Zonal reconstruction of daylighting in historic built environments

A workflow to model and evaluate light in spaces and over periods

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Introduction

Spatial and temporal dimensions of historical lighting

Lighting is a key quality of any built environment. The study of historic lighting relates building practice, building design, and technological development in natural and artificial lighting, e. g. luminaires, fuels, window glass, with the lighting conditions that afford use and the perception of architecture.

Due to loss or alteration of architecture, historic lighting often cannot be studied in situ but by reconstruction and simulation. This requires that the propagation of light is modelled based on plausible assumptions in terms of light sources and reconstructed geometry and material properties of the building (Noback, 2019). However, lighting conditions are variable, and the positions and view directions of occupants are often unknown. This has motivated the expansion of lighting simulation in the temporal domain, e. g. using Climate-Based Daylight Modelling (CBDM), and space, e. g. zonal evaluations of illuminance and derived metrics (Monteoliva et al., 2020).

The computational demand and complexity to calculate metrics that are not reduced to planar, i. e. horizontal or vertical, illuminance still hinder scholars to investigate potentially more telling expressions of the luminous conditions in historical built environments. The development and application of such metrics typically fall into the field of (modern) lighting research and are detached from the realm of scholars studying e. g. the functional and social correlation with historic activities and building practice: These are typically confronted with the result of metrics produced by other experts or suggested by off-the-shelf tools rather than including them in their research.

Fig. 1. The four anlaysis zones are highlighed (rooms 5 and 6 highlighted in green, blue; courtyard zones A and B in red and yellow) and the modelled obstructions (grey) of the House of the Priestesses in Ostia.

The recent development of the *raytraverse* adaptive sampling strategy in spatial and temporal domains allows to include contrast- and image-based metrics that were so far computationally too expensive and extend the range of illuminance-based metrics beyond the commonly reported horizontal illuminance. This is achieved by focussing the simulation only on the most relevant regions, e. g. image regions of high contrast, time periods with sudden changes of sky conditions, or areas where the luminous conditions change significantly (Wasilewski et al., 2022).

Objectives

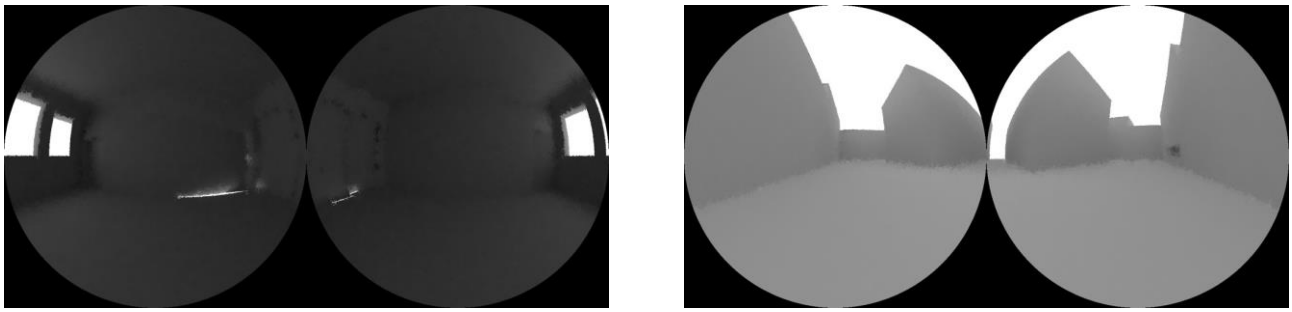
The python module *phos4dtool* implements the computation of a wide range of daylight metrics that are considered to indicate affordances in the historical context of the assessed sites by *raytraverse,* employing the lighting simulation software *Radiance* as a back-end. The application of *phos4dtool* shall be demonstrated for the case of a residential complex in Ostia. Integration with a Geographical information System (GIS) is suggested to allow overlaying the simulation results with other, spatially organised archaeological research data such as site plans and the location of finds indicating activities. It is intended to cross the barriers between those performing daylight simulation and developing daylight metrics and those correlating them to other sources. This shall foster interdisciplinary collaboration in the research of historic lighting.

Method

Modelling in a residential unit in Ostia

A reconstruction of one unit of the House of the Priestesses (Italian *Casa delle Ierodule*, also called House of Lucceia Primitiva, Ostia III,IX,6: Falzone and Pellegrino, 2014) was modelled including a simplified representation of the solar obstructions formed by the other building blocks of the insula.

In the exemplary application of *phos4dtool,* the luminous conditions of two interior building zones within the unit as well as two areas of the adjacent courtyard as shown by Fig. 1 shall be evaluated. While the demarcation of the interior zones is intuitively guided by the boundaries of the rooms, the exterior zones are defined based on their relation to the main obstruction. One zone lies just in front the unit's East-facing facade, and extend from North to South. The second exterior zone lies East of the first. It extends to the East and is framed by two higher building blocks to its South and North.



a) *b)*

Fig. 2. Exemplary test images generated for a two viewpoints in room 6 (a) and courtyard zone A (b).

Zonal daylight simulation and application illuminance-based metrics

In the absence of a predefined work plane, lighting conditions are evaluated at an eye level of 1.40 m. Imagery for a sequence of views is generated for each zone (Fig.2), allowing preliminary checks on the model import.

The subsequent simulation recursively refines a set of viewpoints to adapt to the local variance of the annual distribution of incident sun- and skylight. At each viewpoint a full 360-degree panorama is sampled by a sparse set of few view rays, chosen so that any image from the point can be reconstructed. This sampling strategy, adaptive over the spatial and temporal dimensions of location, direction, and sky condition, forms the core of the *raytraverse* method and has been initially developed for zonal glare assessment. The method also allows to derive e. g. planar (e. g. horizontal and vertical), spherical, hemi-spherical and cylindrical illuminance. A set of such illuminance measures has been implemented in *phos4dtool* and is currently assessed for correlations with visual requirements attributed to possible activities in an antique residential context.

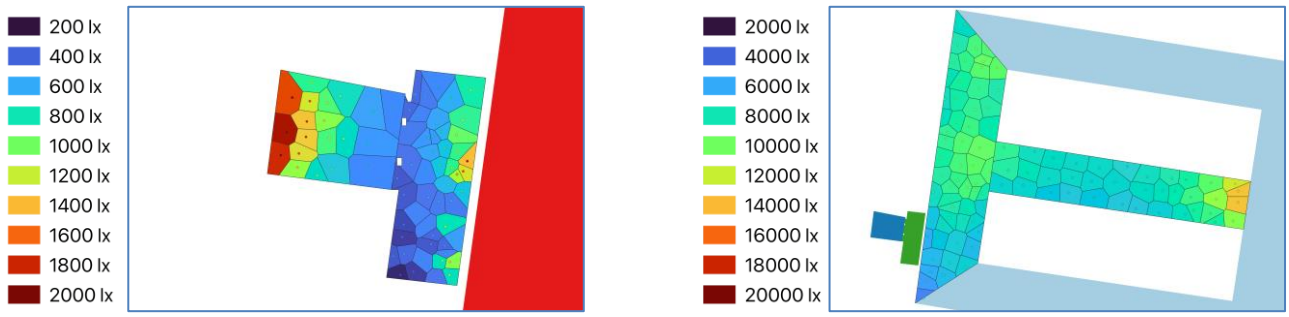
The simulation results in a dataset spanning temporal (e. g. hourly time-steps) and spatial (e. g. locations) domains. Reduction along the temporal axis by calculation of percentiles (including the median) produces spatial distributions, that describe the occurrence of illuminance-based metrics at locations in the four zones. One result is e. g. the cylindrical illuminance at one location as a median value, i. e. achieved at half of the assessed time steps.

Integration with a Geographical Information System

The temporal percentiles are imported into a GIS database as non-spatial attributes of the locations, which are themselves the results of the spatial adaptation of the sampling algorithm. The locations are expressed by georeferenced Cartesian coordinates typically in a projected UTM reference system. The interface between simulation and GIS is implemented in *QGis*[1] by importing the tabular results from *phos4dtool* as separated text files.

To interpolate between the sparse set of locations, Voronoi cells are produced by the GIS platform and intersected by the analysis planes. This produces a polygon layer that allows querying for any of the metrics at any location in the four zones from within the GIS environment (Fig. 3, showing the distribution of cylindrical illuminance as an example). The layer is stored in a PostGIS[2] schema, that is shared and accessible to other researchers with access to the GIS database.

[1] https://www.qgis.org
[2] https://postgis.net



a) *b)*

Fig. 3. Imported sparse view locations in rooms 5 and 6 (a) and courtyard zones A and B (b) as result of the adaptive spatial sampling and Voronoi cells allowing to query for the computed metrics at any location in the analysis zones.

Conclusions and outlook

The capability of the method to produce a GIS layer representing a set of zonal daylight metrics that can be overlaid with other, spatial research data has been demonstrated for the case of a unit of an insula in Ostia. The first results show the potential to integrate daylight metrics in interdisciplinary research. Relying on open and well-documented GIS standards further opens a robust path to archiving and reusability for daylight simulation, that alight with practice in historic research.

A possible extension of the GIS integration to maintain the temporal dimension of the simulation results is currently investigated. This would make it possible to develop data-processing workflows, such as the formulation and application of metrics, entirely within the GIS environment, and thereby overcome one more separation between the realms of simulation and historical research.

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