International Conference
FLORENCE HERI-TECH
The Future of Heritage Science and Technologies

Adaptive reuse, refurbishment and conservative rehabilitation of Cultural Heritage by means of Quality and Energy Sustainable Lighting

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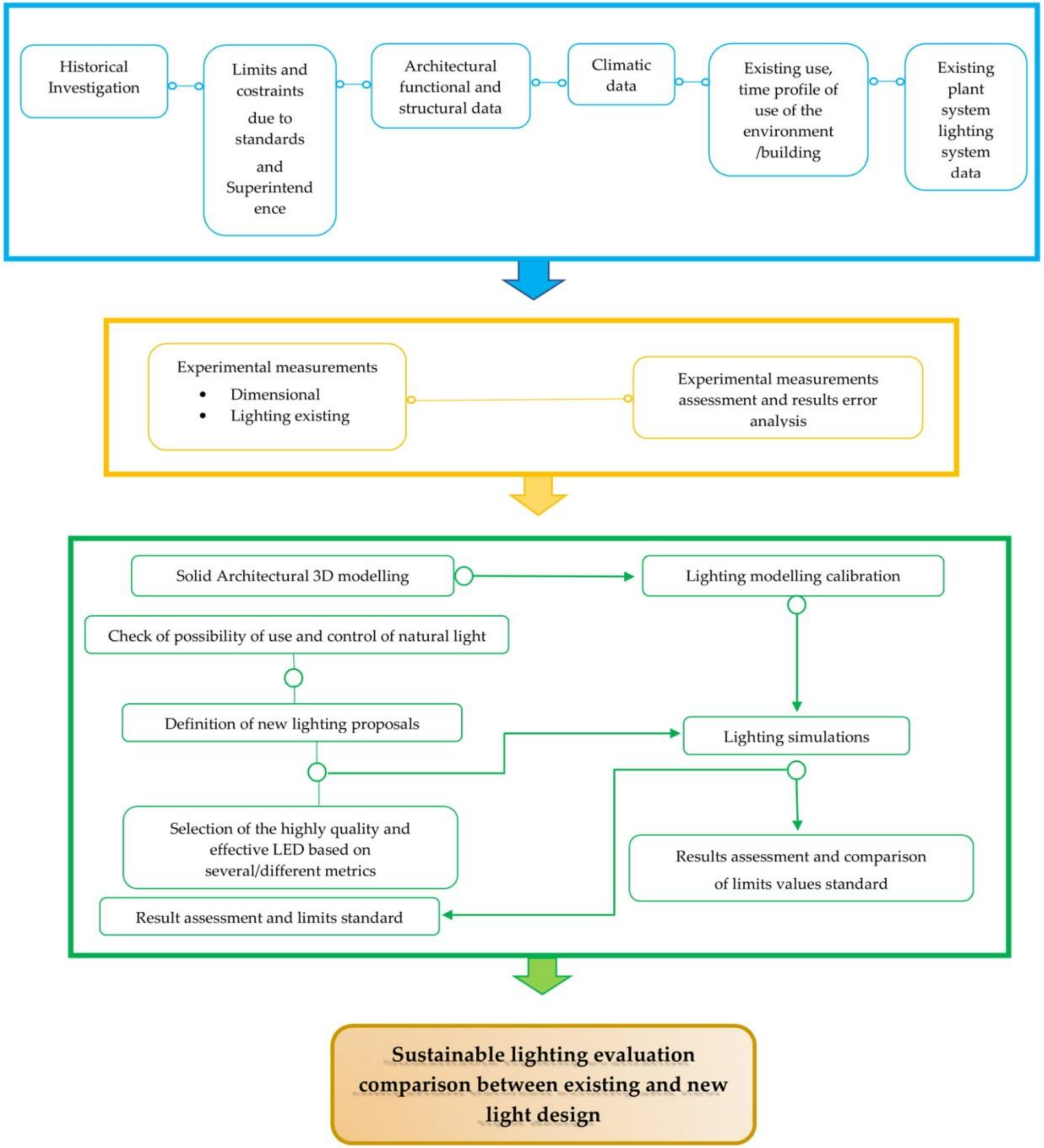
FHT Int. Conference, 14-16 October 2020 Online Edition

Our proposed method uses an approach based on several, complementary metrics, different but interconnected lighting parameters for defining the luminous environment.

Basic steps of the used method is shown by a flow chart.



The proposed method is based on the following crucial phases

1) data collection on historical references, limits and constraints due to current standards, external ambient climate, architectural-functional aspects and different uses of the ambient;
2) technical data on the existing lighting system and evaluation of the possible recovery and re-use of the existing electrical, suspending and control systems;
3) existing luminous climate assessment by experimental measurement on natural and artificial light;
4) building modelling and lighting simulation;
5) results analysis and comparison with current standards;
6) new lighting proposal by means of adaptivity, sustainability and reversibility concepts, by recovering of the space meaning and the historical-philological memory of the environment, finding lighting scenarios referring to the historical building/environment and its existing use, restoring its original architectural features, identifying different volumes and paths.

The case study is a historic church converted into university library and was used as pilot and test project in order to check the extensibility, adaptability and real applicability of the proposed methodology to all similar cases.

The 3D model of the environment with the existing lighting system, built up in one our recent research, was used.

The whole building and library belong to CH and are listed. The library is 10,93 m in length, 12,43 m in width and 9,82 m in height; the reading room is 22,93 m in length, 12,43 m in width and 10,62 m in height.

The natural light access is from vaulted openings placed in the highest part of the two side walls of the church: i.e. 29 single-glass windows placed at a height of 7,60 m from the floor: eight on the East and eight on the West walls, and 13 on the walls in the apse.

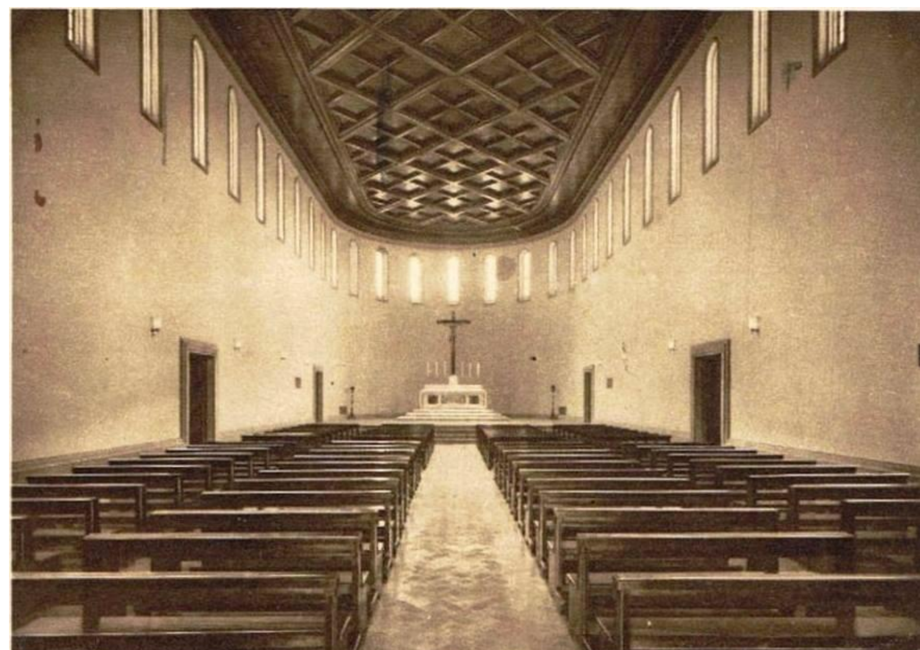
(Ed.ni Brogi) 9039. CONTORNI DI FIRENZE - Montughi - Villa di Sir Labouchere.

(Ed.ni Brogi) 9073. CONTORNI DI FIRENZE - Montughi - Salone della Villa di Sir Labouchere.

Photo – Historical documentation

Views, from Villa of Sir Labouchere (Villa Cristina) in Montughi near Florence

to the sumptuous hall of Sir Labouchere's villa (Villa Cristina) in Florence and at the end... The minor seminary chapel.



Alinari Archive, currently Santa Marta library

The validated lighting simulation models obtained in our recent research were used as starting base for the new proposal by using the commercial software Dialux-Evo-8.2.

The new lighting proposal was based on reversibility, easy maintenance and possibility of disassembly and removal of all the elements/components.

Higher performances, quality and efficiency of the new LED systems is clearly visible, comparing the existing (Table1) with those used (Table 2: values are referred to fundamental metrics used for the LEDs performance evaluation

Commercial name	Lamp type	Luminous flux [lm]	Power [W]	Correlated colour temperature [K]	N. installed luminaries	Height from floor [m]
3F LINDA	LED	5200	58	3000	6	3,00
Steel LED	LED	2145	58	5000	8	6,51
Afrodita	LED	6600	70	3000	6	3,34
Canes	Compact fluorescent	1500	36	4000	6	4,50
Damp Proof LED	LED	1000	39	4000	4	2,20
F30 LED	LED	2000	150	4000	2	6,00
Tubular	Compact fluorescent	5000	49	2000	32	6,51

Technical and photometric data of the existing artificial lighting system

Commercial name	Lamp type	Control System	Luminous flux [lm]	Power [W]	Ra	Rf	Rg	Correlated colour temperature [K]	Number installed lamps	Height from floor [m]
Optec Wallwasher	LED	DALI	511	8,6	92	90	100	3000	8	5,51
Optec Washer	LED	DALI	4685	36	92	90	99	4000	4	6,51
Parscan Zoom	LED	DALI	630	6	92	90	100	3000	14	5,51
Parscan Zoom	LED	DALI	1161	14	92	90	99	4000	8	6,51
Lucy	LED	DIMMER	221	13	92	90	100	3000	18	1,50

Technical and photometric data of the new proposed artificial lighting system

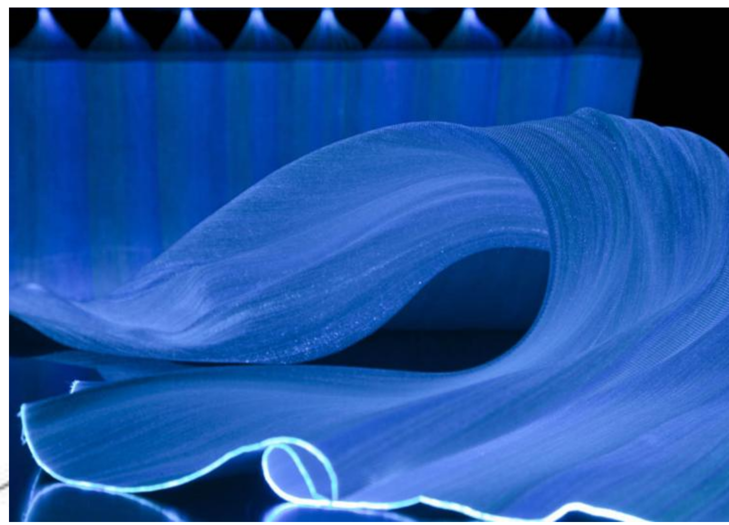
The new proposed artificial lighting system

Optec Washer spotlight

The two spotlights Parscan Zoom

Optic wallwasher spotlight
with lens

Luminaries for work



Fiber-optic textile

The polymeric optical fiber, known also as "smart textiles" were integrated in the new lighting. Light sources of the fiber optic textiles were both natural and LED lighting.

The new lighting solution was non-invasive and did not require any other intervention on the vaulted windows, walls or ceiling for natural light control

The existing transversal electrified tracks were re-used for the suspension and fixing of two sail systems made of the optic fiber textiles, which provide homogeneous light distribution and diffusion in their lower part towards the environment below, and diffuse reflection from the upper part towards the ceiling.

The main lighting scenarios were studied:
museum-philological-historical and functional library and then at 100% working condition, connected to the reading/writing zone of the nave and aisles

Optic fiber textile systems and LED sources were modelled; each LED was checked for beam and aiming angle, position and connected regulation system used

Design choices

1. LEDs on display case, designed for the exhibition scenarios, working and dimmable respect the standard limit values;
2. presence sensors for the whole church in relation to the museum lighting scenario;
3. workstations with an "on board" element in order to reduce energy consumption, guarantying high removability and reversibility, as well as optimal specific lighting for visual tasks;
4. spotlights installed on the existing electrified tracks for the reading zone with a tilt angle of 30° providing the artificial light source of the optic fiber textiles and which can be custom made considering a ligh flux of 100 lm/m2;
5. wall-washers LEDs for narrow beam grazing lighting along the two perimetral walls in the zone between the apse and the two sail systems;
6. spotlight LEDs with a tilt angle of +30 ° and -30° depending on display case type and position for the museum zone.

Design choices

Solar radiation and daylight were assessed by the calculation of the hourly variation of the incidence angle on the splayed arched windows.

For simulations the transparence index results were used and suggested “asymmetrical” artificial light sources for the two sail systems of optic fiber textile. Due to the asymmetry in the intensity distribution of natural light, two different control and regulation groups for the dimming LEDs, installed in the optic fiber textiles, were designed.

At the entrance zone and in the centre of the church (i.e. in the nave zones) emergency lights were connected to the electrified tracks. Taking into account the natural light availability, different dimming systems were used for LED sources grouping luminaires in different control groups: this choice provides important energy savings guarantying light quality, in compliance with the current standards of IES (Illuminating Engineering Society of North America); UNI EN 15193-1-2017; CEN/TS 16163-2014 UNI EN 16883-2017

Results and discussion

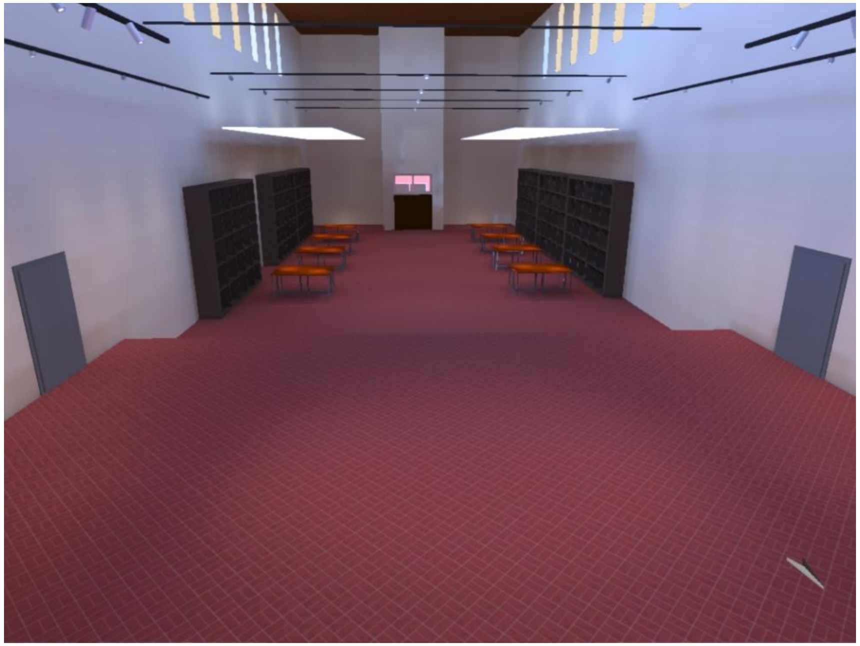
Simulation results show the efficiency and efficacy of the adaptive and sustainable lighting solutions.

The dimensionless Modelling index (M) was evaluated for the two new lighting scenario, in the precautionary condition of mix between the highest levels of natural and artificial light (i.e. artificial lighting system operating at 100% without dimming and control and at 10 a.m.) and referring to 1.2 m height from the floor for people sitting and 1.6 m height for people standing as required for the average cylindrical illuminance maintained (Esc) evaluation.

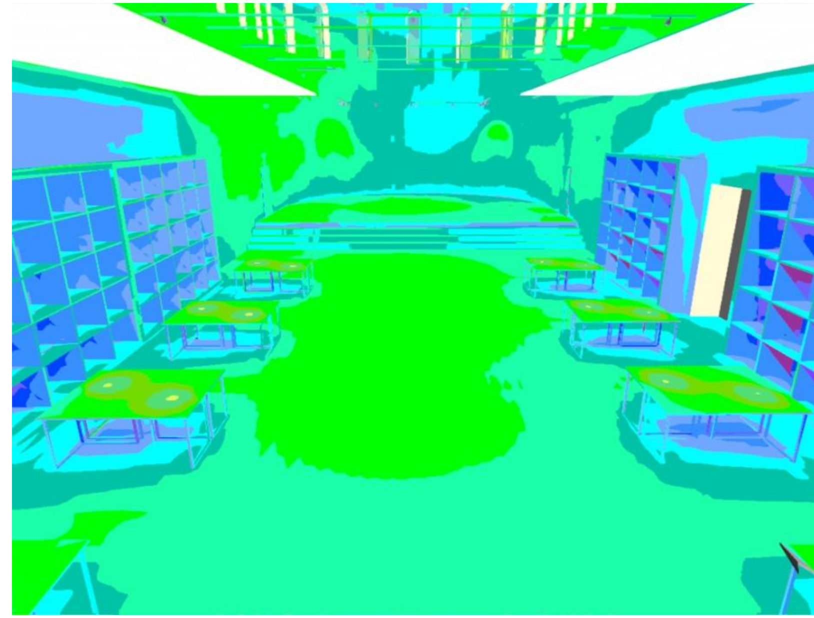
M index value for the whole library/reading/apse zone, is within the limits (i.e. 0,8-1,3) Table shows the M index results that prove light optimal mix, good distribution and uniformity, and goodness of light modelling.

	Parameters	100% working	Museum-Philological_History	Functional Library
Apse	Esc (1,2m) lx	59,0	58,9	46,6
	Esc (1,6m) lx	63,4	63,3	52,7
	Ev (1,2m) lx	70,7	70,7	57,9
	Ev (1,6m) lx	73,2	73,2	63,6
Reading Room	Esc (1,2m) lx	125	123	137
	Esc (1,6m) lx	116	125	124
	Ev (1,2m) lx	160	155	168
	Ev (1,6m) lx	144	153	153
Modelling Index (M=Esc/Ev)	Apse (1,2 m)	0,83	0,83	0,8
	Apse (1,6 m)	0,87	0,86	0,83
	Reading room (1,2 m)	0,80	0,80	0,81
	Reading room (1,6 m)	0,80	0,82	0,81

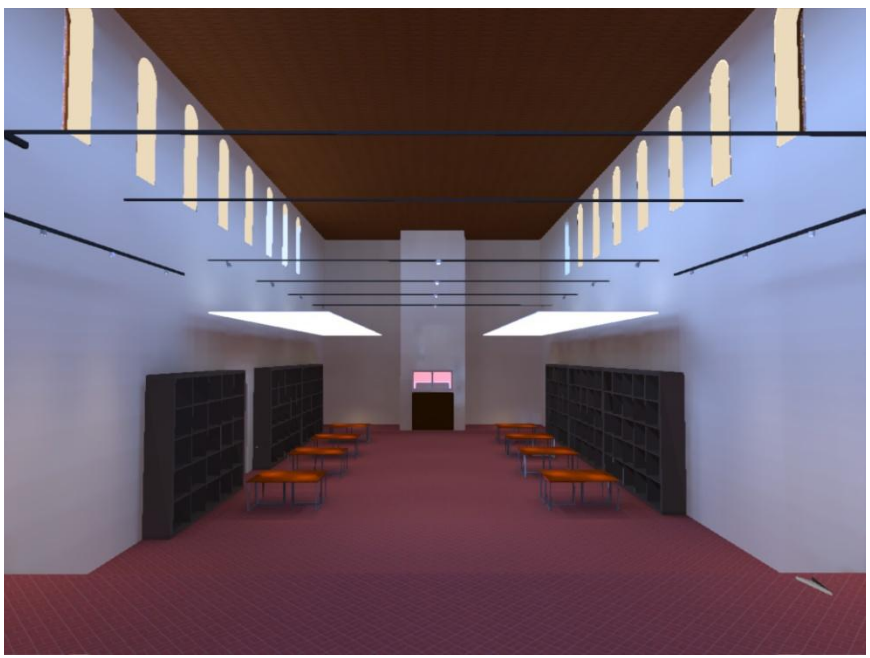
Illumination and M Index value new lighting design



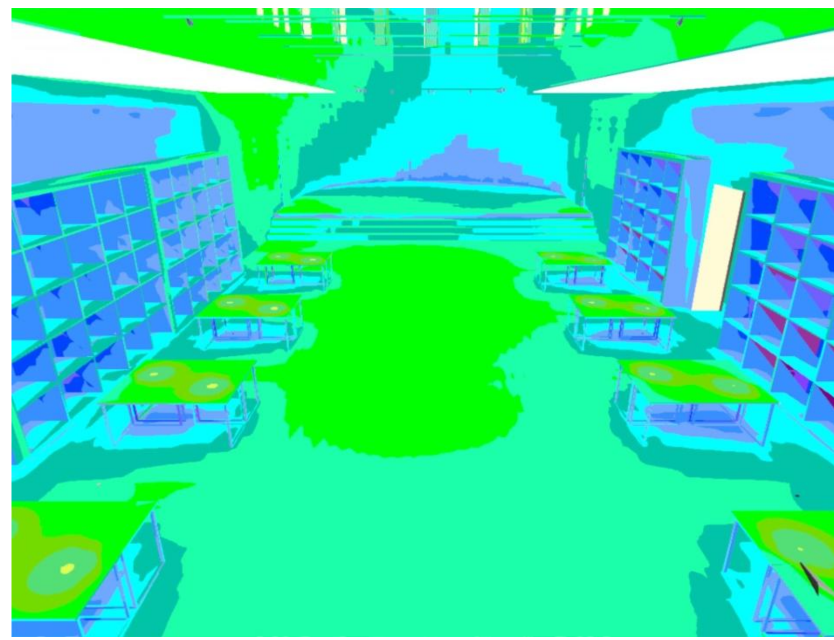
100 % render morning



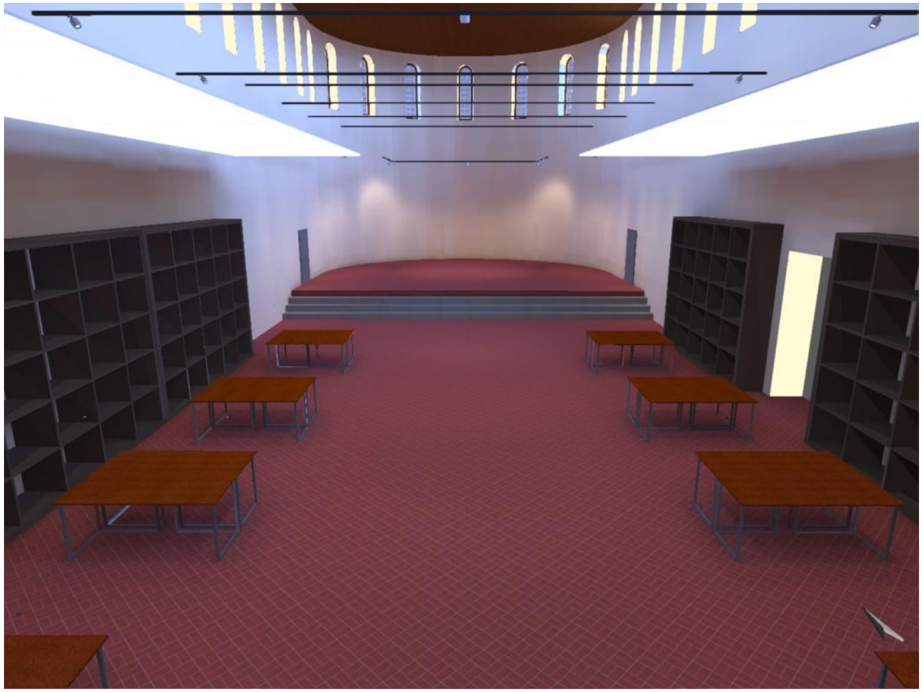
100 % lux morning

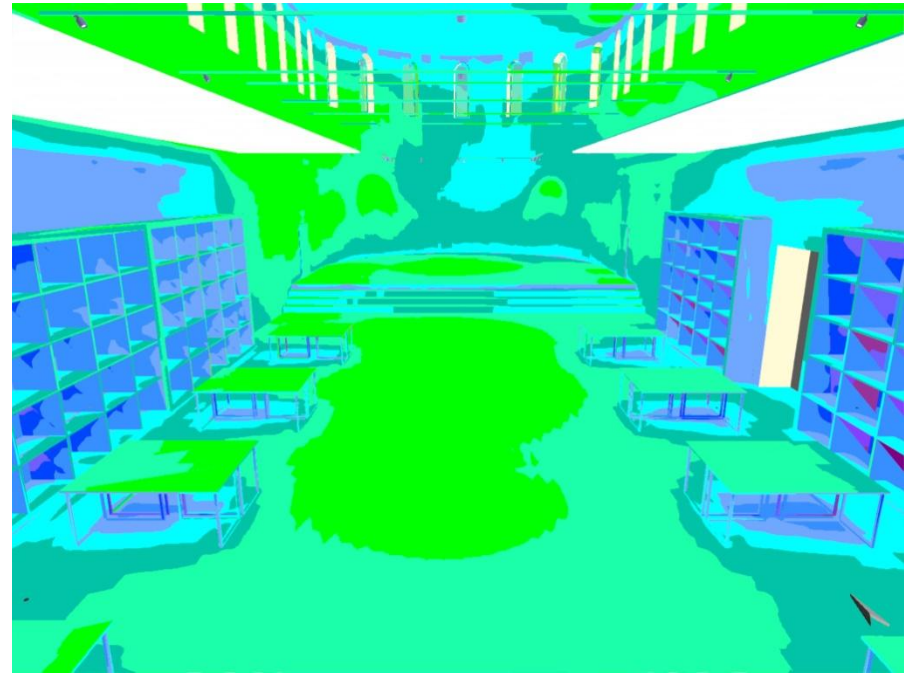


Library render morning



Library lux morning





At the top left: Museum render morning

At the top right_ Museum LUX morning

At the bottom: Museum cd/m² morning

The mean illuminance level is always in the range of 30-50 lx during morning, i.e. within the limits suggested. Table provides also minimun, maximum and mean illuminance values, for the Reading plane, Desk-reception plane and Apse-plane, calculated on the working level at 0.75 m, in precautionary conditions with all the luminaries working at 100% and highest value of external solar radiation

Luminance uniformity and its specific values are shown. The contrast rendering factor for vision and perception, was calculated by the ratio between the luminance for two work planes of two desks (L2) taken as tests and the luminance of the background (L1)

	Reading Plane (lx)	Desk-reception Plane (lx)	Apse Plane (lx)
E_{min}	74	72	123
E_{max}	526	473	171
E_{mean}	204	187	160

The floor is as reference the most important surface.

The work planes correspond to the worst lighting conditions in the existing state: 1 desk (desk_left) is on the left side of the library and in darkness condition; 2 (desk_right) is on the right side under the higher illuminance values due to natural light.

	(cd/m^2)	East Wall	West Wall	Apse Wall	Reading Room Floor	Apse Floor	Whole ceiling
Functional Library	L_{min}	0,20	0,6	1,14	0,06	0,76	0,37
	L_{max}	21,8	30,2	10,9	4,70	4,25	2,08
	L_{mean}	9,47	12,7	6,6	2,26	2,01	0,86
100% working	L_{min}	0,33	0,6	1,14	0,06	1,6	0,37
	L_{max}	21,9	29,7	11,3	4,73	4,55	2,14
	L_{mean}	9,66	13	8,43	2,26	2,26	0,89
Existing State	L_{min}	0,1	0,001	1,65	0,005	0,12	0,001
	L_{max}	72,7	72,5	36,43	14,6	16,3	11,2
	L_{mean}	12	17,2	14,30	6,02	4,44	3,06

It can be noted that for all the scenarios, the proposed lighting solutions guarantee visual comfort and ergonomics with absence of glare phenomena.

Value of the contrast rendering factor – new lighting design

Functional library	L_2 (cd/m^2)	L_1 (cd/m^2)	C
Desk 01 (morning)	3,3	1,3	1,54
Desk 02 (morning)	2,9	1,0	1,9
Desk 01 (evening)	3,3	1,1	2,0
Desk 02 (evening)	2,9	0,9	2,2

Energy performance and efficiency of the lighting proposal, for all the lighting scenarios, was evaluated by means of LENI assessment, total energy consumption and costs. Taking into account the operating conditions of the regulation system designed for each control group of connected LED group, the average percentage incidence of the control/regulation system on the energy consumption of all the lighting scenarios is 3,7.

Proposed lighting scenarios	LED reading room	LED media room	LED reading room	LED apse zone	LED cases
Functional-library	100 %	100 %	100 %	Off	off
Museum-philological-historical	Off	Off	100 %	100 %	off

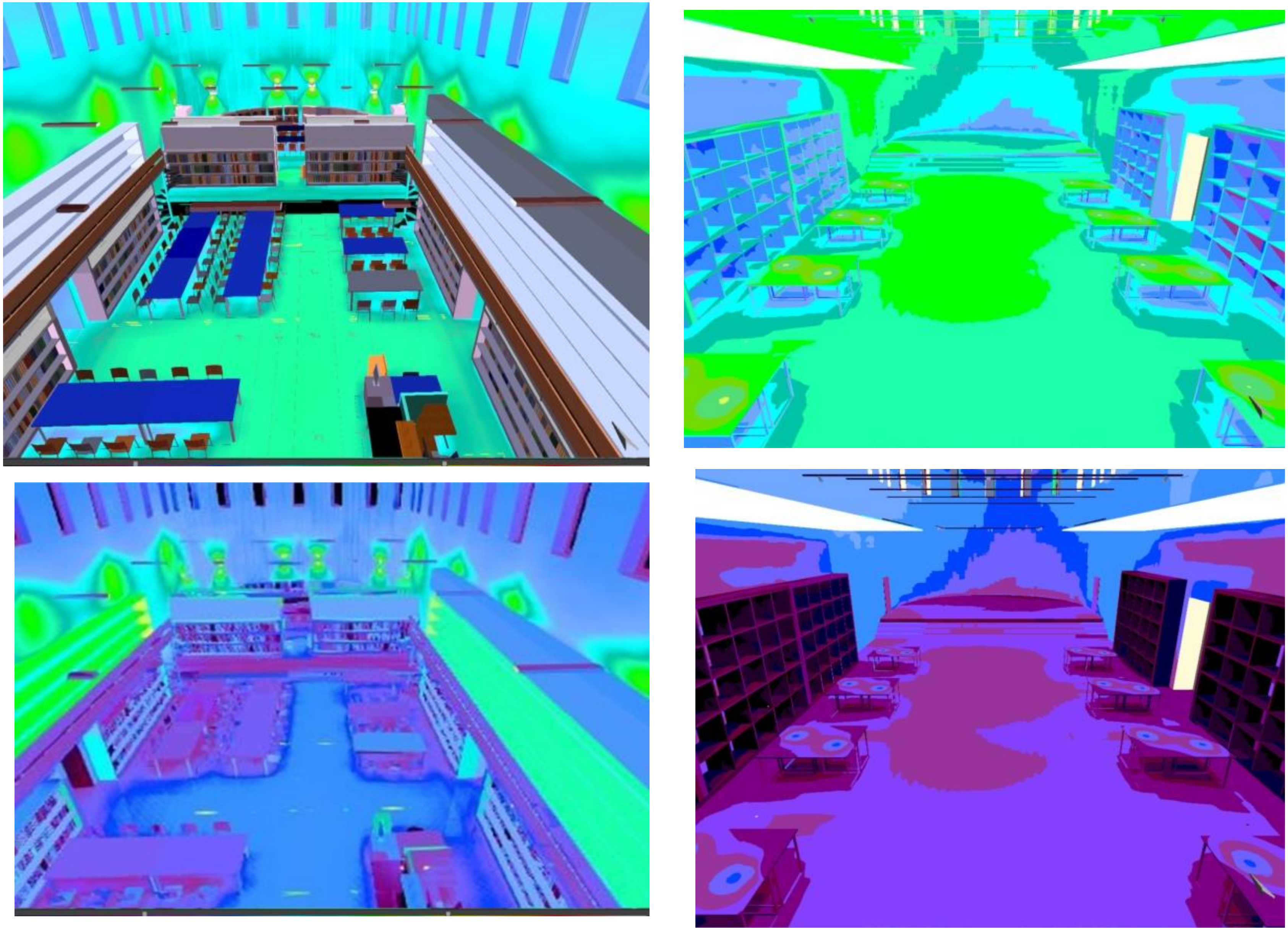
	Existing State	**100%**	**Museum-Philological-History**	**Functional Library**
Consumption (kWh/year)	10300-15100	3800-5700	2500-3600	3400-5150
Costs (€/year)	3093-4528	1139-1709	800-1200	1025-1538
LENI (kWh/year/m^2)	22-23	9-14	6-8	8-12

CONCLUSIONS

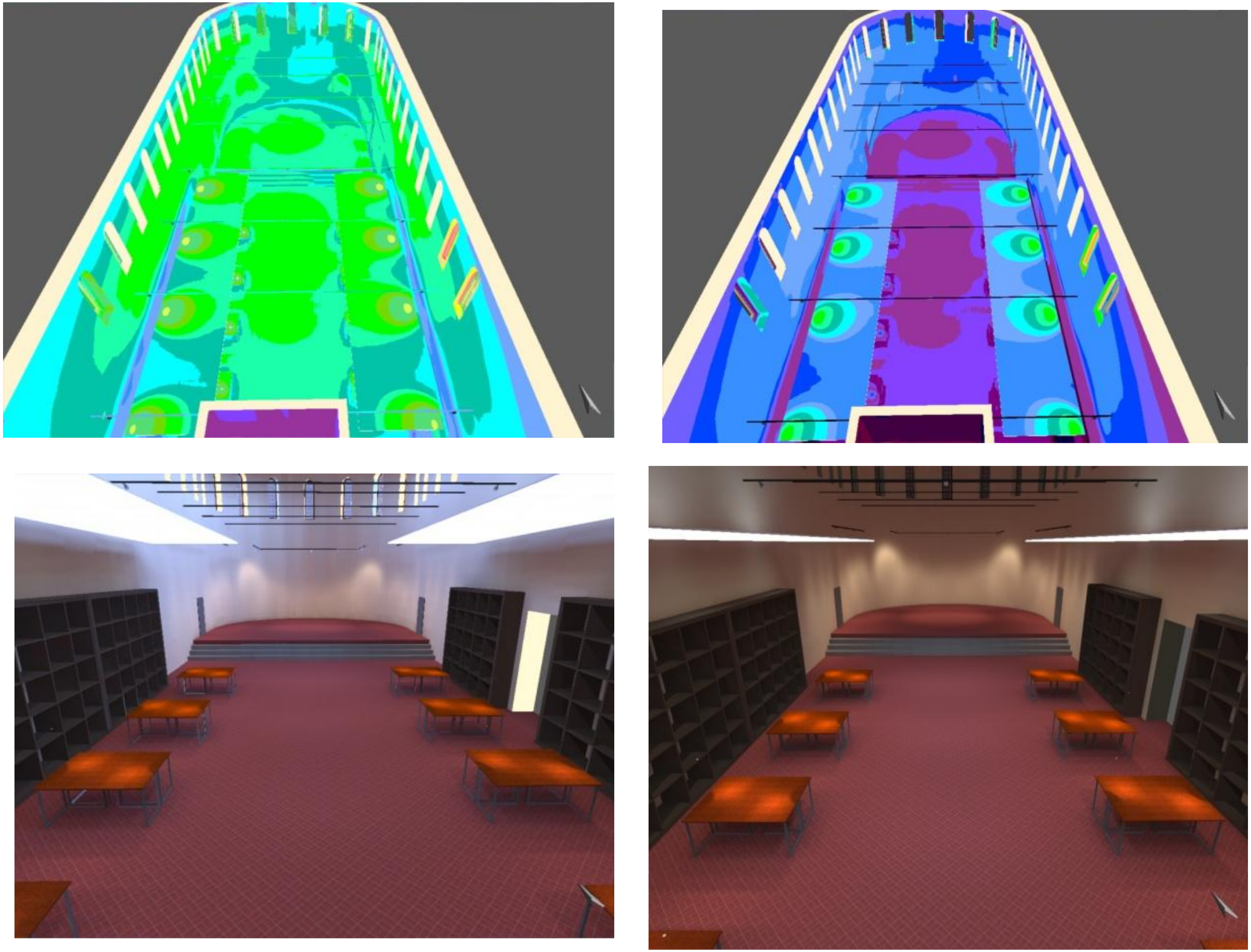
- It is always possible to combine the adaptive re-use concept with adaptive re-lighting design and health, protection and preventive conservation of works/objects of CH in historical buildings, by means of a natural lighting design based on its optimal mix with artificial light and effective control systems;

- The proposed method can be a useful tool for adaptive and sustainable re-lighting design also oriented to the “Human Centric Lighting (HLC)”

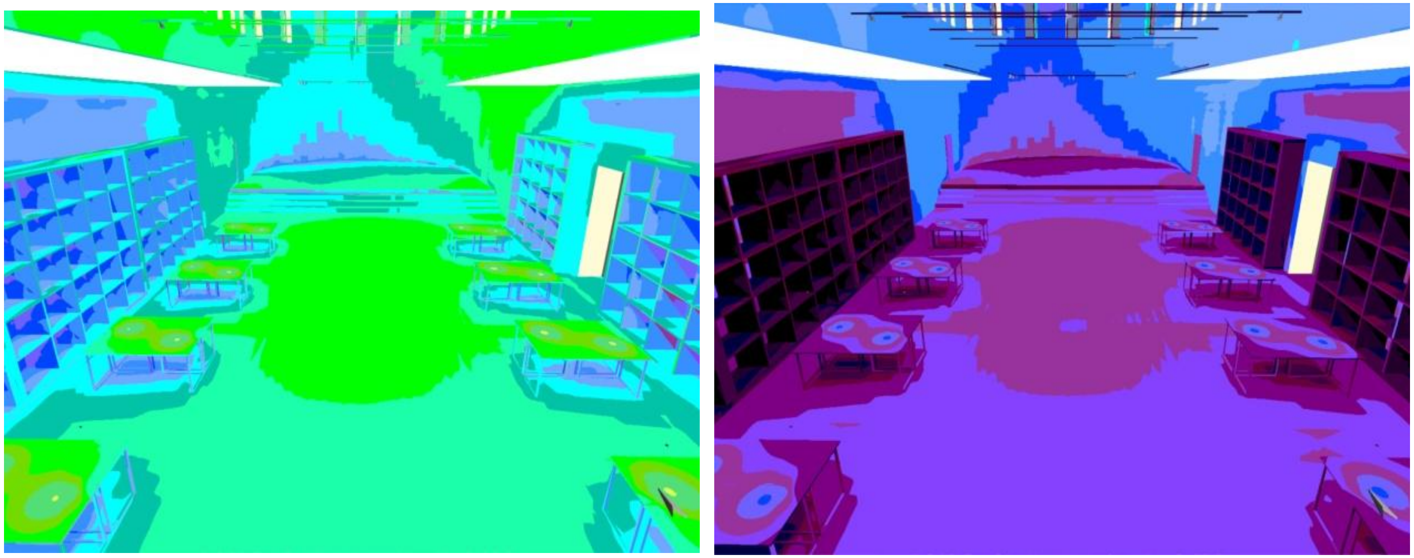
- Following these basic concepts, our findings highlighted that sustainable, reversible and adaptive re-lighting solutions, oriented to the integration of HCL with preventive conservation of cultural heritage, can be achieved by the optimal mix between natural and artificial light combining efficient control and dimming systems with innovative application of LED technologies and smart-advanced textiles.



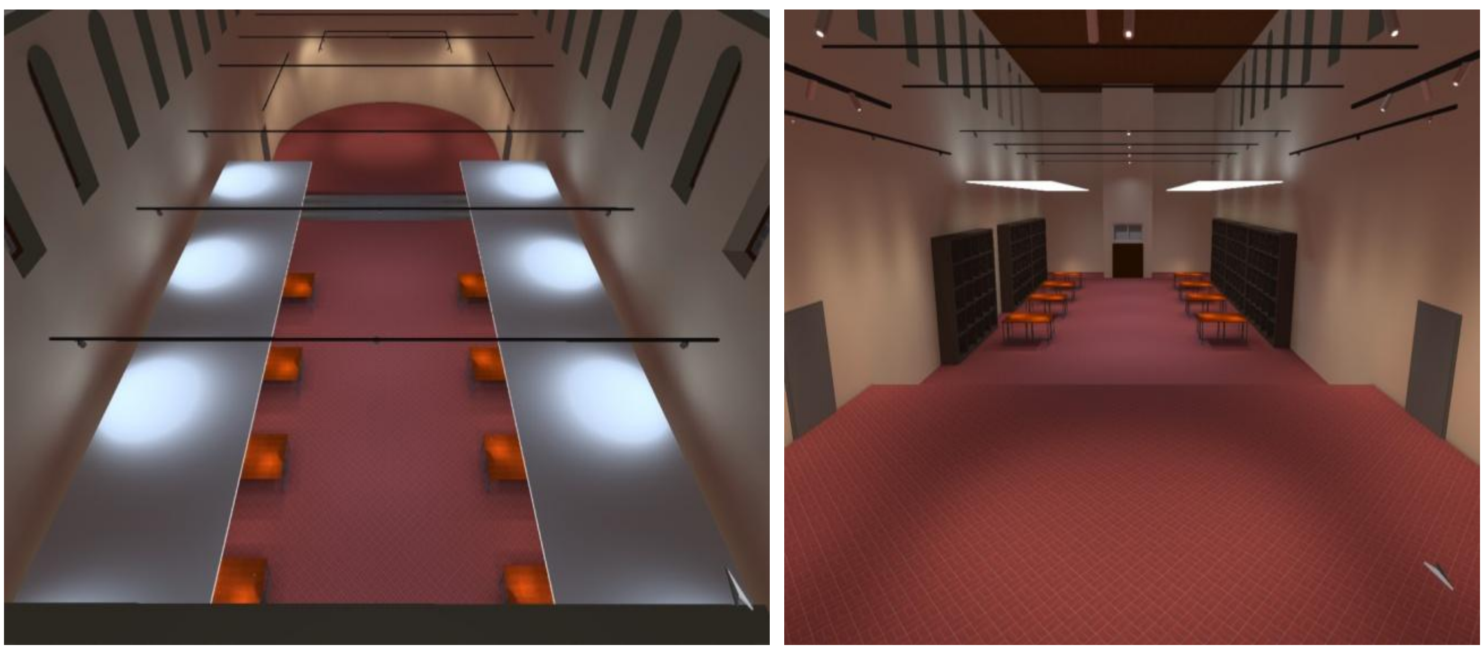
Illuminance (lx) and luminance (cd/m2) distribution at 10 a.m. for functional-library scenario: (top left) illuminance at the existing state; (top right) illuminance of the new lighting; (bottom left) luminance at the existing state; (bottom right) luminance of the new lighting.



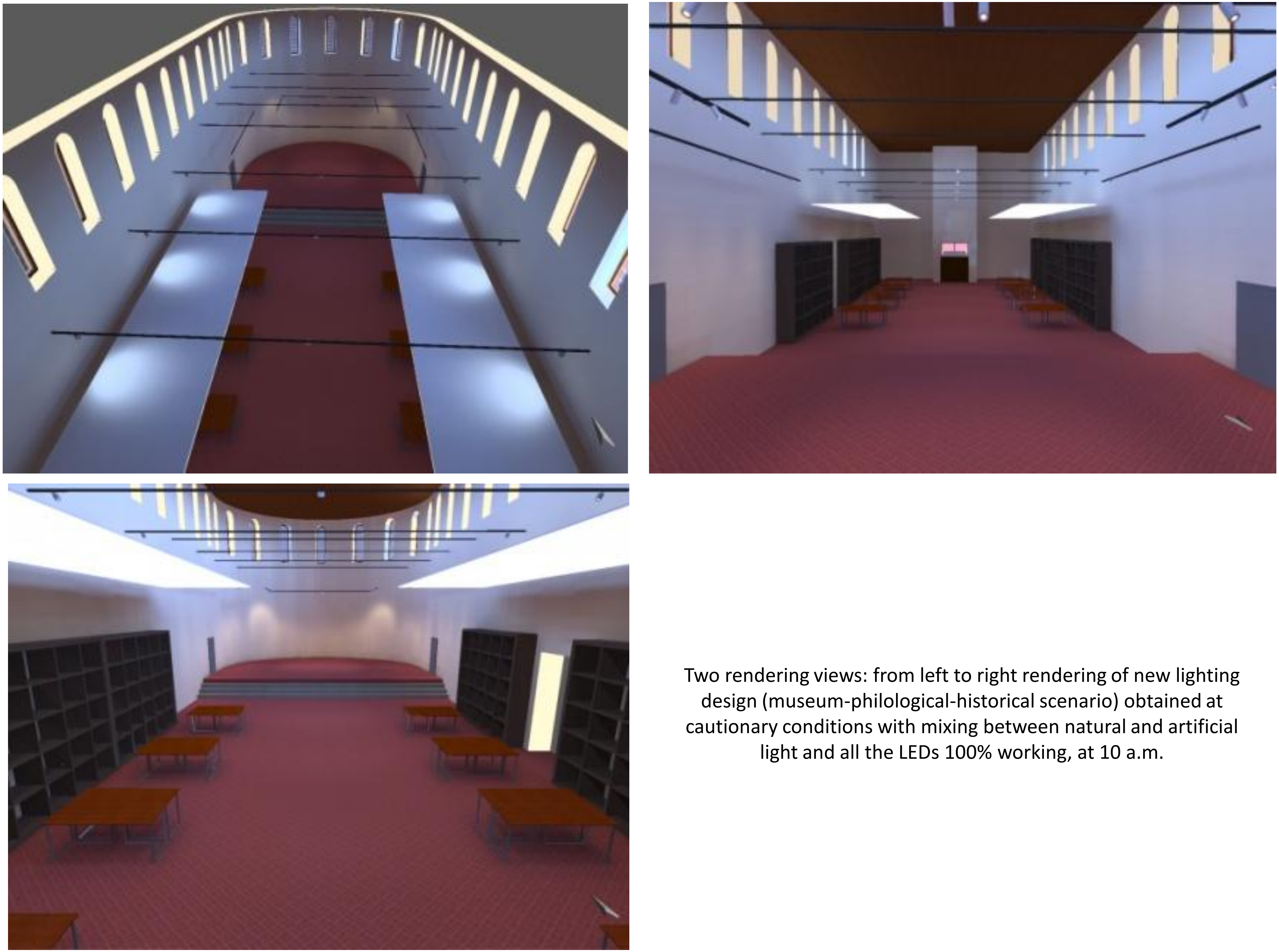
New lighting design for the functional-library scenario at cautionary conditions with mixing between natural and artificial light and all the LEDs 100% working at 10 a.m.: (top left) false colours render of illuminance values (lx); (top right) false colours render of illuminance values (cd/m2); (bottom left) rendering at 10 a.m. and (bottom right) rendering at 6 p.m.



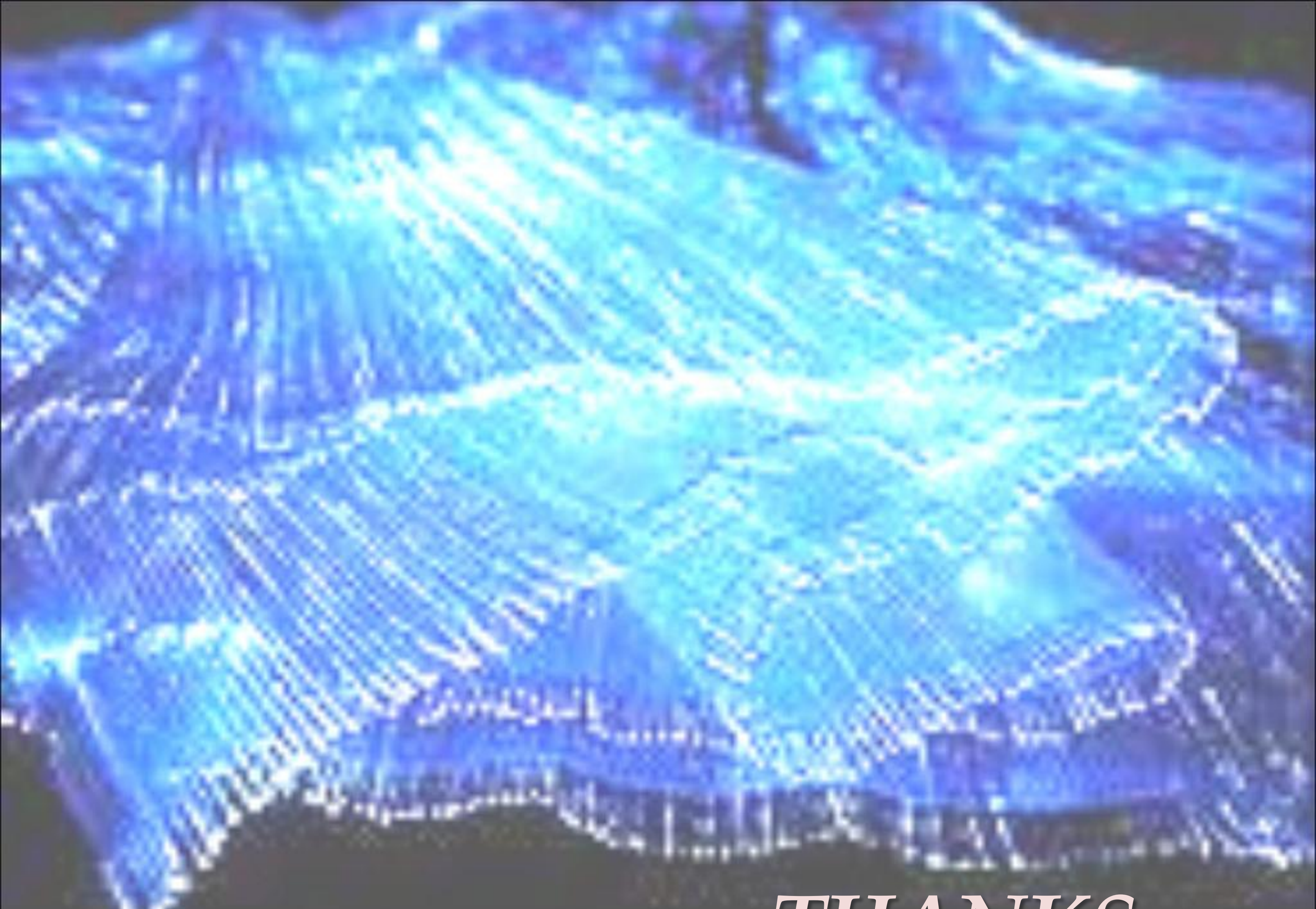
Illuminance values (left; lx) and luminance values (right; cd/m2) at 10 a..m. – only natural light (artificial light off) for the functional library scenario design; a view below the two sails system with optic fiber textile.



Two rendering views: from left to right rendering of new lighting design of the functional-library scenario obtained with all the LEDs at 100% working conditions in the evening at 6 p.m. (without natural light).



Two rendering views: from left to right rendering of new lighting design (museum-philological-historical scenario) obtained at cautionary conditions with mixing between natural and artificial light and all the LEDs 100% working, at 10 a.m.



THANKS