic range photography as a luminance data acquisition system. *Lighting Research & Technology*, 38(2): 123-134 (<https://doi.org/10.1191/1365782806li1640a>).
- KACEL S., LAU B., 2013. *Investigation of the Luminous Environment in Louis I. Kahn's Kimbell Art Museum A qualitative and quantitative study*. PLEA2013 - 29th Conference, Sustainable Architecture for a Renewable Future, Munich, Germany, 10-12 September 2013. (<https://mediatum.ub.tum.de/doc/1169320/file.pdf>).

- KAYA S.M., AFACAN Y., 2017. Effects of daylight design features on visitors' satisfaction of museums. *Indoor and Built Environment*, 27(10): 1341-1356 (doi:10.1177/1420326x17704028).
- LAM W.M.C., 1977. *Perception and lighting as formgivers for architecture*. Edited by Christopher Hugh Ripman. McGraw-Hill, New York (NY).
- MATTERN S., 2014. Animated Spaces. *The Senses and Society*, 9(2): 131-150 (<http://dx.doi.org/10.2752/174589314X13953118734742>).
- MAZOUZ S., BENHSAIN S., 2009. *Handling Architectural Complexity by Combining Genetic and Syntactic Approaches. The Case of Traditional Settlements in North Africa*. In: Koch D., Marcus L., Steen J. (eds), Proceedings of 7th International Space Syntax Symposium. KTH, Stockholm, Ref 073, pp. 1-13 (http://sss7.org/Proceedings/03%20Spatial%20Analysis%20and%20Architectural%20Theory/073_Mazouz_Benshain.pdf).
- MEYER M., 1989. La communication par le son dans les musées et les expositions. *La Lettre de l'OCIM*, 4: 16-19 ([https://doc.ocim.fr/LO/LO004/LO4\(4\)-P.PDF](https://doc.ocim.fr/LO/LO004/LO4(4)-P.PDF)).
- MOECK M., 2001. Analysis and Synthesis of Lighting Atmospheres. *Journal of the Illuminating Engineering Society*, 30(1): 141-153 (DOI: 10.1080/00994480.2001.10748342).
- MUSHTAHA E.S., SHADID R., 2015. Evaluating Daylight Performance of Sharjah Archaeology Museum in UAE with a Reference of Kuwait National Museum. *Journal of Civil Engineering and Urbanism*, 5(6): 265-271.
- NIK KHAH M., MIRALAMI S.F., POURSAFAR Z., 2021 (2020). Route analysis in the architecture of museums and tomb buildings through space syntax case study: (Tomb of Nader Shah in Mashhad, Avicenna Mausoleum in Hamadan, and Mausoleum of poets in Tabriz). *Journal of Asian Architecture and Building Engineering*, 20(6): 640-649 (DOI: 10.1080/13467581.2020.1807990).
- PERESSUT L.B., 1999. *Musées. Architectures 1990-2000*. Actes Sud - Federico Motta, Arles - Milano.
- PIERSON C., WIENOLD J., BODART M., 2017. Discomfort glare perception in daylighting: influencing factors. *Energy Procedia*, 122: 331-336 (<https://doi.org/10.1016/j.egypro.2017.07.332>).
- REYNOSO C., REYNOSO N.P., 2012. *Space Syntax In Museum Exhibition Security And Scripting Effects: The Museo Nacional de Colombia*. In: Greene M., Reyes J., Castro A. (eds.), Proceedings: Eighth International Space Syntax Symposium, PUC, Santiago de Chile.
- ROHLOFF I.K., PSARRA S., WINEMAN J., 2009. *Experiencing Museum Gallery Layouts through Local and Global Visibility Properties in Morphology An inquiry on the YCBA, the MoMA and the HMA*. In: Koch D., Marcus L., Steen J. (eds), Proceedings of the 7th International Space Syntax Symposium, KTH, Stockholm.
- SARAIVA M., 2001. *L'environnement sensible dans les musées à caractère ethnologique*. Thèse de doctorat encadré par: J.F. Augoyard.
- SARAQUI S., BELAKEHAL A., ATTAR A., BENNADJI A., 2018. Evaluation of the Thermal Comfort in the Design of the Museum Routes: The Thermal Topology. *Journal of Contemporary Urban Affairs*, 2(3): 122-136 (<https://doi.org/10.25034/ijcu.2018.4727>).
- SARAQUI S., BELAKEHAL A., ATTAR A., BENNADJI A., 2019. The Topological Reading of Ambiances in the Built Environment: The New Methodology for the Analysis of the Luminous Ambiance in the Museum Space. EAEA14 2019. *SHS Web of Conferences*, 64, 03004 (<https://doi.org/10.1051/shsconf/20196403004>).
- SCHIELKE T., 2020. Interpreting Art with Light: Museum Lighting between Objectivity and Hyperrealism. *LEUKOS*, 16(1): 7-24 (DOI: 10.1080/15502724.2018.1530123).
- TAILLET R., VILLAIN L., FEBVRE P., 2013. *Dictionnaire de physique*. De Boeck, Bruxelles.
- TZORTZI K., 2007. *Museum building design and exhibition layout: patterns of interaction*. Proceedings, 6th International Space Syntax Symposium, Istanbul, 2007.
- TZORTZI K., 2017. Interroger le rôle de l'espace dans le musée. *La Lettre de l'OCIM*, 169 (DOI : <https://doi.org/10.4000/ocim.1732>).
- WILDER R., MUKHOPADHYAY J., FEMRITE T., AMENDE K., 2019. Evaluating Glare in Leed Certified Buildings To Inform Criteria For Daylighting Credits. *Journal of Green Building*, 14(4): 57-76 <https://doi.org/10.3992/1943-4618.14.4.57>.
- YAMU C., VAN NES A., GARAU C., 2021. Bill Hillier's Legacy: Space Syntax—A Synopsis of Basic Concepts, Measures, and Empirical Application. *Sustainability*, 13(6), 3394 (<https://doi.org/10.3390/su13063394>).
- YUAN L., HUANG J., YANG L., 2020. From functional space to experience space: Applying space syntax analysis to a museum in China. *International Review for Spatial Planning and Sustainable Development*, 8(2): 86-99 (DOI: http://dx.doi.org/10.14246/irspsda.8.2_86).

Submitted: October 10th, 2021 - Accepted: April 25th, 2022
Published: December 6th, 2022