Good morning everyone, I'm [Your Name], and I'm happy to present our paper *Rediscovering Romanesque Mural Paintings: Experiencing Medieval Art as Originally Conceived Through Historical Light Simulation*. This is joint work with my colleagues from UPC, UdG, and UVic.

Today I'll show how we can not only digitally reconstruct medieval paintings — but also recreate their original **light**.

Why lighting matters

Original paintings at MNAC's museum

Recreation illuminated with a candlelight

Let's start with this striking comparison. On the left, a medieval mural as we see it in a museum. On the right, a reconstruction of the same painting under candlelight. Same artwork — yet two very different experiences. Light doesn't just affect visibility — it changes meaning, atmosphere, and how we connect emotionally to art.

Problem statement

DH 25


MNAC's museum

Current museum lighting

≠

Historical lighting


Lighting with candles

Most Catalan Romanesque paintings are displayed in bright museum galleries. But when they were created, they were meant to be seen in dim churches, illuminated by sunlight at specific times of the year, or by candles and oil lamps. This gap prevents us from truly understanding the original visual and symbolic impact.

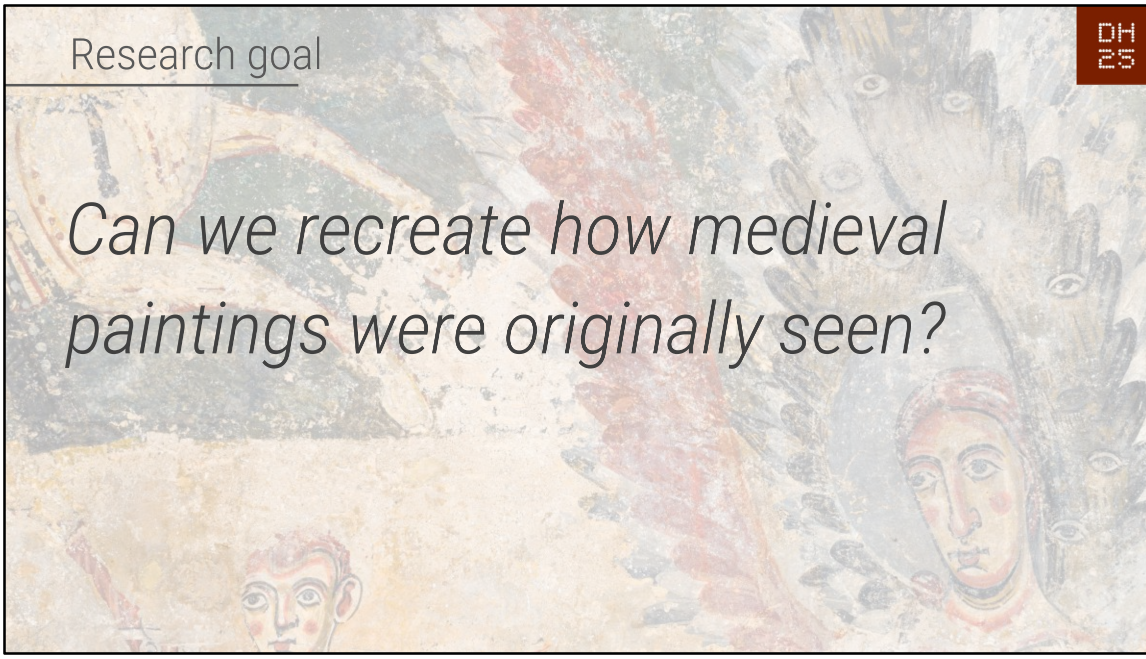
Prior Work


[Happa et al. 12]


[Gutierrez et al. 08]

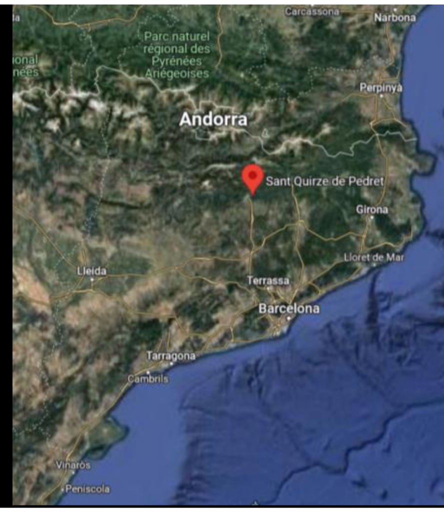

[Gonçalves et al. 09]

Previous work has studied daylight simulation, participating media, flame rendering, and even applied these ideas in cultural heritage. But what was missing is a complete pipeline: from measuring real historical light sources, to physically based rendering and an accessible tool for art historians and the public.



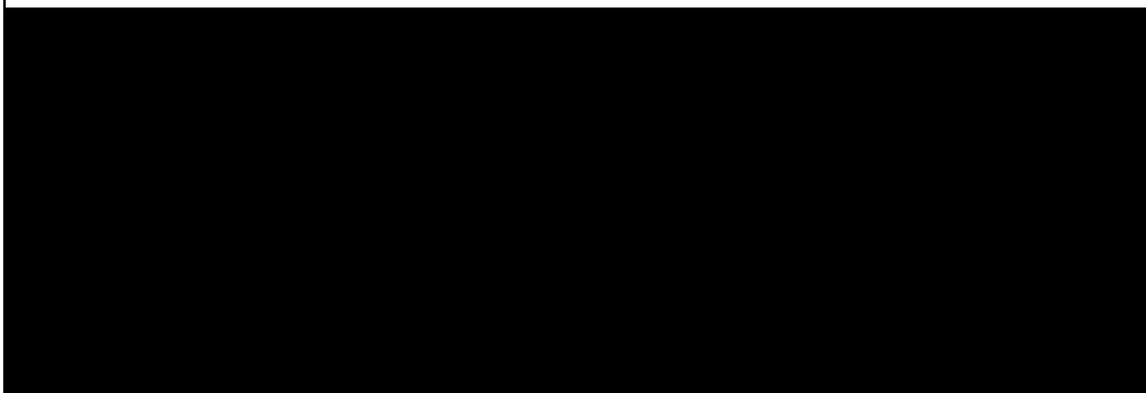
So our research question is simple but ambitious: **Can we recreate how medieval paintings were originally seen?** Our goal is to let users explore artworks under hypothesized historical lighting conditions — as close as possible to what medieval worshippers experienced.

Case study: *Sant Quirze de Pedret*



Our case study is Sant Quirze de Pedret, a small but very significant medieval church in the Catalan Pyrenees known by the quality of its mural paintings.

Case study: *Sant Quirze de Pedret*



Different architectural phases and mural painting layers

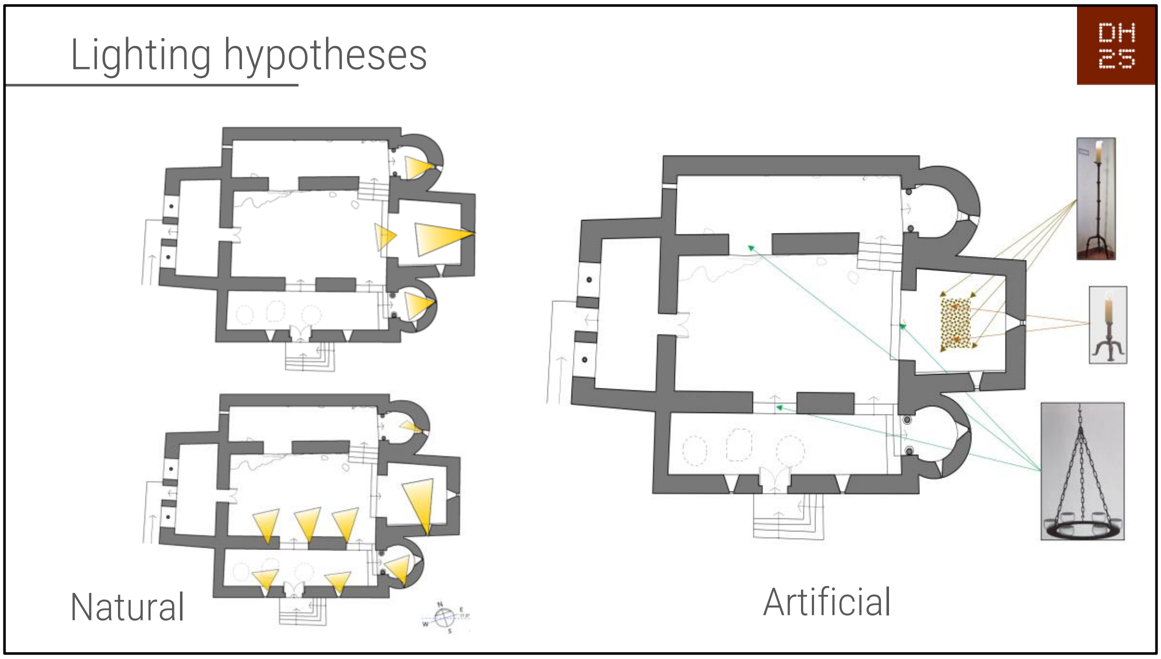
It was built in the 9th century, expanded in the 10th, and altered again in the 13th. Its walls displayed two painting cycles: an earlier pre-Romanesque one, later covered by a second layer that became a significant example of the Catalan Romanesque style.

Case study: *Sant Quirze de Pedret*

Current situation

Most frescoes were removed and transferred to museums, in Barcelona and Solsona, at the beginning of XXth century.

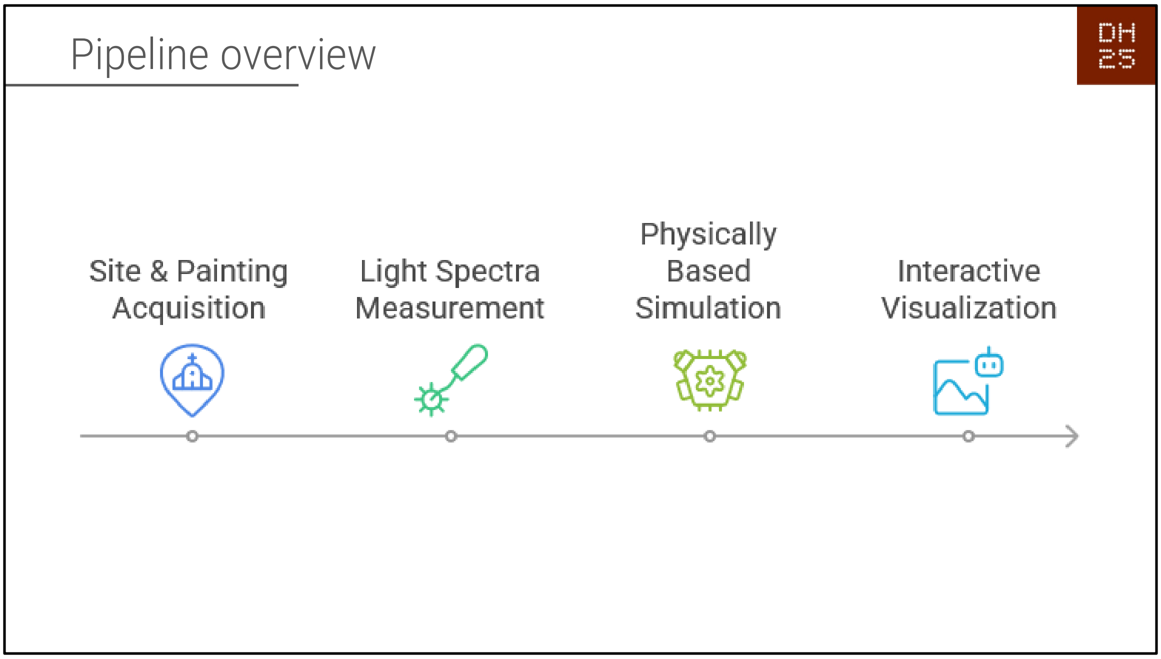
This makes Pedret a case where it is almost impossible today to imagine what it was like in the Middle Ages to observe the mural paintings.



We considered two families of lighting hypotheses.

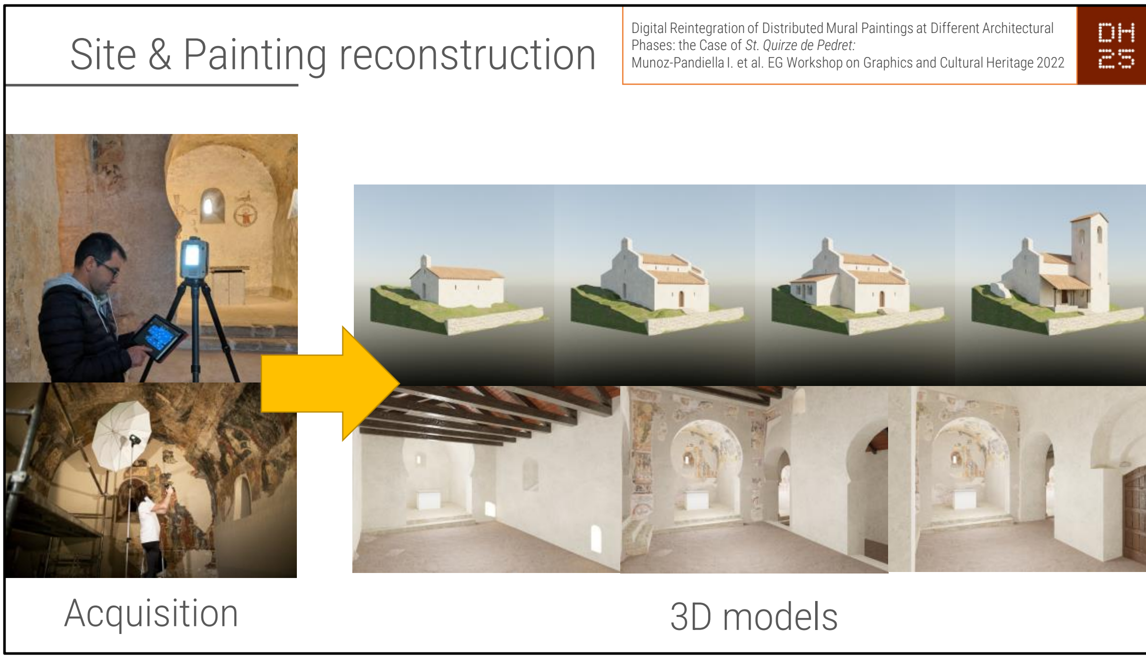
For **natural light**, windows changed over centuries, and sources mention solar alignments on liturgical dates and solar times (sunrise and noon).

For **artificial light**, historians suggest chandeliers near the altar, table candles on it, and polycandelon oil lamps hanging from the apses and entrances. Each of these hypotheses can completely change how the paintings were perceived.



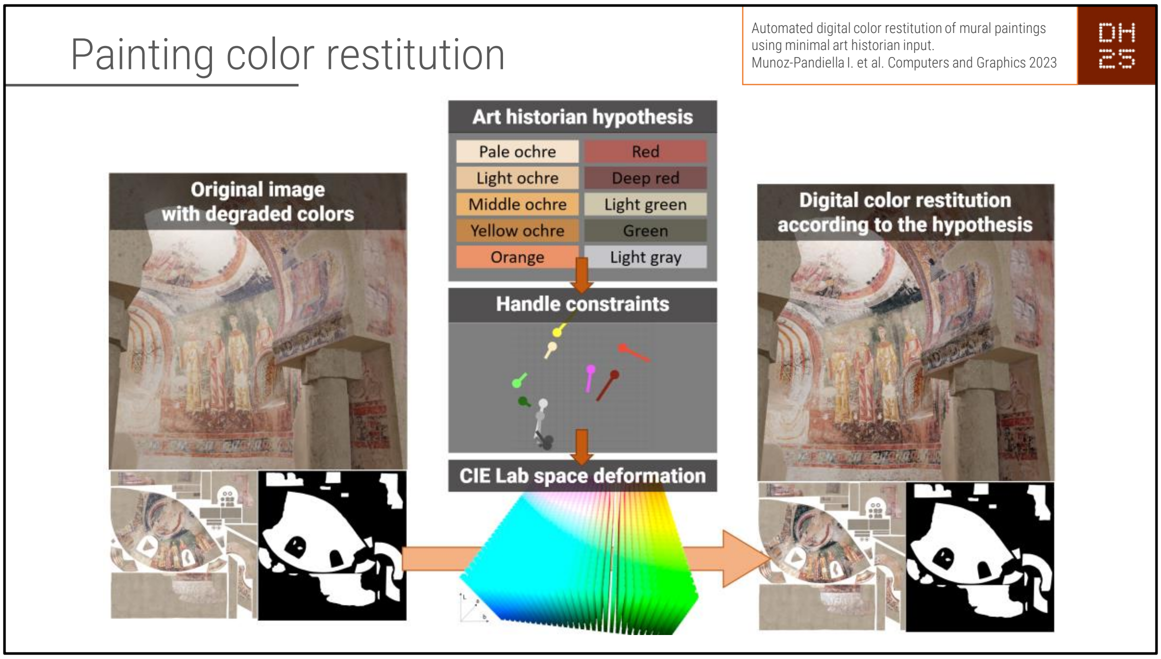
Here is our pipeline. Step 1: reconstruct the church and the paintings. Step 2: measure spectral data of historical light sources. Step 3: simulate both natural and artificial light with a physically based renderer. Step 4: deliver results through an interactive web tool.

This complete workflow helps us to recover the original experience of medieval worshippers

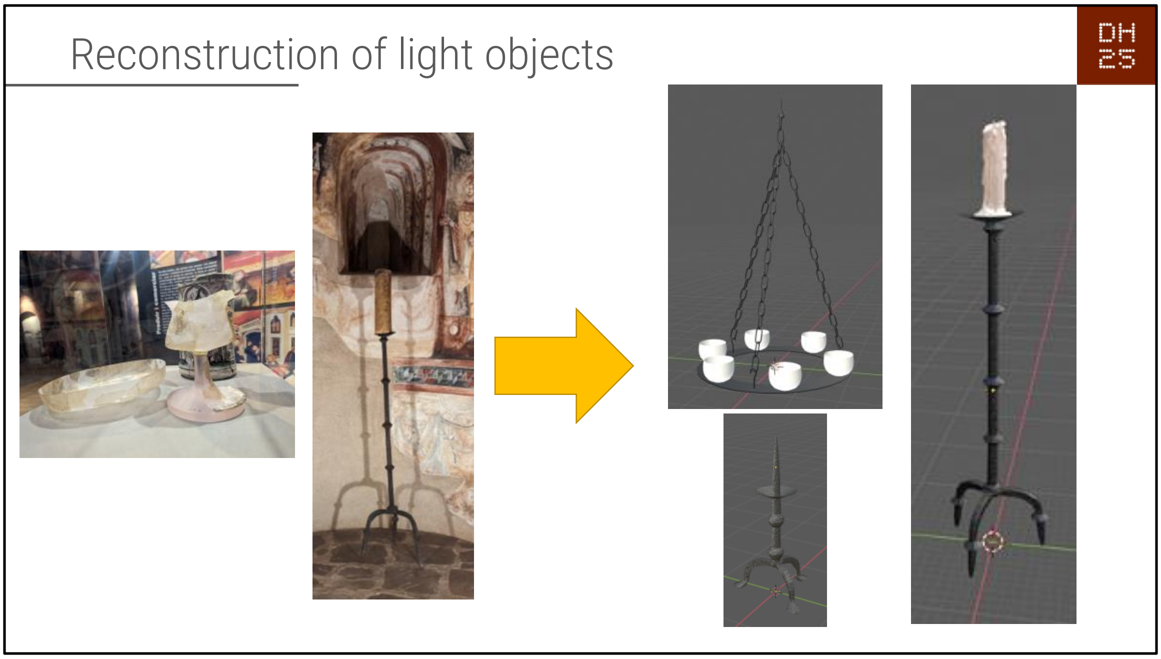


The first step consists on reconstructing the church.

We began with a 3D reconstruction of the site, using laser scans and photogrammetry. We then joined again the paintings — scattered between museums and the remaining church walls — and placed them back virtually into their original positions. After this, we obtained different 3D models for each significant moment of the site's history.



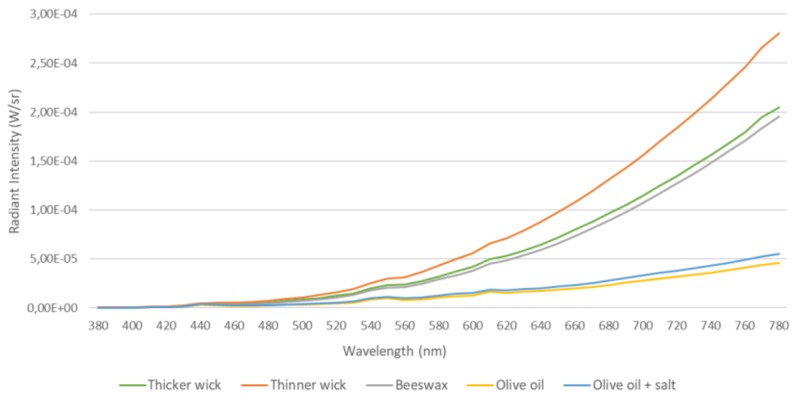
After that, we applied digital color restitution, to approximate the original tones of the frescoes, which are now faded.



Finally, we modeled the lighting artifacts based on original Pedret lighting objects that are exposed in Berga’s musem.

After the creation of the 3d models, we started the second step related to the acquisition of light data.

Light source acquisition



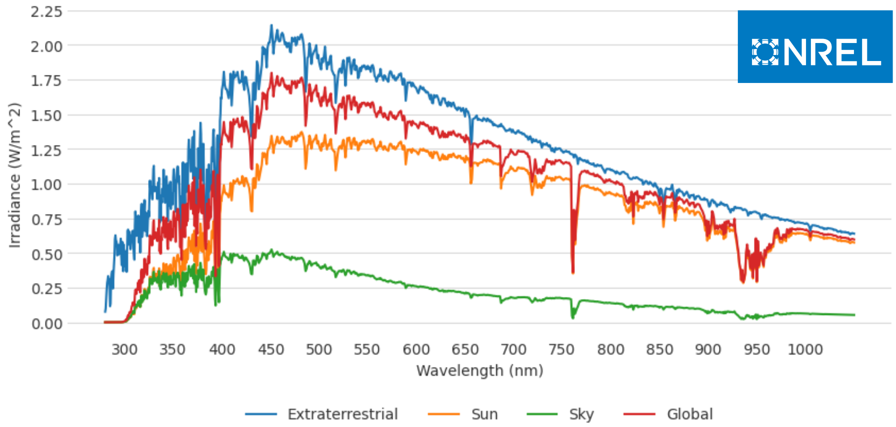
Measured spectra: candles & oil lamps

For the artificial lighting, we acquired spectral data from real historical light sources. We measured paraffin and beeswax candles, and oil lamps with different compositions. Measurements were taken at different angles in a specialized optics lab.

The spectra turned out to be smooth, with only intensity varying with angle. However, some changes in shape are noticeable depending on the combustion material. Oil lamps, for instance, emit less intensity in the higher part of the spectrum.

This acquisition makes our simulations physically grounded.

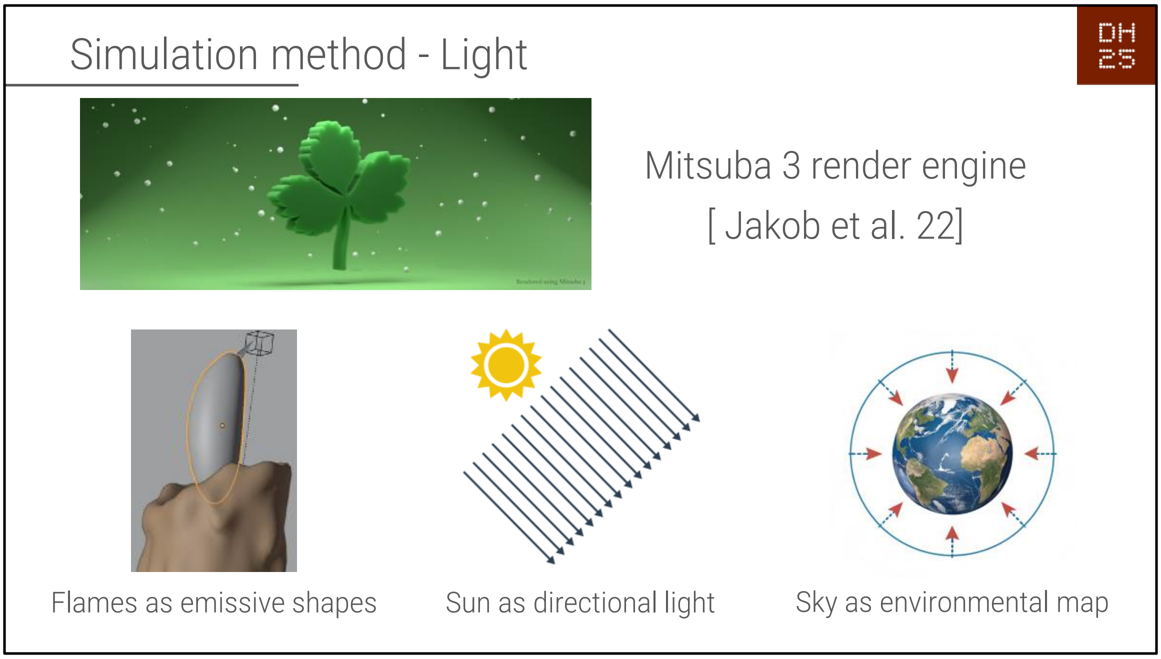
Natural Light Simulation



Solar and sky spectra simulated using
SMARTS model [Gueymard 2001]

For the sun and sky, we used the SMARTS model from NREL. This model allows to precisely simulate spectral information of sun and sky given a set of parameters. We configured it with geographic coordinates, seasonal conditions, and historical solar time.

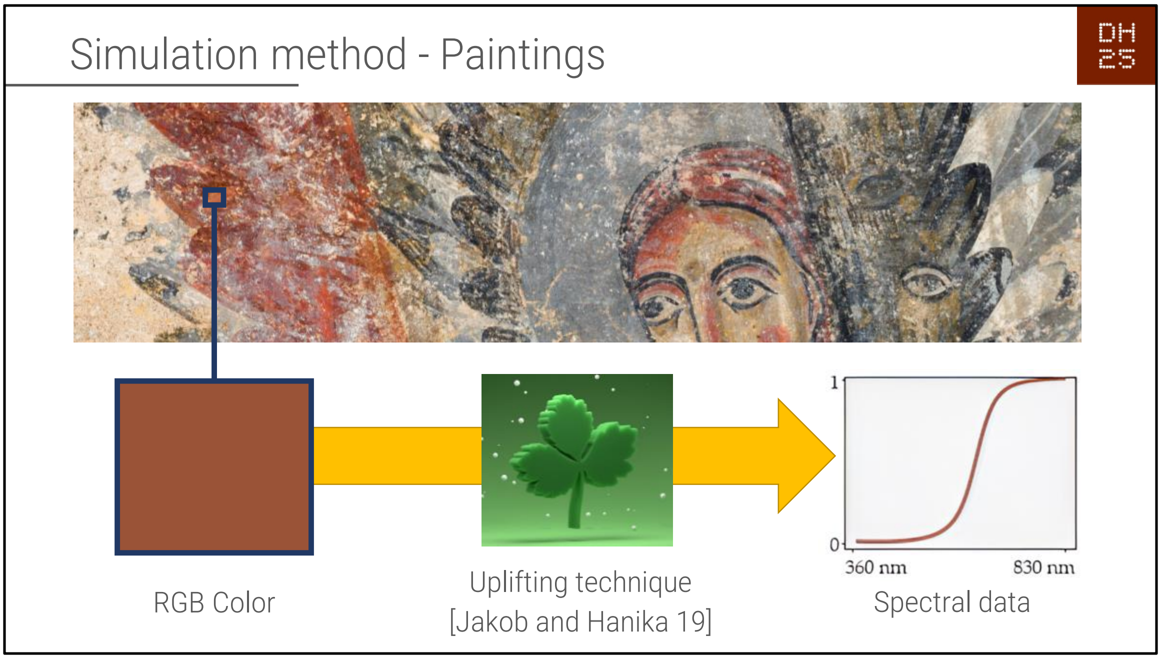
This ensured that the natural light used in the simulations closely reflects our historical hypotheses.



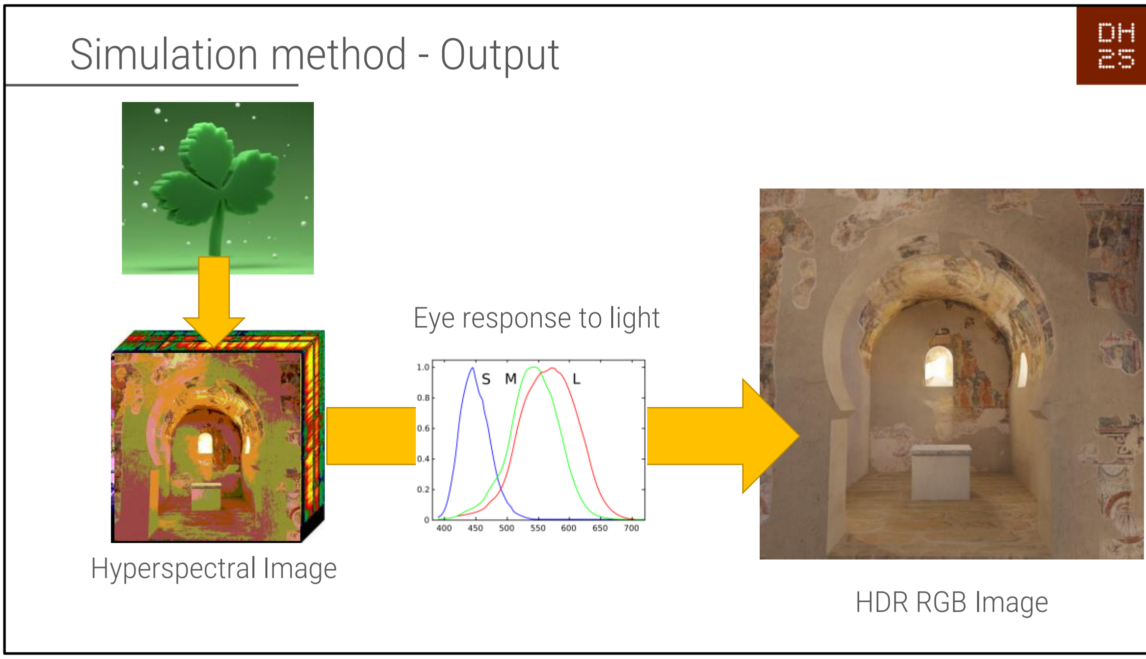
Now, let's talk about the simulation step.

To simulate light, we used *Mitsuba 3*, a physically based renderer that can work with spectral data. In other words, a tool that allows us to simulate light with higher precision.

Flames were modeled as emissive shapes driven by our measured spectra. Sun was modeled as a distant directional light and sky as a constant environmental map. Although this setup does not account for variation in skylight, this contribution is negligible due to the sky's low intensity inside the church.



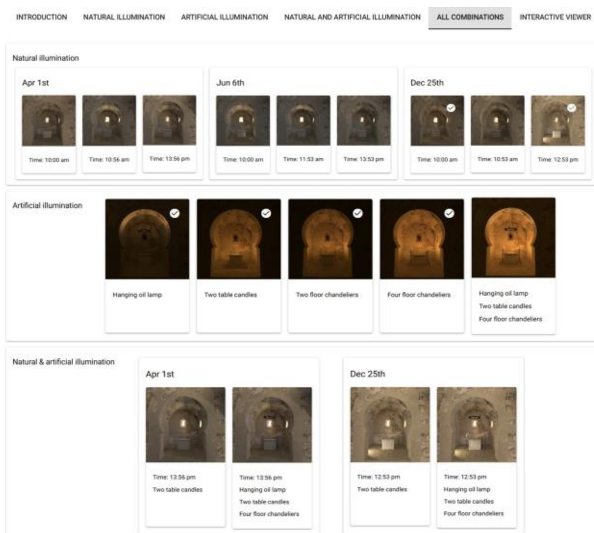
As we do not have spectral information of the paintings, we need to convert the RGB colors to spectral data. We use an uplifting technique that is already available in mitsuba.



After the simulation in Mitsuba, we obtain a hyperspectral image that we convert, taking into account the eye response to light, to an HDR image with RGB information.

This HDR image is still based on the light energy that reaches the camera, but considers the behavior of human eye cones. However it is not normalized, so it can not be displayed directly. This is where the visualization step come into play.

Visualization tool - Menu



To make results accessible, we created a web app. It has a visual menu that allow users to chose for inspection one or several images, that represents the simulated hypothesis.

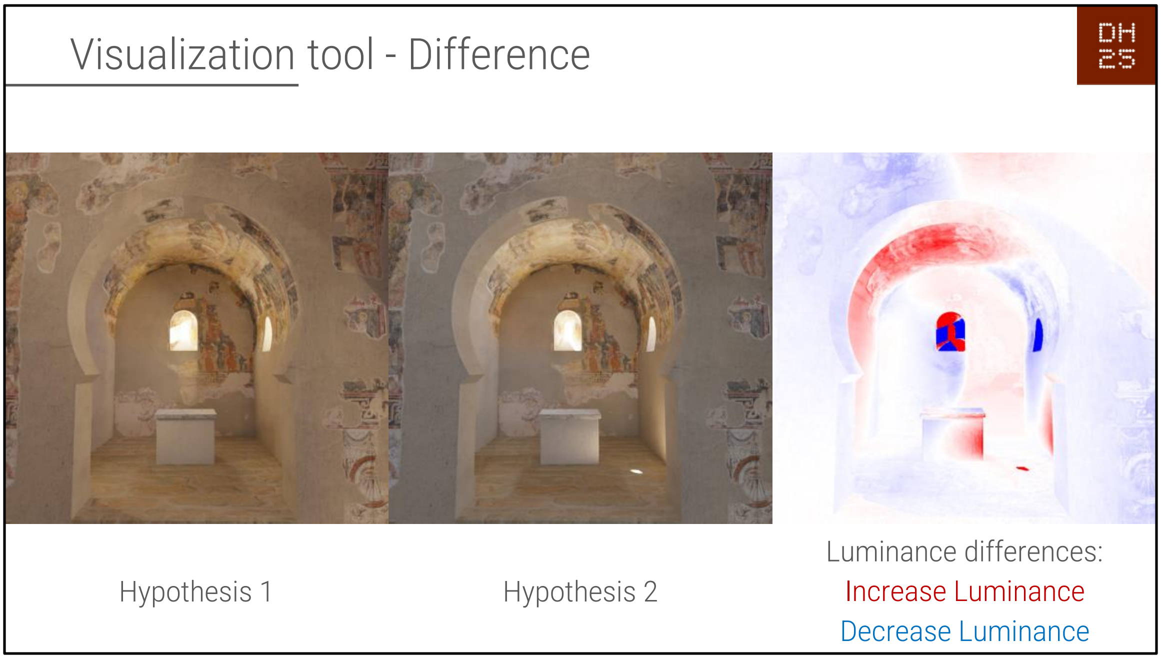
Visualization tool - Viewer

It allows panning, zooming, and side-by-side comparisons. It has a minimalist drop-down menu that allows users to configure visualization parameters while maximizing the viewing area.

Visualization tool - Operators

Linear | Reinhard | Extended Reinhard | Luminance

Users can simply choose among tone-mapping operators, between Linear and two Reinhard versions, and view luminance maps. Reinhard was chosen by its known color realism. One version is easy to use while the other allow more tuning by the user. This makes the tool useful not only for computer scientists but also for art historians who may not have rendering expertise.



Finally users can compute a luminance difference image that shows where light increases or decreases. It allows the user to analyze subtle lighting behaviors due to the use of different light sources or architectural changes.

Let’s now see our results recovering the original experience visiting the church in the Middle Ages.

Results - daylight

December 25th 10:00	June 16th 10:00	December 25th 14:00

Here you see simulations for three dates and times. Notice how in winter the lower sun brings more light inside the church than in summer, where light enters at a steeper angle. These differences would have strongly affected the paintings' perception, and could only be analyzed with this kind of simulation.

Results – artificial light

Table candles | Oil lamps | Chandeliers | All combined

Artificial light created very different atmospheres. Candles highlight the altar, oil lamps illuminate the apse vault, and chandeliers provide general lighting.; perhaps intentionally drawing attention to each corresponding zone.

When combined, the effect is richer and more complex. This tells us that medieval ceremonies would have involved subtle variations of mood depending on the chosen setup.

Results – combining natural and artificial lighting

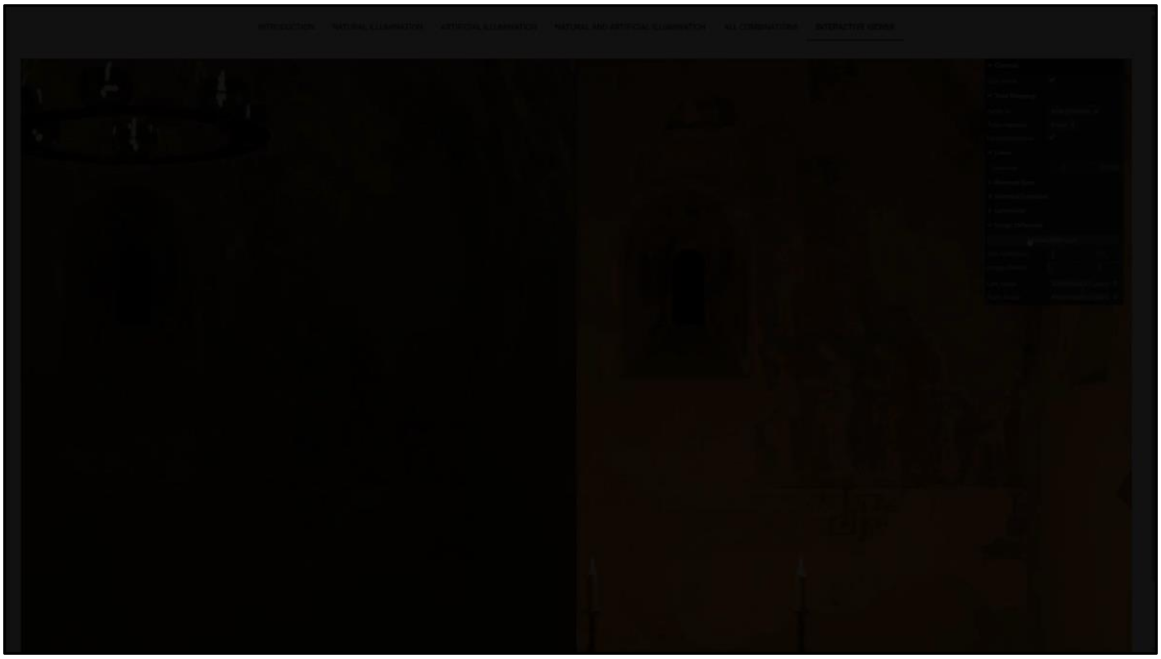
DH 25

April 1st, 14:00

Table candles,

Chandeliers and oil lamps.

We also simulated combinations of natural and artificial light. In this image you see all artificial sources plus spring daylight. Although natural lighting dominates the scene illumination, we can see subtle increases of warm light on surfaces near the flames.



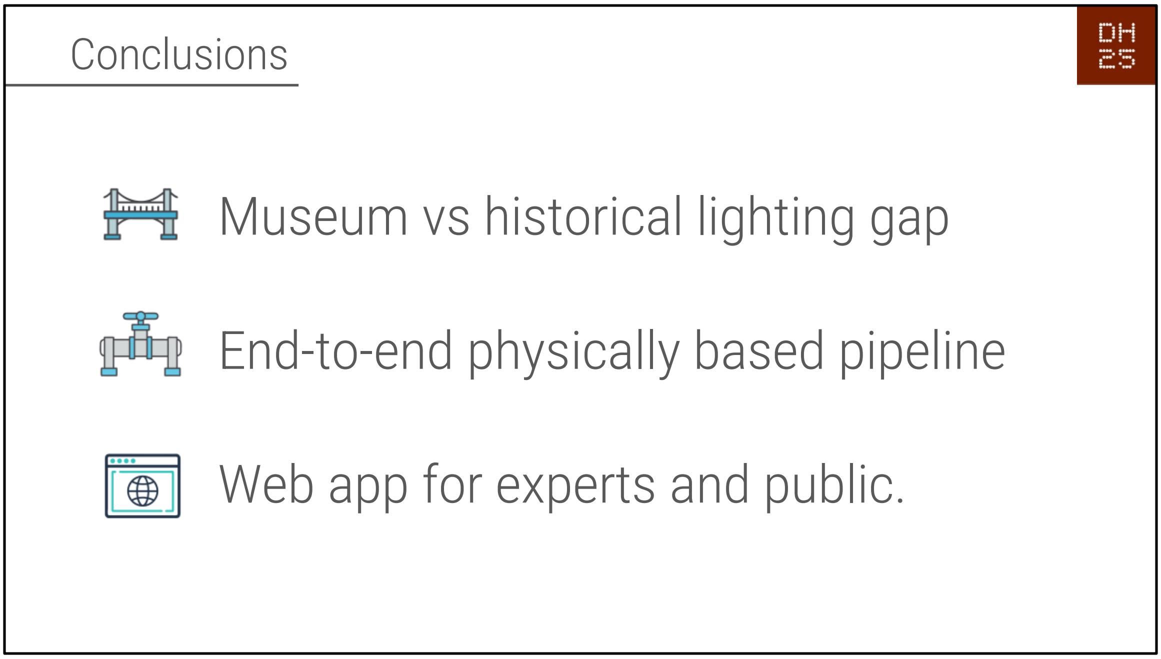
Now let me show you the tool in action.

The application menu includes a collection of tabs that organizes the simulated hypotheses. One tab corresponds to natural illumination in which renders are organized per dates and times. On the tab of artificial lighting, the user can chose between different configurations of lights. We also have a tab for hypotheses in which artificial and natural light is combined. Finally, a tab that overviews all the available experiments.

Users can select different hypotheses to be visualized in the interactive viewer. There, they are shown side by side. The user can adjust the exposure and inspect the paintings by zooming and panning. The user can also compute the difference image in which luminance variations between the hypothesis are shown.

Now, we are switching to images with natural lighting on December 25th. We can see how the user can also adjust the exposure, inspect the paintings and visualize the difference image. The user can also switch tone mapping operators and adjust their parameters.

This interactivity is what makes the tool valuable for both researchers and the wider public. This tool allows art historians to test hypotheses — something impossible in a museum or in situ today.



To conclude: we addressed the gap between current museum lighting and historical conditions. We developed a complete pipeline, from spectral acquisition to rendering. And we made results accessible via a web app that allows exploration and comparison.

Our work benefits both scholars and non-experts who wish to rediscover medieval art in its original atmosphere.

We see this as a model for how computer graphics can help cultural heritage — not just documenting the past, but reviving lost experiences.

Future work

- Measure spectral reflectance.
- Study perception in dim light.
- Emotional/cognitive impact.
- VR experience.

Looking ahead, we plan to measure the spectral reflectance of the paintings themselves, to refine accuracy. We want to study how human perception adapts in dim light, and how viewers respond emotionally. And we will extend this work to immersive VR, enabling visitors to enter the church virtually and experience its original light.

If you remember one thing from this talk, let it be this: **we don't just restore medieval paintings digitally — we restore their light.** And with light, we restore part of the original spiritual and emotional atmosphere of these works.

Acknowledgements

Funders

Art Historians

Museums

Finally, I'd like to thank our art historian colleagues, the collaborator museums, and the funders…

And of course all of you for your attention. Let me also mention that you can find code and datasets in our GitHub repo.