Daylight scattering by late antique window glass from Ephesos

Reconstructing the spatial distribution of daylight in lost architecture

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Introduction

Window glass and daylight in late antique building

Since the advent of window glass as a material first used in Roman bathes of the 1st century (Baatz, 1991), but soon applied in other public and private buildings, the availability of daylight in architectural spaces is inseparably intertwined with the practice of glassmaking (Fontaine, 2008). The chemical composition of glass, as well as the surface irregularities and inclusions that result from its artisanal processing (Komp, 2009) shape the spectral and spatial distribution of transmitted light, and thereby the visual perception of the illuminated interior. While the analysis and reconstruction of Roman and late antique interiors have a long tradition in building history (e.g. Demetrescu et al., 2016), the studies of daylighting in this context are rare and often depend on assumptions in lack of empirical data (Papadopoulos and Earl 2014). Measurement and modelling of the optical properties of Roman window glass are key elements for the predictive rendering of these interiors and bridge a gap between material culture and sensory studies (Noback, in press).

The find of a larger amount of window glass in a late antique-medieval city quarter in Ephesos (Schintlmeister, 2018) offers the opportunity to extent the authors earlier research on the measurement and optical modelling of Roman glass and daylighting of historic interiors (Grobe et al.). The find poses the challenge to study glass and the material manifestation of an interior in context – the remaining walls, floors, and decoration, indicating the lost tangible structure of the building, and the fragments of its glazing, traces that may lead to an understanding of the perception and utilization of the building by its occupants.

Objectives

We describe the methodology and first outcomes of two key elements of our research in daylight scattering by window glass from Ephesos:

- The measurement of light scattering, and its attribution to the particular geometric properties of glass samples as caused by manufacturing as well as later deterioration of the finds, and
- The modelling of the spatial distribution of daylight transmitted through such window glass, aiming at an empirically grounded reconstruction of the luminous conditions in the building forming the architectural context of the finds.

The presented results reflect the ongoing development of a method that shall lead to a systematic research on the optical properties of Roman window glass from different origins, times and production methods as well as their impact on the development of fenestration, use and architectural typology.

Sample and method

A sample of window glass from Ephesos

A set of 19 glass fragments from the excavation site in Ephesos was chosen, that covers the three main types of window glass and different stages of deterioration (Fig. 1a). Out of this set, one sample was selected for a detailed characterization, and to develop and test methods to model its light scattering properties (Fig. 1b).

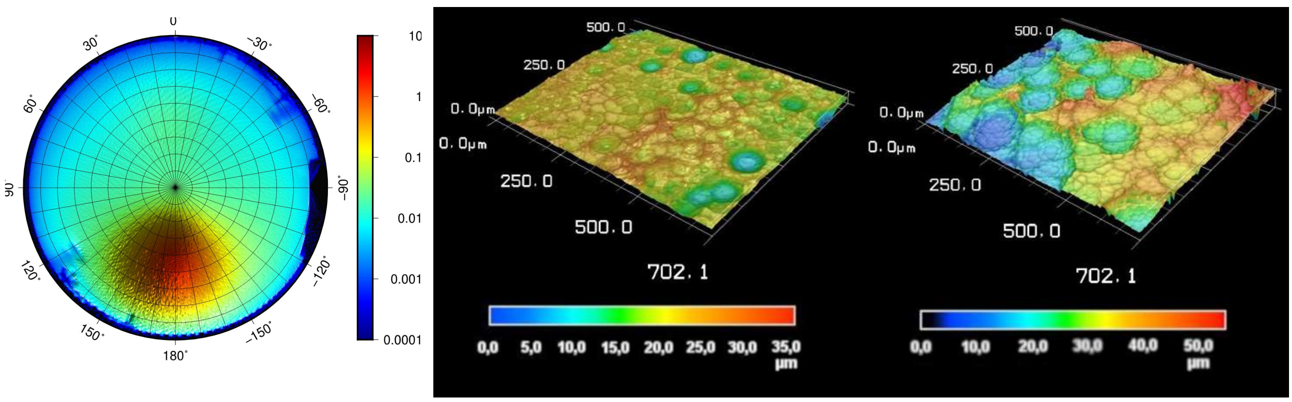
A b

Fig. 1: Set of 19 glass fragments from Ephesos (a). One sample of the set, marked by a red frame (a) and shown in detail (b), was chosen for characterization and modelling.

Characterization of light scattering properties and surface relief

Light scattering by the sample was directly measured by means of the Bidirectional Scattering Distribution Function (BSDF), an average quantity of a defined surface area that describes reflection and transmission distributions as a function of the directions of incident and outgoing light (Apian-Bennewitz, 2010). Assuming isotropic transmission, the hemispherical distribution of transmitted light is sequentially recorded in terms of illuminance at a dense set of > 150,000 arbitrary outgoing, or scattered, directions (θ_s,ϕ_s), for few incident directions defined by varying off-normal angle (θ_i) but constant angle (ϕ_i) in the sample plane. The measured distribution for once incident direction θ_I = 50°, ϕ_i = 0° is illustrated by Fig. 2 a). For all measured incident directions, distinct forward-scattering is observed that represents a widened peak in the hemispherical distribution. The direct-hemispherical transmission, calculated by integration of the hemispherical distributions, ranges from 0.696 (θ_I = 0°) to 0.322 (θ_I = 70°).

Light scattering by the sample, which comprises a theoretically clear, non-scattering material, is caused by refraction at the rough surfaces, which optically form the outer interfaces between a dielectric solid and air as its surrounding medium, and inclusions of air and other particles, that form internal interfaces. Scans of the height reliefs of the surfaces were prepared by confocal microscopy to relate geometric properties of the sample with the measured BSDF. Fig. 2 b) and c) show the height reliefs of the surfaces. The origin of the caldera-like pattern asks for further investigation and can be assumed to have a strong influence on the light scattering properties of the sample.



a b c

Fig. 2: Measured BSDF for incident direction θ_I = 50°, ϕ_I = 0° (a), and height-reliefs of top (b) and bottom (c) surface.

Data-driven modelling of light scattering for predictive rendering

Based on the measured BSDF, a data-driven model was set up employing a tool-chain that is part of the lighting simulation software Radiance. In a first step, the command pabopto2bsdf approximates the distributions by a set of radial basis functions, and interpolates between the measured incident directions. Then, the command bsdf2ttree samples the interpolants and builds a three-dimensional tensor. This data-cube is subsequently translated into a tree-structure by selectively merging cells where the distribution's gradient is low. The result is a compact model of locally adaptive resolution, that replicates the light scattering properties of the sample. Fig. 3 shows the distributions returned by the model for three different incident directions. Fig. 3 a) and c) represent directions that were included in the model generation, with Fig. 3 c) corresponding to the measurement shown in Fig. 2 a). Fig. 3 b) shows the result of interpolation between the two measured directions $\theta_I = 20°$ and $\theta_I = 30°$.

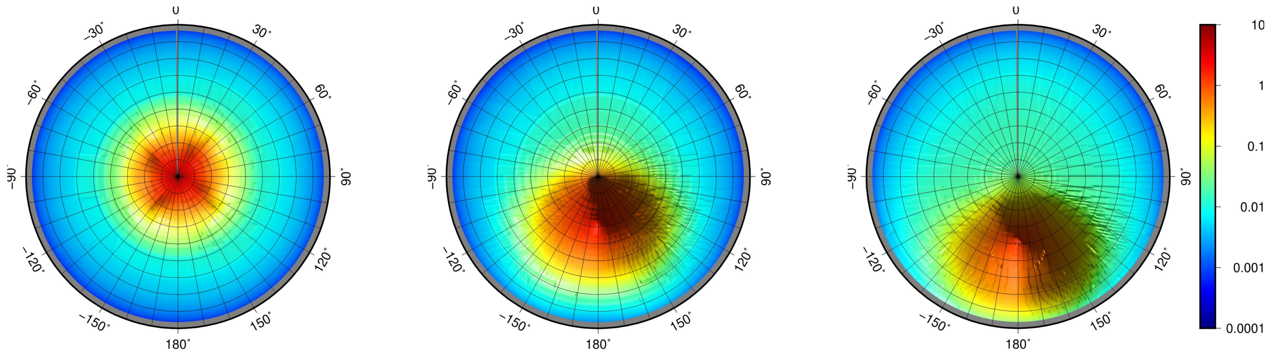


Fig. 3: Distributions of transmitted light for incident directions $\theta_I = 0°$ (a), $\theta_I = 25°$ (b), $\theta_I = 50°$ (c) predicted by the model.

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