Views on ancient lighting

Modelling lighting devices and their effects in architecture

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Introduction and objectives

Artificial lighting and daylighting as methods to deliberately bring light into the dark respond to the design and use of architecture. If these are altered or lost, our knowledge about the history of that practice is inferred from archaeological evidence of preserved lighting devices, indications for window openings sometimes accompanied by finds of glass panes, and other sources such as texts and illustrations. From this fragmented knowledge the effects of lighting, which often results from the combined utilisation of daylight and other lighting devices, can be reconstructed employing computational simulation (Noback et al, 2020).

Pre-modern lighting devices, or luminaires, such as torches, open fires, candles, and oil lamps (Garnett et al., 2019), almost exclusively rely on flames as light sources. Modelling light emission of such flames can be based on an analytical representation of the combustion processes, or phenomenological approaches e. g. data acquired from photometric measurements. The luminaire is illuminated by the initial, approximately uniform emission of light from the flame. Mirror-like surfaces or diffractive solids, e. g. reflecting metal disks or glass lamps filled with clear fuels, can modulate the flame light and form complex distributions (Kider et al., 2009). If based on valid geometric models of the luminaires, simulation produces descriptions of lighting in terms of physical quantities: imagery representing luminance distributions in the field of view, or tabular data, e. g. illuminance distributions on defined surfaces. Based on these, metrics and models of human visual response allow to analyse effects of lighting on architectural spaces and features (Doulos et al., 2019). These can be functional, e. g. the provision of illuminance for visual tasks, or perceptual, e. g. on the appearance of space and surfaces (Noback et al., 2020) or the luminaires themselves.

A plentitude of approaches exist in computer graphics to model flames and their visual effects by flames. These techniques often focus on the dynamics of flames, e. g. by particle systems, but do hardly aim at physical validity. Physically valid luminaire modelling that is applicable in lighting simulation of architectural spaces with potentially many light sources has to maintain validity but hide the complexity of internal processes in the flame. This paper presents a method for the study of lighting and perception based on modelling luminaires and their effects on the illumination of architectural spaces with the lighting simulation suite Radiance. In the presented, preliminary phase, the model of the flame is static, i. e. not accounting for movement, flicker and intensity changes. The applicability of the method to selected cases of lighting devices and preliminary results shall discussed, leading to an outlook into the authors' ongoing and future research activities in the field.

Methods and cases

Modelling the flames of oil lamps and candles

The presented, phenomenological approach visually represents the flame using image textures, but models its emission by an invisible proxy source. The method requires the photographic acquisition of textures and the goniometric, or angular, measurement of the intensity distribution.

The flames are combined with detailed geometric models to form luminaires, and introduced into exemplary architectural spaces. The selection of cases demonstrates different sources (candles and oil lamps) and effects of lighting such as the perception of the luminaire itself (cases 1 and 3), and the interaction of light with complex reflection and transmission properties of luminaire and architecture (case 2). Simulations were performed employing Radiance, resulting in HDRI that was adjusted by a human perception model, and numerical data of the illuminance on surfaces.

Case 1: A Roman pottery lamp from Italy

The mould-made lamp[1] features a discus showing two fighting gladiators, whose names are inscribed. Remains of fuel may have caused a glossy reflection. The relief suggests that the decoration was pronounced by the shadows casted due to the oblique illumination produced by the flame. The illustrated scene may have been further animated by movements of the flame, an effect that the proposed, static flame model does not account for. Fig. 1 (left) shows the model of the lamp on a surface, that – depending on its reflection properties and distance – reflects the flame's light.

Case 2: A Byzantine polycandelon with glass lamps

The 6th century silver circular polycandelon can hold 12 lamps by its outer ring, and an additional four within (Fig. 1, right). If clean and polished, the silver surfaces must have featured significant specular reflectance. Combined with typical glass lamps, this polycandelon is expected to produce a complex reflection and refraction pattern. To illustrate the effect when combined with a specular surface typical of its time, a preliminary model is introduced into a vaulted room with gold mosaics as shown by Fig. 2 (left). The mosaics are represented by a layered procedural model that modulates reflection according to the perturbation of the surface geometry at micro-, meso- and macro-scales (Noback et al., 2020). The effects of moving and flickering flames on the appearance of the gold mosaic have yet to be studied.

[1] British Museum asset number 1613683440, https://www.britishmuseum.org/collection/image/1613683440

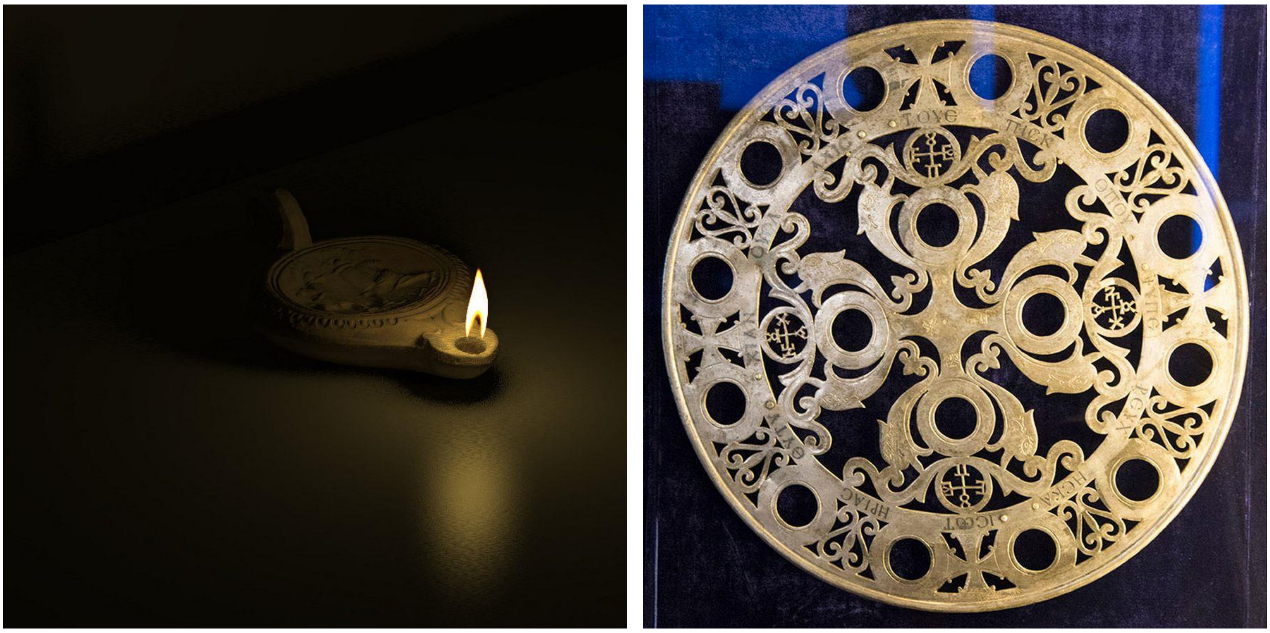

Fig. 1. Left: Simulation of a pottery lamp with a phenomenological flame model. Right: Byzantine polycandelon[2].

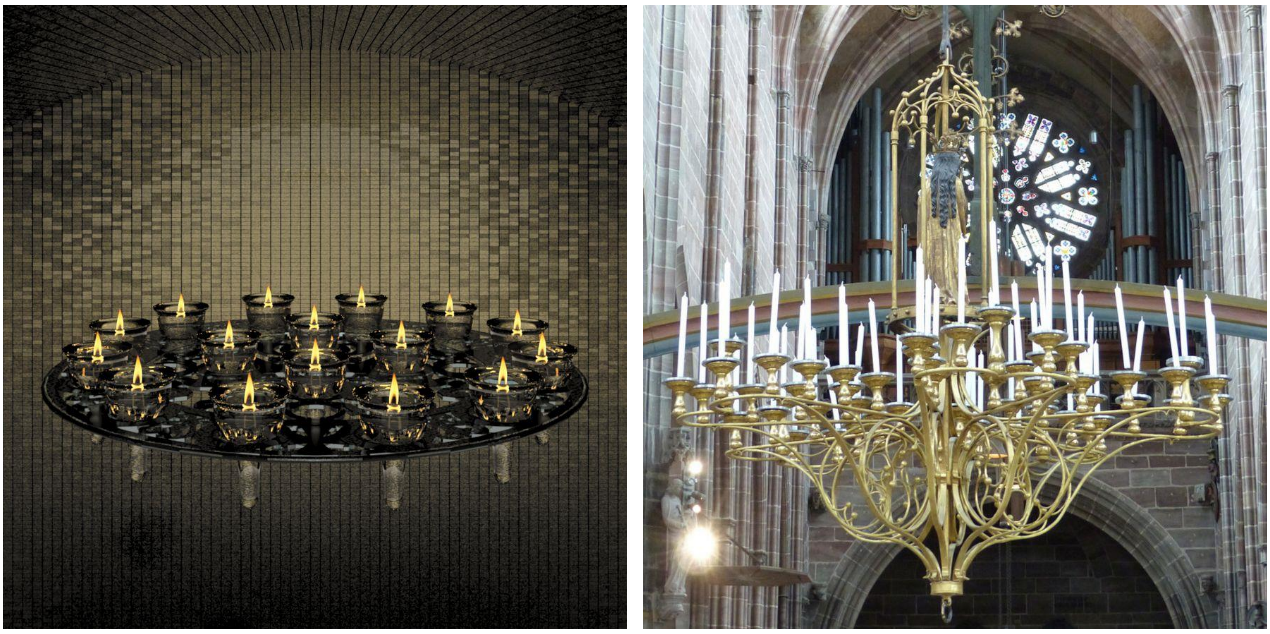

Fig. 2. Model of gold mosaic illuminated by the polycandelon. Right: Chandelier with the Virgin Mary from Nuremberg.

Case 3: A chandelier with the Virgin Mary from Nuremberg

The chandelier with the statue of the Virgin Mary holds 55 candles, 11 candles on each of its five arms (Henkelmann, 2020). The centrally placed figure of the Virgin Mary is thus evenly surrounded and illuminated from all sides; mounted slightly elevated, however, it is illuminated from below (Fig. 2 right). Besides being a functional luminaire, the chandelier´s light serves a central element of the choir space with the high altar and further furnishings. Lighting simulation shall provide means to study these two aspects of the chandelier.

[2] Antalya Museum, A. 1054, photograph Dick Osseman https://pbase.com/dosseman

Discussion

The cases illustrate a range of possible research problems that a modelling method for flames shall account for. Since the presented research is ongoing, not all these cases have been modelled yet. Based on the completed cases, the method has been found viable as an qualitative approximation of the visual appearance of a flame as well as its quantitative effects on the illumination of surfaces in its proximity in lighting simulation. Two important limitations of the method are a) that does not account for dynamic changes of intensity, flame shape and position; and b) that its parametrisation was not based on a common data-set but combined literature value of flame emission with photographic, non-calibrated photographs. Enhancements of the technique addressing this shortcoming, as well as a measurement setup to provide data for the consolidated parametrisation of the model are currently investigated.

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Conflict of Interests Disclosure

The authors declare no conflict of interests.

Author Contributions

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