

Let the Light in. Using LiDAR- and Photogrammetry-based BIM Reconstruction to Simulate Daylighting in the House of Trebius Valens, Pompeii

Nikolai Paukkonen <nikolai_dot_paukkonen_at_helsinki_dot_fi>, Doctoral School of Geosciences, University of Helsinki, Finland  <https://orcid.org/0000-0002-4072-9379>

DOI: <https://doi.org/10.63744/q79ueyxyznhv>

Abstract

From ancient authors, such as Vitruvius, we know that the Romans considered lighting and especially daylighting an important factor in designing buildings. Instead of windows, which were usually few and small, a typical Roman house would get most of its daylight from an atrium and a peristyle that were open to the sky in the middle. Quantity of light would determine what kind of action was possible inside and at which hours, in addition to the general experience of space for the individual. Pompeii offers many well-preserved remains of actual houses that allow for attempts to reconstruct this phenomenon. Here a reconstruction and daylighting simulations of the house of Trebius Valens in Pompeii are presented. The reconstructions, done using Autodesk Revit, are based on LiDAR and photogrammetric documentation of the building. The lighting simulations were performed using Light Stanza addon. By assessing hourly alteration in lighting in different spaces, it is possible to visualize the daylighting schedule of the house. Through careful inspection of the results, this article paints a picture of a Roman house's constructed relationship with natural light.

1. Introduction

Proper daylighting is an essential part of a functioning building. Understanding the daily life of a Roman domus without understanding how its lighting functioned is impossible, and straight comparisons to modern living standards can be misleading. The level of lighting dictated what kind of activities were possible and at which hours, and artificial light sources, typically ceramic lamps, would help only so much. In addition to being an enabler of activities, daylight at the latitudes of Pompeii could also be a source of irritation, inconvenience or even danger: during the summer months, straight sunlight's glare and the accompanying heat could have made some spaces close to useless for most activities.

Many Roman authors commented on daylighting. Vitruvius wrote in his *De architectura libri decem* (late 1st century BCE) about the importance of taking light into account when designing buildings. For instance, he points out the influence of orientation: summer dining rooms, for instance, should be oriented towards north, so that direct sunlight does not make the heat and brightness unbearable (6.4.2). In addition to dining rooms and other places of prestige value, he also emphasizes the need to consider daylighting in spaces used by slaves and servants, such as passages and staircases (6.6.7). However, both concerns might have been difficult to fulfill in urban context, as will be seen in the results section of this article. Other writers noted the importance of lighting as well. For example, Pliny the Younger noted the value of properly situated sources of light, both artificial and natural, in creating the atmosphere of a dining room (Plin. Ep. 2.17.5). Pliny mentions *valvis*, as does late Roman Sidonius (Carmina 22.205), which refer to some sort of curtains or folding doors, which could have been used to limit the passage of light.

Light has multiple functions in architecture and is an essential element that has to be taken into account in all construction. Obviously light is required for one to be able to see and function. Different actions have different lighting

1

2

3

requirements – a scribe or a craftsperson needs different levels of light compared to a slave carrying water. Lighting greatly affects how we experience space, its shape and its colors (human eye's color vision does not function in too dim conditions), influencing the atmosphere and the emotions generated. Furthermore, daylighting is an important factor in orientating oneself on a larger scale, i.e. a person's whereabouts in relation to the outside world. It gives a person sense of the time, following the cyclical change from morning to evening and acting as a natural initiator of sleep cycles (Phillips, 2004, pp. 5–6; Rea and Figueiro, 2018). All in all, daylight and artificial lighting are major influencers of human experience and well-being in built spaces (Van Creveld and Mansfield, 2020; Molar Orozco, 2022).

Starting in the 1990s, computer simulations based on reconstructions of Roman buildings have been possible (Ellis 1995, 65), but large scale studies are still scarce. Villa dei Misterii, perhaps the most famous villa in Pompeii, has been used in a few daylighting simulations before, using another metrics for lighting [Monteoliva et al. 2019], [Monteoliva n.d.]. Another Pompeian house under modern daylighting research has been the House of the Greek Epigrams (V, 1, 18) [Campanaro 2023a], [Campanaro 2023b]. Daylighting simulations with other Mediterranean sites have been done as well, beginning in earnest in early 2000s [Campanaro 2023b], [Campanaro 2023a]. However, one main limitation for this reconstructive approach is the limited number of properly preserved walls and roofs. If the level and inclination of the roof or the locations and sizes of window-holes are not known, it is impossible to do precise daylight simulations.

In addition to studies about daylighting, artificial lighting scenarios have been simulated in ancient Mediterranean contexts as well by e.g. Mollou et al. [Moullou, Doullou, and Topalis (2018)], but they are outside the scope of this article. Regardless, the conclusions of this article show clearly that some kind of artificial lighting would have been required in the house of Trebius Valens, especially during the early morning and late evening. A glazed lamp was found in one of the rooms during the original excavation [Spano 1916]; in addition to that, a chain found in the atrium might have been part of a suspended lantern [Spano 1915, 339]. Concerning the general sparsity of finds it is however very likely that the inhabitants would have used multiple lamps for various purposes.

This work examines the daylighting of the House of Trebius Valens (III, 2, 1) in Pompeii, located at Latitude 40°45' N, Longitude 14°29' E WGS84 (Figure 1). At its current stage it has an area of c. 540 sqm and 25 rooms, but at least some of the rooms around the atrium had a second floor. It is on the northern side of the important street Via dell'Abbondanza, and one of the few totally excavated houses in Regio III, which otherwise remains largely unexcavated. Despite the house's average size, it boasted multiple luxurious elements, such as a small private bathroom (rooms y and q), a decorated summer triclinium in room x, a complicated fountain system, and many rooms decorated in colorful 2nd and 3rd style wall paintings. As is typical with many Pompeian houses, no written sources about the house have survived, except for a few graffito and election messages found on the walls.

4

5

6

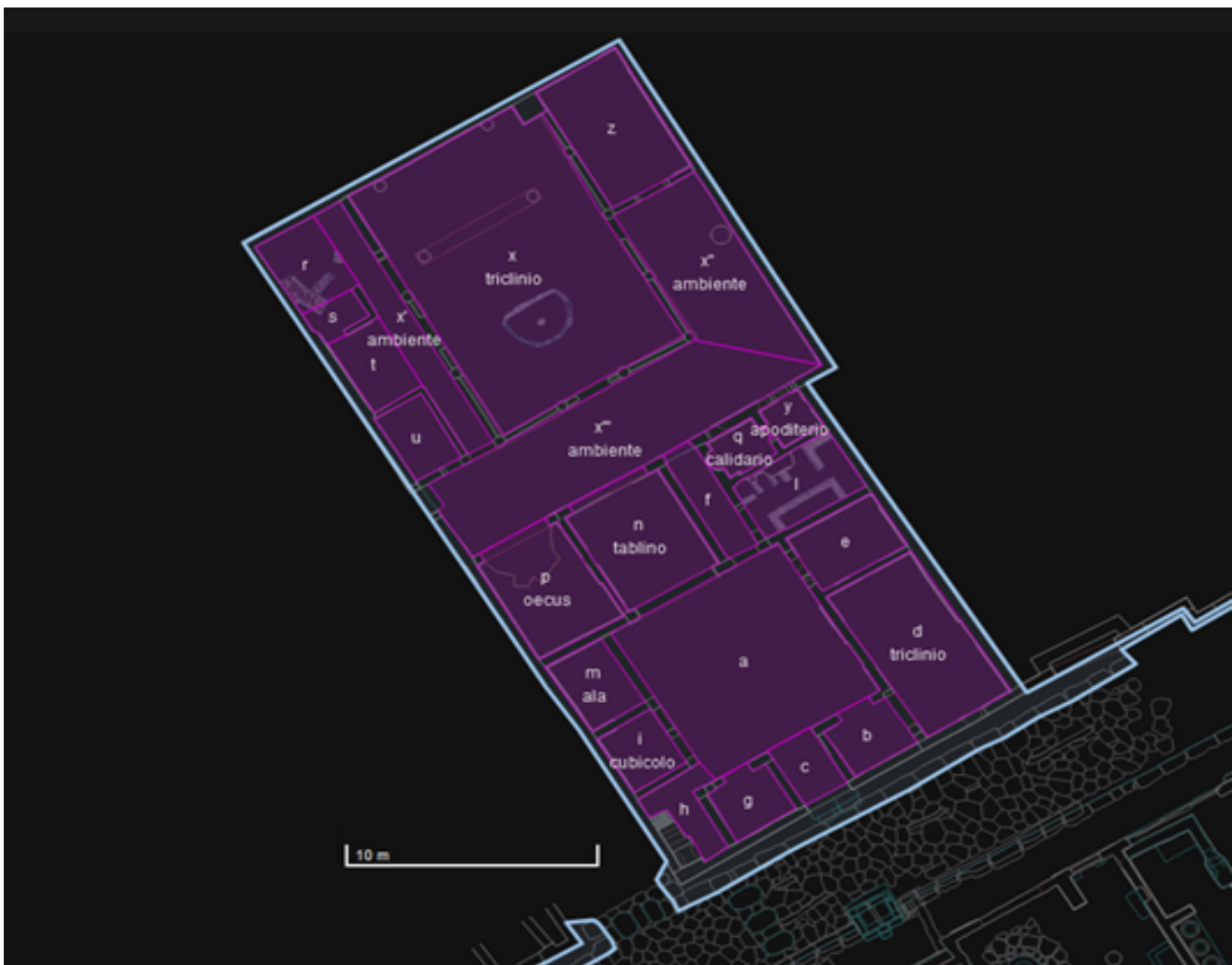


Figure 1. The plan of the house of Trebius Valens (III, 2, 1) with the commonly used naming scheme for the rooms (<https://open.pompeisites.org/>)

The house is currently under close examination by the cross-disciplinary Institutum Romanum Finlandiae working group project “Living in Loca Amoena”, which aims to shed light on the Roman relationship with nature through case studies done in this compact but multi-faceted structure. Sun and daylight in general are fundamental elements of nature that call for human action in either sheltering from them or making the most out of their usefulness. The aim here is to provide clear basis for further analysis of the functioning of the house: how did daylight interact with the lives of the inhabitants, and where would artificial light have been required? The background and technical details on which the study is based are presented first, after which the results and their implications are reviewed, paying special attention to the atrium and the peristyle with their surrounding rooms, in addition to the private baths. The article shows that despite the lack of large windows, daylight was a major influence in the functioning and daily schedule of a Pompeian atrium house.

7

2. Materials and Methods

2.1 Reconstruction

Reconstructing the 3D BIM model of the house was an essential part of the project, since the current remains of the structure are both badly damaged and/or heavily rebuilt in the 20th century. The excavation of the house was conducted during the 1st World War, beginning in 1915, and as such, the level of documentation is not always sufficient to answer the questions of modern research. For instance, very little information about small and fragmentary finds is available, and the remains of the roofs were not accurately documented, except for the rare instance of roof tiles and roof structure found *in situ* in the eastern *ambulatorio* of the peristyle [Spinazzolo 1916]. Concerning the lighting of the

8

house, this means that we do not know about possible lamp sherds or window glass fragments that may have been among the removed soil. Later on, in 1943, an Allied bomber dropped its payload on the atrium, causing significant damage to the extant walls [Pollard 2020, Figure 2, Appendix A]. As such, visiting the house today may give a false perception of its daylighting conditions: especially the lack of most of the roofing from the atrium and peristyle allow a lot more sunlight to enter the building compared to its original state.

The main sources of daylight for the house would have been the atrium and the peristyle, as was stated above. The roof of the atrium was not preserved in the time of excavation, but it was most likely a common Tuscan roof with no pillars to support it and a rectangular opening in the center that allowed air, water and light to enter. Some fragments of lion-shaped terracotta *grondaie* gutters were found close to the center of the atrium in 1915, to further prove this conclusion (Spano 1915, 339). The roofs in general were reconstructed following the circa 15-17 ° inclination of the part of the roof that was found in situ, as was done in the earlier hand-drawn reconstructions by Spinazzolo [Spinazzolo 1953, tav. XLIV, XLV].

A short documentation campaign performed in February 2024 allowed us to photograph and measure the building carefully. Digital 3D photogrammetry was used to create a precise model of most of the house, except for rooms l, q and y, in which the light conditions did not allow shooting of a proper set of photographs. The processed models were brought to correct scale using small pre-measured scale bars with 16bit automatically detectable markers, and all processing of the photographs was performed using RealityCapture software (v. 1.3). Additionally, a LiDAR model of the house, scanned in 2022 by the Parco Archeologico di Pompei, was used to align the data and to fill in the areas not covered by the photogrammetrically created model. Alignment and editing were done using the free and open-source software CloudCompare (v.2.13).



Figure 2. Current state of the House of Trebius Valens (III, 2, 1) and some of its remaining window openings. (a) The façade of the house and the southern wall of triclinium d with a clerestory window; (b) western inner wall of cubiculum l and its wall painting with a small splaying window (photograph by Henna Ala-Lehtimäki); (c) western inner wall and a window opening of corner room h seen from room g (photograph by Henna Ala-Lehtimäki).

The digital reconstruction was performed mainly in Autodesk Revit 2024 (version 24.2.0.63). A point cloud created by

combining the LiDAR and photogrammetric data was imported into Revit, where walls, roofs, openings and other features were inserted on top of the point cloud data. In the case of features destroyed by the Allied bombing, archival photographs were used to recreate the approximate locations of windows and other openings.

Only features that might have had a clear influence on the spread of light were reconstructed, which excluded smaller and lower structures, such as remains of counters or the built *lecti* in the triclinium in room x. However, all the windows were carefully reconstructed, including their splaying, which was clearly intended to increase the amount of daylight they provided. This was especially crucial in the small private bath, where the two round windows (outside diameters were 23 cm and 36 cm, whereas on the inside they were c. 80 cm and 103 cm, respectively) would have provided enough light for bathing. No signs of window glass remain or are mentioned in the excavation diaries, which would fit the dating of the wall paintings to the later 1st century BCE – apparently glass windows were introduced only later, during the 1st century CE (Haan 2010, 37; 2007, 131). The doorways and curtains, such as the *valvi* mentioned in the introduction, were not reproduced, as there is no direct evidence of their use or existence in this particular house. It is likely that the front door would have been closed during some times of the day, but we do not know if this was the case during the daylight hours. Similarly, in Herculaneum some wooden folding screens in front of the tablinum have been recovered, but how and when were they used is not known. Regardless, the main light sources, i.e. the openings in the atrium and the peristyle, could not have been effectively blocked, and as the following simulations show, they had by far the greatest influence on the daylighting of the house.

The resulting model (Figure 3) was then exported to the cloud service of the Light Stanza addon, where the daylighting simulations were performed.

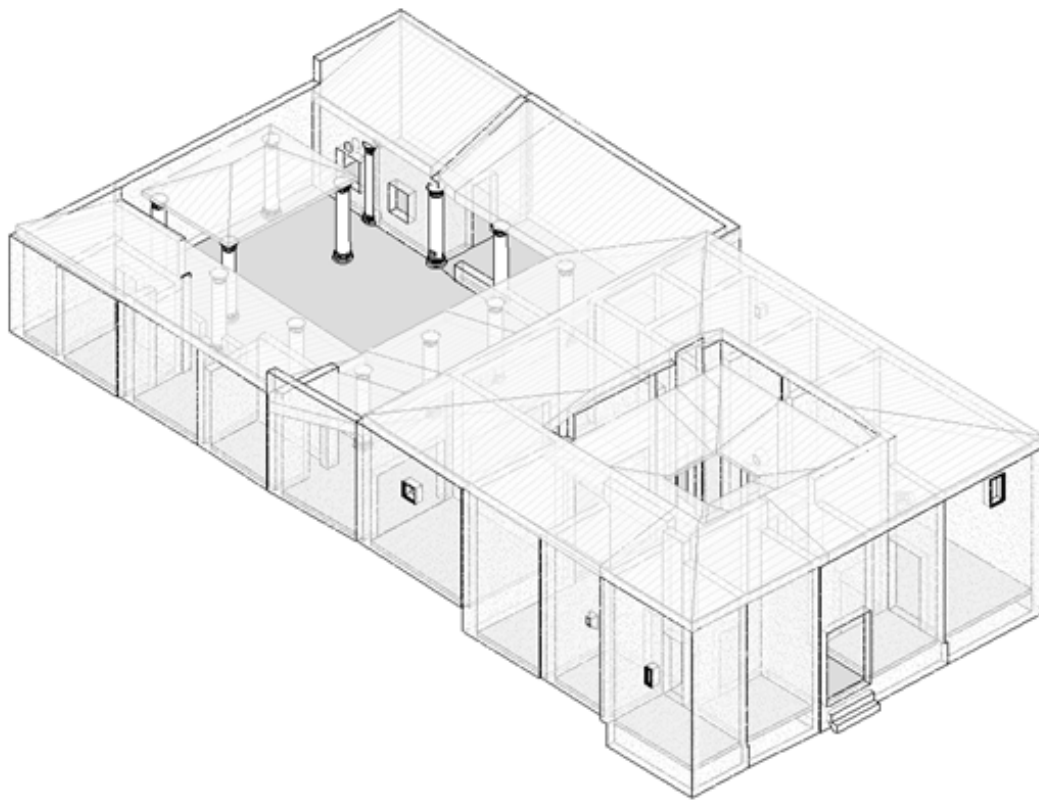


Figure 3. A 3D BIM reconstruction of the House of Trebius Valens, created using Autodesk Revit 2024.

2.2 Daylighting simulation

Light Stanza, a cloud-based Autodesk Revit addon was used to perform the simulations. Illumination Engineering Society (IES) defaults were used for surface reflection, with 20% reflectance for floors and 50% reflectance for walls. All

of the walls were originally plastered and many also painted in varying colors, but the functional differences in their reflectance values for the purposes of this study would have been minimal. After uploading the BIM model created in Revit, the simulations could be run in the highly automated user interface of Light Stanza web service. The grid based on the floor space of the house and used for the simulation was 1 x 1 m, as per the EU standard. After the simulation has been calculated, Light Stanza allows the user to download the resulting data in various formats, such as rendered PDF, SVG and PNG pictures, in addition to providing detailed numerical data in CSV format.

Estimating daylight factor and illuminance are complicated operations and require multiple calculations. Light Stanza uses the common Radiance suite, which is used for the lighting simulation, including the rendering of the simulations [Smith (ed.) 2006, 442]. The suite uses ray tracing for the lighting calculations. One must note that generally these simulations do not take into account wall hangings or furniture, which may give slightly higher illuminance results compared to the “real-life” situation [Simm and Coley 2011, 329–334].

Illuminance is a central physical quantity commonly used in the field of photometry, i.e. the measurement of various aspects of light, such as its intensity. Illuminance means the luminous flux on unit area of a surface; its unit being usually measured using the SI-unit lux (lx). It depicts how much light illuminates the surface, wavelength being corrected by the luminosity efficiency function to correlate with human perception (IEC 60050 - International Electrotechnical Vocabulary - Details for IEC number 845-21-060: ‘illuminance’, no date). One lx equals one lumen per square meter, lumen signifying the luminant intensity of a candela (roughly one regular candle) uniformly spreading on a solid angle of one steradian. However, for a layperson these units by themselves may be difficult to perceive – therefore, tables of ideal or recommended illuminance conditions are useful, and have been prepared by many different actors in science, architecture and engineering (Table 1; Table A1; A2).

Activity	Illuminance
Activities with very high eye strain: precision drawing, jewelry etc.	1000 lx
Short duration activities with high or very high eye strain: reading, drawing, etc.	750 lx
Short duration activities with medium or high eye strain: work in general meetings, etc.	500 lx
Short duration activities with low or medium eye strain: storage movement, social activities, etc.	250 lx

Table 1. An example of modern recommended illuminance values for different activities, following Serra 1998 [Serra 1998, 129]. The ancient Romans were most likely used to significantly lower levels of illuminance.

A daylight factor (DF) analysis was performed first. Daylight factor represents the ratio of indoor to outdoor light levels, calculated using the formula $DF = (E_i / E_o) \times 100\%$. E_i refers to the daylight illuminance at a specific point on the indoor working plane, while E_o denotes the simultaneous outdoor illuminance on a plane exposed to an unobstructed overcast sky. In effect, the resulting value shows how well illuminated the point is compared to the theoretical illumination that the point would receive if there were no structures to obstruct the light. For instance, with mean outdoor illumination of 10,000 lx, an indoor space with DF of 5% would receive 200 lx, which is above the minimum standard value of 100 lx given in some sources [Müller 2013, 236]. Modern studies often state a value of 5% to be the minimum for a well-lit area, whereas values of 2% or under are considered underlit and require artificial light sources (Chartered Institution of Building Services Engineers, 1999).

A single day, 21st of September, was chosen for the hourly grid-based simulation. The date follows the Commission Internationale de l’Éclairage (CIE) standard and is widely used in architecture and engineering. This allows for comparisons to be made with other studied sites that use the same standard. Light Stanza does not support simulating daylighting during historical years, such as 1st century CE. However, the changes in Earth’s orbit, axial tilt and axial precession are relatively minor in a period of c. 2000 years, and as such the position of Sun in relation to Earth would

have been very similar in 21st of September 79 CE and 21st of September 2024, considering the resolution of this analysis.

The hourly analysis of daylighting during the 21st was performed using Light Stanza's Calculate Grid Analysis function. It would calculate the illuminance of every square in the 1 x 1 m grid at the beginning of each hour of the day, starting at 00:00 and finishing at 00:00 on the next day. In addition to the numerical values, a visualization was created, using a colored scale to depict different levels of illuminance, 0 lx being blue and 700+ lx red, with varying shades in between. Sky conditions were set to follow the CIE definition of clear sky, meaning that the results depict a cloudless and sunny day. The general principles of where the daylight would have spread and at which hours would have been the same in overcast conditions, however – the level of illuminance would just have been lower.

19

One limit in the approach used here is that it focuses on the illuminance on the floor level. This is different compared to the cubic illuminance analysis used by Monteoliva et al ([Monteoliva et al. 2019]), which records also the illuminance on vertical wall surfaces. However, the simulation here does take the reflectance of the walls into account. Furthermore, the visualization of the approach used here is simpler to perceive, especially since the intention is ultimately to examine each different room as a whole.

20

Another feature that is not taken into account is the surrounding foothills of the Apennine Mountain range, which effectively block the sunrise for some time. Compared to astronomical twilight, this means that the sun actually rises roughly 1 hour 30 minutes later than in the simulations. Taking this into account, we must discard the first few hours of light visible in the simulation results and instead start inspecting them only after 07:00. For the sunset there is no similar effect, since there are no mountains to the west of Pompeii.

21

3. Results

3.1 Daylight factor

Daylight factor analysis gave clear results showing the impact of daylight coming from the atrium and the peristyle, and simultaneously expressing the limits of lighting received from the small windows (Figure 4, Table B1). The area of the summer triclinium in room x (against the northern wall) receives a significant amount of sunlight, even though it is covered by a canopy roof. This may not have been an entirely desired state of things: high DF value implies high temperature and possible glare, making dining during summer months uncomfortable. As mentioned in the introduction, Vitruvius explicitly stated that summer triclinia should not be aligned facing south (6.4.2). On the other hand, DF values on the sides of the atrium are on the lower end, while still implying sufficiently lit conditions for work.

22

It is worth noting that many of the rooms seem to be entirely in the dark, with DF value of every or almost every square being 0. For example, the two supposed kitchens, rooms r and i, seem to be completely dark, despite the open doorways and the small window in room i. Same applies to triclinium d, oecus p, or the baths, where the two impressive round windows do not seem to help at all. However, the hourly illuminance simulations presented below will show a more nuanced picture. The single visualization provided by DF analysis works as an excellent summary of the basic daylighting conditions in the house of Trebius Valens.

23

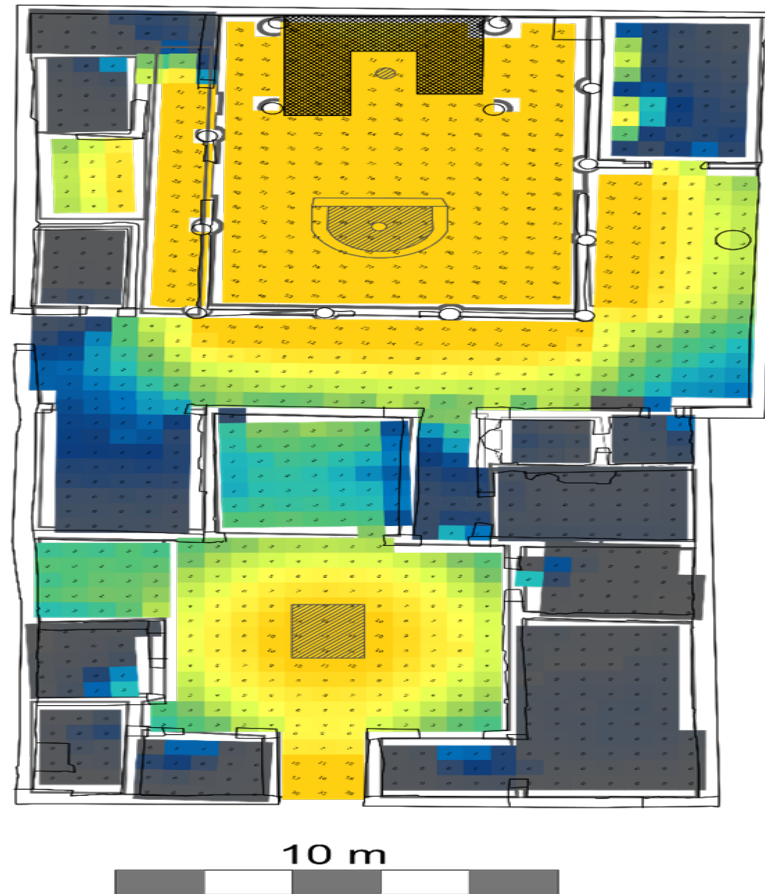
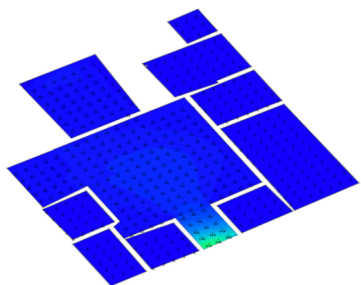


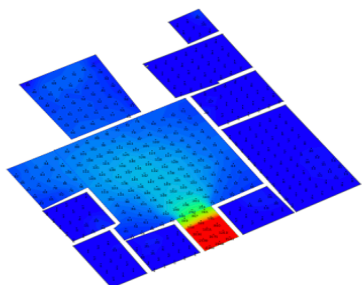
Figure 4. The results of the Daylight Factor analysis performed using Light Stanza. Gray areas signify areas with a DF value of 0, blue the values 1-2, greens 3-4 and yellow and orange values of over 5.

3.2 Atrium and surrounding rooms

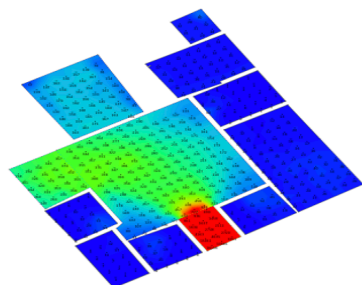
Running the hourly simulation for the atrium and its surrounding rooms shows a more detailed, diachronic visualization of the illumination in said spaces (Figure 5, Table B2). Especially in the hours preceding 08:00 the large front door to the house is the main source of daylighting – the door, however, was most likely closed during the night, and we have only hints of when it would usually have been opened. After 08:00 one can clearly see the blot of intense, over 700 lx illuminance coming from the atrium roof opening and following the passage of sun on the sky until roughly 16:00, when the sun ceases to shine directly into the building. The *cubiculae* e and l remain relatively dim throughout the day. Tablinum n, where the master of the house most likely received his clients, is quite well-lit through the morning hours into late afternoon.



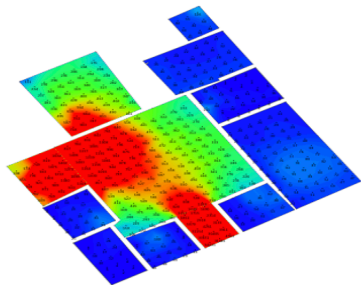
05:00



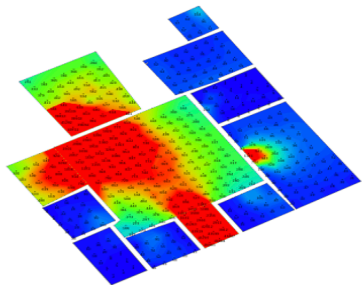
06:00



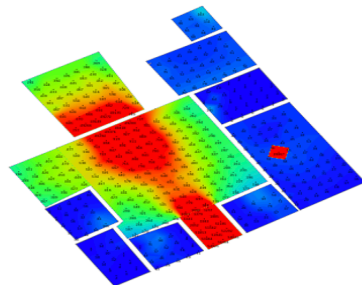
07:00



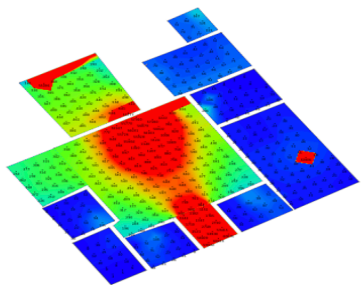
08:00



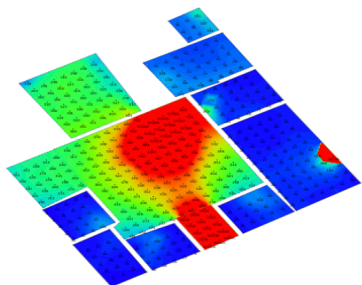
09:00



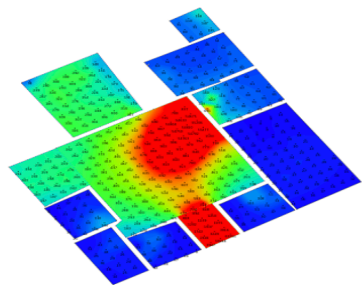
10:00



11:00



12:00



13:00

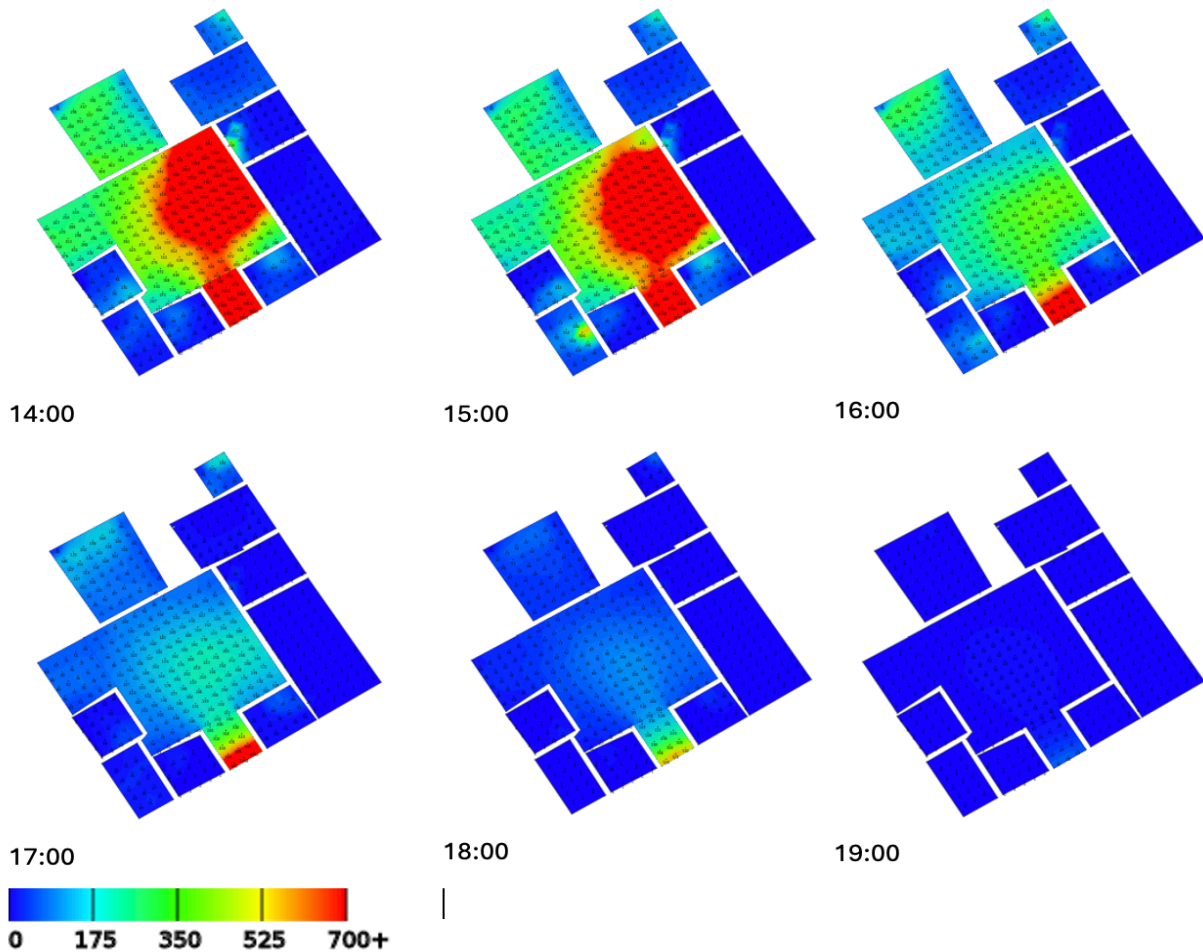
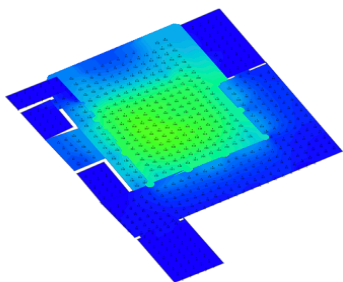


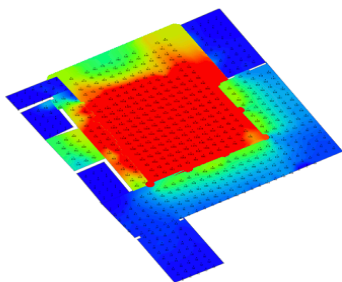
Figure 5. Hourly change of illumination in the atrium and its surrounding rooms from 05:00 to 19:00. Outside these times the spaces are virtually dark.

3.3 Peristyle and surrounding rooms

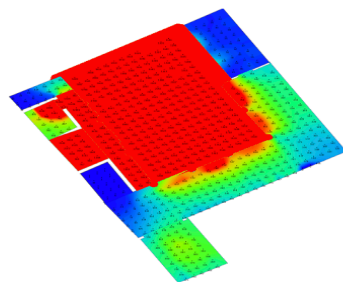
The same general notions that applied to the simulated results on the atrium area apply also in the peristyle and its surrounding spaces (Figure 6, Table B2). However, the area in direct sunlight is much larger and remains so through the day until early evening. On a sunny September day, the peristyle garden and the summer triclinium would be flooded with sunlight, as was already shown in the DF analysis. Furthermore, the ambulatories to the south and east of the peristyle would receive plenty of light, especially around noon and afternoon. Compared to the picture painted by the DF analysis, one can here also see how the triclinium z in the NE corner would receive a pleasant amount of light, over 100-200 lx but staying below 700 lx during the noon and early afternoon. Similarly room p, oecus, would also receive comparatively decent amounts of daylight at certain hours of the day. Only the few rooms adjacent to the western wall, rooms u, s and r, would remain relatively dark through the whole day.



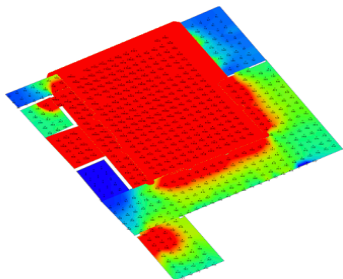
05:00



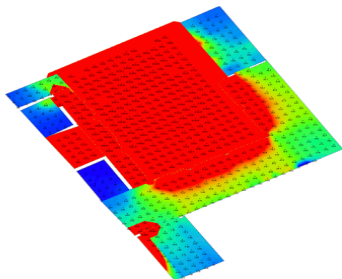
06:00



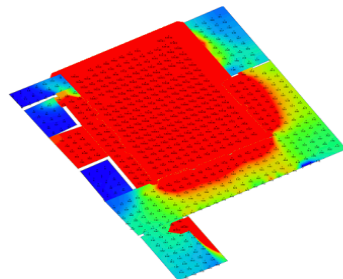
07:00



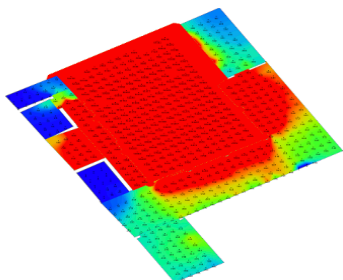
08:00



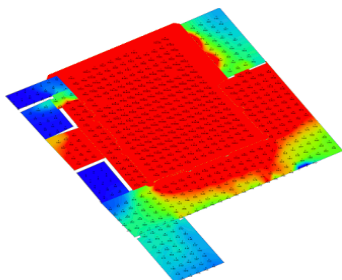
09:00



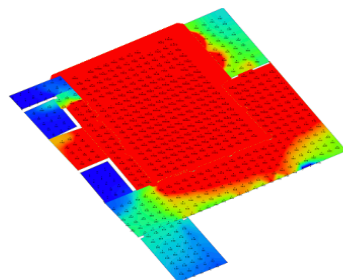
10:00



11:00



12:00



13:00

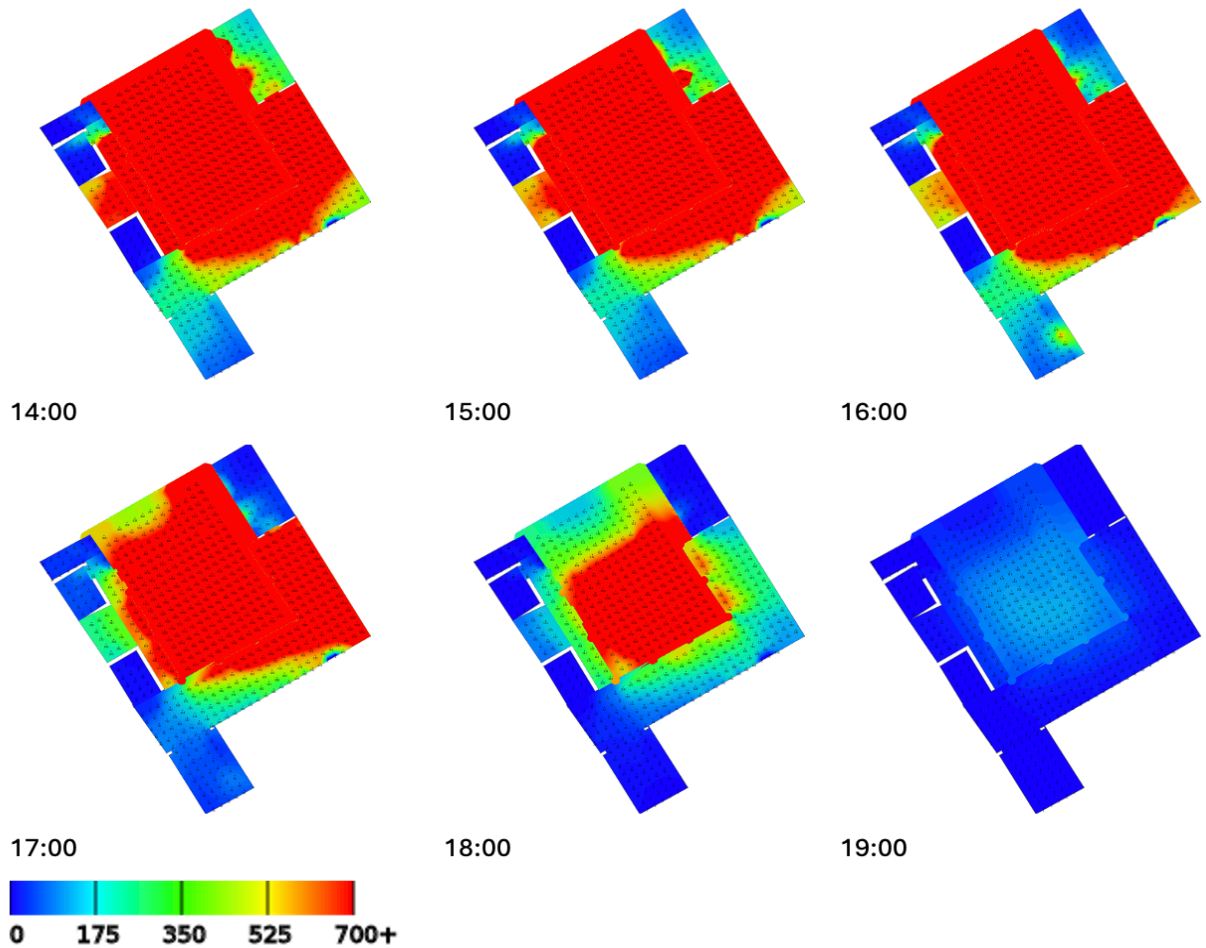
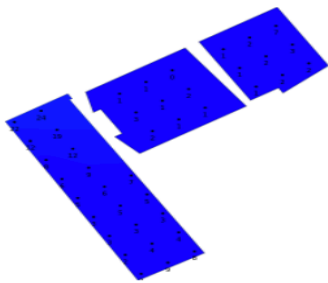


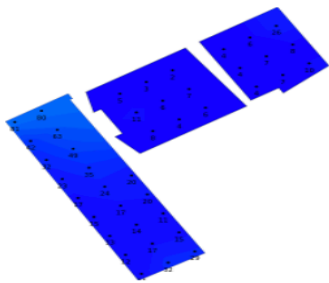
Figure 6. Hourly change of illumination in the peristyle and its surrounding rooms from 05:00 to 19:00. Outside these times the spaces are virtually dark.

3.4 Private bath

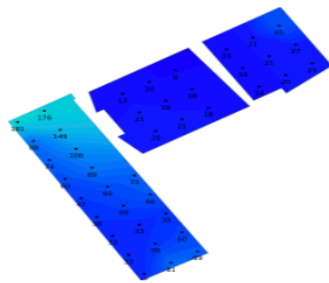
Looking at the results, one can instantly see that despite the large splaying windows, the small bath complex remained relatively dim even through the afternoon hours, when the peristyle would have been covered in bright sunlight (Figure 7, Table B2). The corridor f on the left is clearly sufficiently lit for traversing and carrying load, which was not shown in the DF analysis. The bathrooms themselves seem to be dim, but on a closer look the results actually display a quite consistent lighting between 08:00 and 16:00: apodyterium reaches an illuminance of over 150 lx on some parts, and the *calidarium*, used mainly for washing, maintains a dim but consistent level of c. 50 lx through several hours, which would make the space functional even without any artificial lighting.



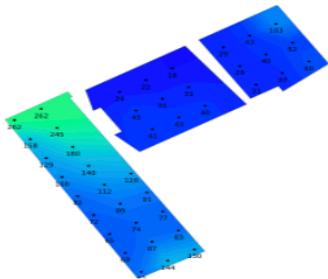
05:00



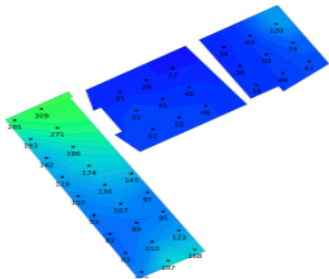
06:00



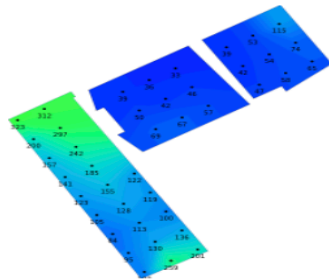
07:00



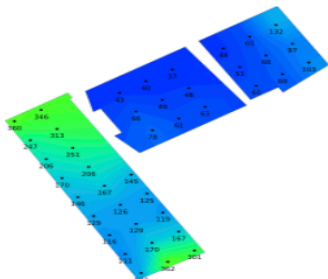
08:00



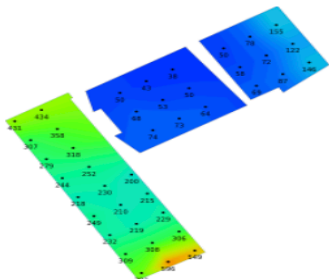
09:00



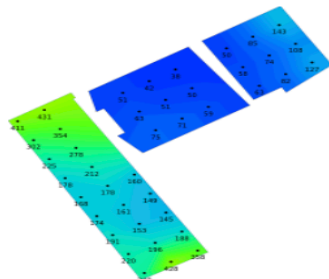
10:00



11:00



12:00



13:00

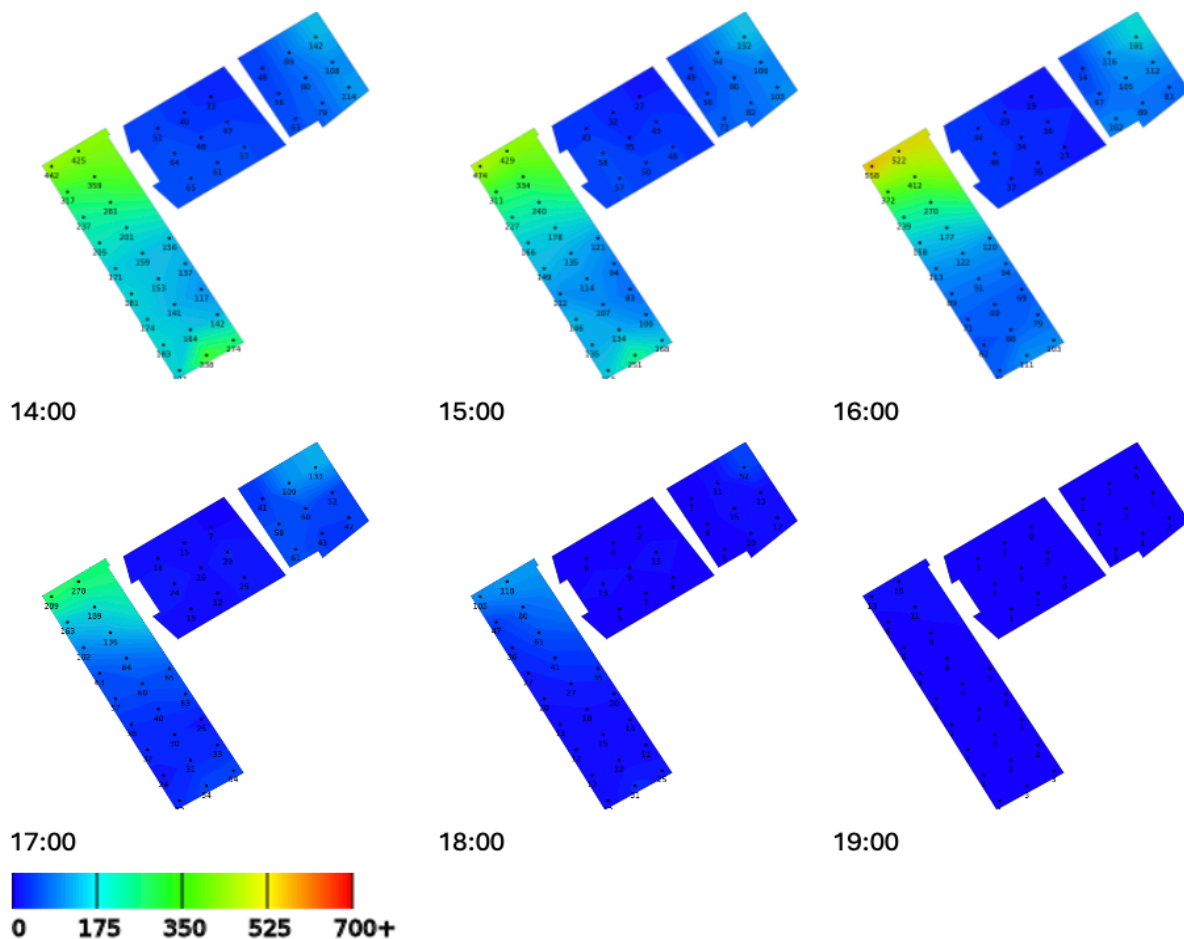


Figure 7. Hourly change of illumination in the bath and the corridor next to them (rooms q, y and f) from 05:00 to 19:00. Outside these times the spaces are virtually dark.

The results reveal a notable discrepancy with our field observations. While documenting and photographing the wall paintings in *calidarium* q and apodyterium y, we typically required plenty of artificial lighting due to the inadequate natural light. The only exception occurred during the afternoon, between 15:00 and 16:00, when the sun shone directly towards the splaying windows and illuminated the space sufficiently. We hypothesized that this would have been the ideal bathing time for the inhabitants and marveled at the geniality and precision of the architecture. This phenomenon was not replicated in the simulation, however. The reason became quickly apparent: with the walls and the roof on the western *ambulatorio* and the rooms r, s, t and u reconstructed in the 3D model, the direct daylight is obstructed and does not reach the windows during any time of the day. This highlights how present-day daylighting conditions at ruined sites can mislead researchers and lead to erroneous conclusions.

27

4. Discussion

A short epigram by Martial from the 1st century CE depicts nicely the daily schedule of a Roman domus (4.8):

28

The first hour and the second tires out callers, the third busies hoarse barristers, Rome stretches her various tasks until the fifth, the sixth will be rest for the weary, the seventh the end thereof. The eighth to the ninth suffices for the oily wrestling bouts. The ninth commands us to crush the piled-up couches. The tenth, Euphemus, is the hour of my little books [...]

-Transl. by D. R. Shackleton Bailey

Aligning the Roman timekeeping system with modern 24-hour day is complicated, but some details can be inferred from the verses. On September 21st in Pompeii, sunrise would have effectively risen only after 07:00. This would have been the first hour for the clients to begin visiting their patrons. Tablinum and atrium would have been already sufficiently lit for this activity. The third hour until the fifth (c. 9:00-11:00) would have been good time for various activities around the house, whereas the sixth and the seventh (12:00-13:00) – the siesta – would have seen people retreat for rest, perhaps in the cubacula, which would remain dim. At the eighth and ninth hours (perhaps 14:00-15:00) Romans would have enjoyed wrestling and other sports (according to Martial), and perhaps this would have been the ideal time for bathing as well – the light in rooms q and y would still be sufficient. After that, the dinner, *cena*, would follow. Daylight would have illuminated these activities until the sunset, after which the conditions would have relied upon artificial lighting, such as lamps and torches.

29

The case of summer triclinium in room x is an interesting one and begs the question of its supposed use during summer. If the Romans indeed began serving their dinner already at around 15:00 [Ellis 1995, 65]; [Carcopino 2003, 287–289], that would mean that the guests at the house of Trebius Valens would be sitting in the direct sunlight for several hours, with illuminance of even tens of thousands of lux, possibly making the heat and glare unbearable. Due to the large size of the peristyle, no efficient covering or screening was likely. Perhaps the guests would have begun their dinner later in the afternoon, or perhaps they had their first courses and drinks served in another triclinium and then moved to enjoy the evening sun and the fountains for the later courses and entertainment.

30

Considering the bathing activities, the daylighting provided by the windows was possibly sufficient. With a lamp or two the spaces would have been well-lit for washing oneself. With the bath windows the designer of the space had to consider the tradeoff of too large openings: as the *calidarium* was heated using the hypocaust system, of which the *suspensura* is still extant under the opus signinum floors, it couldn't have too large windows, or the heat would dissipate through them. This was a crucial concern especially since glass panels were not apparently available for covering them. An animal skin could have been used for covering, but there is no evidence of it having been done here – if it were, it would have made the apodyterium and the *calidarium* darker. Similarly, there is no evidence about what kind of a door the apodyterium had, if any. Its presence would have obviously altered the daylighting conditions. Vitruvius also took special note on lighting in baths (10.5.4), but it is impossible to know if his suggestion to position the labrum (the washing basin or bathtub) underneath a window was followed, since it has not preserved. De Haan suggests that the basin would have been located on the southern wall, where one can still see remains of a structural hole that could have contained a lead pipe that would have allowed running hot water straight from the kitchen [Haan 2010, 184]. However, this would have meant that the person using the basin would themselves have obstructed all the daylight, in contradiction to Vitruvius' idea.

31

5. Conclusions

The simulations and results provided here show clearly how daylighting would have influenced the daily life and use of a Pompeian domus. All in all, it seems to coincide with many suggestions made by Vitruvius, such as ensuring sufficient light for most of the servants' quarters, except for the kitchens. However, the house diverts from the Vitruvian ideal in having its summer triclinium in room x facing south, the exact opposite of Vitruvius' recommendation. This is probably dictated first and foremost by the urban constraints: the plot of land available for construction and the facing towards Via dell'Abbondanza just did not allow it to be built otherwise.

32

It seems that most spaces would have received sufficient light for regular daily activities through the natural openings of the house. In some cases, there might have even been an excess of light. The few spaces with perpetual darkness or dimness would have received light from artificial sources, since terracotta oil lamps were widely available. The narrow kitchens would have furthermore received light from the hearths, which would have been probably lit during the hours of activity.

33

In addition to the historical perspective, these results can also be of wider use for cultural heritage management. For example, planning for the lighting for the visitors of the current site of Pompeii must consider both the questions of representing the atmosphere of the historical reality being portrayed, but also the questions of safety and convenience.

34

The ancient Roman tolerance for shadows and darkness was higher than ours, and that must be taken into consideration when designing lighting for the modern-day visitors. However, not all excavated houses in Pompeii are suitable for this kind of reconstructive analysis due to their conservation status. The better-preserved structures with second floors in nearby Herculaneum could offer a better basis for large-scale analysis of whether the use of daylighting in Roman atrium houses was indeed uniform, or whether there were significant differences between individual buildings.

One feature left out of these simulations is the second floor. We do not know enough about possible windows and balconies in this particular house to be able to reconstruct them. However, second floors have preserved better in other houses, particularly in Herculaneum, and it could be beneficial to perform further study on them.

35

Funding

The writing of this article was funded by Eino Jutikkala Fund of the Finnish Academy of Science and Letters as part of the author's PhD project. The costs of the fieldwork period and the stay in Rome were partially funded by the Institutum Romanum Finlandiae.

36

Data availability statement

All the CSV, SVG and PNG files generated by Light Stanza are made available in a Zenodo repository: <https://doi.org/10.5281/zenodo.13121001>

37

Acknowledgments

I am grateful for all the other members of the Institutum Romanum Finlandiae working group, whose inspiring and thoughtful comments have helped immensely. I am especially thankful to Dr. Ria Berg, the director of the institute and of the project, whose continuing support and wide expertise were critical for the process. Another heartfelt thank you goes to Henna Ala-Lehtimäki for her comments and support. I am also in gratitude to the personnel of the Parco Archeologico di Pompei and especially Architecture Officer Raffaele Martinelli, whose help in acquiring the LiDAR data of the house was of utmost importance for this project. Furthermore, the two anonymous reviewers deserve gratitude for their thoughtful comments and suggestions.

38

Conflicts of interest

The author declares no conflicts of interest.

39

Appendix A

Space	Illuminance
Areas with traffic and corridors	100 lx
Stairways, escalators, and travelators	100 lx
Lifts	100 lx
Loading bays	150 lx
Coffee-break rooms	200 lx
Technical facilities	200 lx
Storage spaces	100 lx
Electronics workshops, testing, and adjustments	1500 lx
Ball-mill areas and pulp plants	200 lx
Offices and writing	500 lx
Check-out areas	500 lx
Waiting rooms	200 lx
Kitchens	500 lx
Parking areas	75 lx
Classrooms	300 lx
Auditoriums	500 lx

Table 2. (A1) Examples of light requirements for various modern spaces and activities, following The Indoor Lighting Standard as interpreted by the Ensto company [22].

Tasks	19- country Low (lx)	19- country High (lx)	Variation Factor	CEN/TC-169 Proposed European Guideline (lx)
Offices				
General	50	1000	20, 1	500
Video Display, Terminal Tasks	150	750	5,1	5005
Desk	150	1000	7,1	500
Reading Tasks	75	1000	13,1	500
Drafting (detailed)	200	3000	15,1	750
Classrooms				
General	75	750	10,1	400
Chalkboards	250	1500	6,1	500
Retail Stores				
Ambient	50	1500	30,1	300
Tasks/Till Area	100	1500	15,1	500
Hospitals				
Common Area	50	300	6,1	200
Patient Room	30	300	10,1	100
Operating Room	300	2000	7,1	1000
Operating Table	100	1000	10,1	450
Manufacturing				
Fine Knitting	50	2000	40,1	750
Electronics	200	5000	25,1	1500

Table 3. (A2) The lowest and highest recommendations and the variation factor results of a study on 19 different countries lighting recommendations [Mills and Borg 1999] (Table 1).

Appendix B

Room	Area (sq m)	Grid Points	Avg (%)	Max (%)	Min (%)
m	9.44	25	2.11	3.1	1.6
l	7.05	21	0.25	1.5	0
h	7.94	15	0.1	0.41	0.01
g	7.02	20	0.2	0.92	0.03
c	5.55	15	14.09	32.93	695.
b	7.19	15	0.31	0.96	0.05
n	20.91	51	1.68	2.73	0.35
a	60.02	154	5.72	11.67	1.75
e	10.18	30	0.11	1.51	0.01
i	13.86	25	0.12	0.2	0.08
d	27.44	70	0.07	0.21	0.01
q	4.48	9	0.17	0.33	0.06
y	3.51	9	0.21	0.63	0.1
f	7.37	23	0.84	2.54	0.28
z	21.67	45	0.84	5.2	0.14
x	99.2	242	54.65	83.68	6.77
u	7.03	15	0.05	0.21	0.01
t	8.42	15	5.02	7.87	2.84
s	6.85	15	0.16	1.17	0.04
r	5.84	21	0.18	0.83	0.02
p	19	45	0.53	1.32	0.17

Table 4. (B1) DF analysis results of the different rooms.

Name	Date	Area (sq m)	Grid Points	Avg (lux)	Max (lux)	Min (lux)
a	09-21 00:00	60.02	154	0	0	0
a	09-21 01:00	60.02	154	0	0	0
a	09-21 02:00	60.02	154	0	0	0
a	09-21 03:00	60.02	154	0	0	0
a	09-21 04:00	60.02	154	0	0	0
a	09-21 05:00	60.02	154	23.57	42.5	9.88

a	09-21 06:00	60.02	154	105.93	291.84	36.58
a	09-21 07:00	60.02	154	260.58	727.07	72.78
a	09-21 08:00	60.02	154	570.25	1482.86	150.05
a	09-21 09:00	60.02	154	668.69	2986.48	173.4
a	09-21 10:00	60.02	154	1794.99	49417.51	141.39
a	09-21 11:00	60.02	154	4551.11	57909.96	180.19
a	09-21 12:00	60.02	154	4987.44	57618.54	168.12
a	09-21 13:00	60.02	154	3693.48	55476.77	170.28
a	09-21 14:00	60.02	154	2160.47	54599.33	207.04
a	09-21 15:00	60.02	154	808.28	2900.87	180.68
a	09-21 16:00	60.02	154	260.61	411.04	89.92
a	09-21 17:00	60.02	154	144.31	222.65	52.62
a	09-21 18:00	60.02	154	71.32	119.07	24.62
a	09-21 19:00	60.02	154	8.71	15.17	3.06
a	09-21 20:00	60.02	154	0	0	0
a	09-21 21:00	60.02	154	0	0	0
a	09-21 22:00	60.02	154	0	0	0
a	09-21 23:00	60.02	154	0	0	0
a	09-22 00:00	60.02	154	0	0	0
b	09-21 00:00	7.19	15	0	0	0
b	09-21 01:00	7.19	15	0	0	0

b	09-21 02:00	7.19	15	0	0	0
b	09-21 03:00	7.19	15	0	0	0
b	09-21 04:00	7.19	15	0	0	0
b	09-21 05:00	7.19	15	1.99	5.92	0.31
b	09-21 06:00	7.19	15	9.93	27.88	1.89
b	09-21 07:00	7.19	15	24.12	53.81	5.53
b	09-21 08:00	7.19	15	45.58	87.71	13.28
b	09-21 09:00	7.19	15	50.37	112.31	14.78
b	09-21 10:00	7.19	15	44.55	97.01	9.64
b	09-21 11:00	7.19	15	49.39	102.54	14.1
b	09-21 12:00	7.19	15	49.02	104.39	17.7
b	09-21 13:00	7.19	15	45.83	111.16	12.2
b	09-21 14:00	7.19	15	58.27	129.38	17.64
b	09-21 15:00	7.19	15	75.35	179.02	15.9
b	09-21 16:00	7.19	15	31.59	87.86	6.78
b	09-21 17:00	7.19	15	28.52	67.26	10.81
b	09-21 18:00	7.19	15	10.08	32.32	1.43
b	09-21 19:00	7.19	15	1.08	3.5	0.16
b	09-21 20:00	7.19	15	0	0	0
b	09-21 21:00	7.19	15	0	0	0
b	09-21 22:00	7.19	15	0	0	0

b	09-21 23:00	7.19	15	0	0	0
b	09-22 00:00	7.19	15	0	0	0
c	09-21 00:00	5.55	15	0	0	0
c	09-21 01:00	5.55	15	0	0	0
c	09-21 02:00	5.55	15	0	0	0
c	09-21 03:00	5.55	15	0	0	0
c	09-21 04:00	5.55	15	0	0	0
c	09-21 05:00	5.55	15	115.91	269.76	43.35
c	09-21 06:00	5.55	15	1318	4183.7	338.87
c	09-21 07:00	5.55	15	4775.27	16156.49	850.72
c	09-21 08:00	5.55	15	12905	34430.61	1490.08
c	09-21 09:00	5.55	15	24501.03	46961.14	1385.33
c	09-21 10:00	5.55	15	32424.29	54924.64	1256.68
c	09-21 11:00	5.55	15	24977.38	60675.21	1142.09
c	09-21 12:00	5.55	15	21907.64	64551.23	1004.4
c	09-21 13:00	5.55	15	9803.2	62250.8	828.32
c	09-21 14:00	5.55	15	1924.09	5948.26	724.77
c	09-21 15:00	5.55	15	1140.17	2435.46	580.46
c	09-21 16:00	5.55	15	801	1607.97	365.9
c	09-21 17:00	5.55	15	518.69	1043.74	235.67
c	09-21 18:00	5.55	15	282.52	571.83	128.4

c	09-21 19:00	5.55	15	36.7	73.88	15.78
c	09-21 20:00	5.55	15	0	0	0
c	09-21 21:00	5.55	15	0	0	0
c	09-21 22:00	5.55	15	0	0	0
c	09-21 23:00	5.55	15	0	0	0
c	09-22 00:00	5.55	15	0	0	0
d	09-21 00:00	27.44	70	0	0	0
d	09-21 01:00	27.44	70	0	0	0
d	09-21 02:00	27.44	70	0	0	0
d	09-21 03:00	27.44	70	0	0	0
d	09-21 04:00	27.44	70	0	0	0
d	09-21 05:00	27.44	70	0.55	1.85	0.15
d	09-21 06:00	27.44	70	7.06	13.51	2.92
d	09-21 07:00	27.44	70	21.39	40.72	8.29
d	09-21 08:00	27.44	70	51.97	93.21	21.19
d	09-21 09:00	27.44	70	117.62	1331.43	21.32
d	09-21 10:00	27.44	70	461.08	29866.5	13.2
d	09-21 11:00	27.44	70	497.63	32805.56	14.46
d	09-21 12:00	27.44	70	529.39	34388.55	12.01
d	09-21 13:00	27.44	70	18.92	29.88	7.73
d	09-21 14:00	27.44	70	10.38	28.83	4.7

d	09-21 15:00	27.44	70	6.16	31.3	2.39
d	09-21 16:00	27.44	70	4.41	29.77	1.61
d	09-21 17:00	27.44	70	3.03	24.5	0.97
d	09-21 18:00	27.44	70	1.48	11.15	0.42
d	09-21 19:00	27.44	70	0.18	0.83	0.06
d	09-21 20:00	27.44	70	0	0	0
d	09-21 21:00	27.44	70	0	0	0
d	09-21 22:00	27.44	70	0	0	0
d	09-21 23:00	27.44	70	0	0	0
d	09-22 00:00	27.44	70	0	0	0
e	09-21 00:00	10.18	30	0	0	0
e	09-21 01:00	10.18	30	0	0	0
e	09-21 02:00	10.18	30	0	0	0
e	09-21 03:00	10.18	30	0	0	0
e	09-21 04:00	10.18	30	0	0	0
e	09-21 05:00	10.18	30	0.62	7.34	0.06
e	09-21 06:00	10.18	30	2.79	27.97	0.26
e	09-21 07:00	10.18	30	7.71	60.46	0.73
e	09-21 08:00	10.18	30	15.99	110.64	2.18
e	09-21 09:00	10.18	30	15.13	114.08	2.65
e	09-21 10:00	10.18	30	11.97	131.12	1.58

e	09-21 11:00	10.18	30	24.84	206.34	6.33
e	09-21 12:00	10.18	30	45.69	358.85	13.8
e	09-21 13:00	10.18	30	117.85	630.93	53.81
e	09-21 14:00	10.18	30	42.13	419.45	9.73
e	09-21 15:00	10.18	30	17.62	216.46	2.03
e	09-21 16:00	10.18	30	9.4	113.11	0.72
e	09-21 17:00	10.18	30	4.56	58.16	0.39
e	09-21 18:00	10.18	30	1.93	24.95	0.14
e	09-21 19:00	10.18	30	0.2	2.63	0.02
e	09-21 20:00	10.18	30	0	0	0
e	09-21 21:00	10.18	30	0	0	0
e	09-21 22:00	10.18	30	0	0	0
e	09-21 23:00	10.18	30	0	0	0
e	09-22 00:00	10.18	30	0	0	0
f	09-21 00:00	7.37	23	0	0	0
f	09-21 01:00	7.37	23	0	0	0
f	09-21 02:00	7.37	23	0	0	0
f	09-21 03:00	7.37	23	0	0	0
f	09-21 04:00	7.37	23	0	0	0
f	09-21 05:00	7.37	23	8.01	24.46	2.24
f	09-21 06:00	7.37	23	29.39	80.56	11.21

f	09-21 07:00	7.37	23	72.76	181.43	32.92
f	09-21 08:00	7.37	23	124.88	262.23	65.01
f	09-21 09:00	7.37	23	148.51	308.81	82.55
f	09-21 10:00	7.37	23	166.42	323.03	84.17
f	09-21 11:00	7.37	23	197.62	361.76	110.88
f	09-21 12:00	7.37	23	307.99	595.86	200.34
f	09-21 13:00	7.37	23	239.15	430.57	144.66
f	09-21 14:00	7.37	23	223.3	441.62	117.01
f	09-21 15:00	7.37	23	190.24	474.19	82.97
f	09-21 16:00	7.37	23	175.84	558.18	62.19
f	09-21 17:00	7.37	23	84.09	289.09	24.44
f	09-21 18:00	7.37	23	34.48	118.46	11.45
f	09-21 19:00	7.37	23	4.59	15.46	1.37
f	09-21 20:00	7.37	23	0	0	0
f	09-21 21:00	7.37	23	0	0	0
f	09-21 22:00	7.37	23	0	0	0
f	09-21 23:00	7.37	23	0	0	0
f	09-22 00:00	7.37	23	0	0	0
g	09-21 00:00	7.02	20	0	0	0
g	09-21 01:00	7.02	20	0	0	0
g	09-21 02:00	7.02	20	0	0	0

g	09-21 03:00	7.02	20	0	0	0
g	09-21 04:00	7.02	20	0	0	0
g	09-21 05:00	7.02	20	1.12	5.02	0.17
g	09-21 06:00	7.02	20	4.87	21.27	0.82
g	09-21 07:00	7.02	20	12.4	39.33	2.09
g	09-21 08:00	7.02	20	32.47	100.41	5.86
g	09-21 09:00	7.02	20	39.32	90.8	9.36
g	09-21 10:00	7.02	20	33.92	97.71	6.51
g	09-21 11:00	7.02	20	36.02	105.31	8.51
g	09-21 12:00	7.02	20	32.74	101.78	8.52
g	09-21 13:00	7.02	20	30.12	82.78	9.12
g	09-21 14:00	7.02	20	36.88	94.13	11.99
g	09-21 15:00	7.02	20	28.16	82.23	10.16
g	09-21 16:00	7.02	20	15.97	52.06	5.56
g	09-21 17:00	7.02	20	7.3	29.31	1.68
g	09-21 18:00	7.02	20	3.3	15.23	0.56
g	09-21 19:00	7.02	20	0.41	1.8	0.07
g	09-21 20:00	7.02	20	0	0	0
g	09-21 21:00	7.02	20	0	0	0
g	09-21 22:00	7.02	20	0	0	0
g	09-21 23:00	7.02	20	0	0	0

g	09-22 00:00	7.02	20	0	0	0
h	09-21 00:00	7.94	15	0	0	0
h	09-21 01:00	7.94	15	0	0	0
h	09-21 02:00	7.94	15	0	0	0
h	09-21 03:00	7.94	15	0	0	0
h	09-21 04:00	7.94	15	0	0	0
h	09-21 05:00	7.94	15	0.77	2.92	0.15
h	09-21 06:00	7.94	15	3.02	11.31	0.58
h	09-21 07:00	7.94	15	5.43	16.81	1.11
h	09-21 08:00	7.94	15	9.4	25.79	1.74
h	09-21 09:00	7.94	15	11.43	33.09	2.4
h	09-21 10:00	7.94	15	10.91	29.22	1.92
h	09-21 11:00	7.94	15	14.54	36.63	3.17
h	09-21 12:00	7.94	15	18.12	38.87	4.16
h	09-21 13:00	7.94	15	28.82	56.41	11.83
h	09-21 14:00	7.94	15	41.24	73.62	22.29
h	09-21 15:00	7.94	15	134.38	556.14	43.21
h	09-21 16:00	7.94	15	81.3	176.86	24.01
h	09-21 17:00	7.94	15	25.01	30.91	12.51
h	09-21 18:00	7.94	15	2.67	8.88	0.72
h	09-21 19:00	7.94	15	0.27	0.87	0.06

h	09-21 20:00	7.94	15	0	0	0
h	09-21 21:00	7.94	15	0	0	0
h	09-21 22:00	7.94	15	0	0	0
h	09-21 23:00	7.94	15	0	0	0
h	09-22 00:00	7.94	15	0	0	0
i	09-21 00:00	13.86	35	0	0	0
i	09-21 01:00	13.86	35	0	0	0
i	09-21 02:00	13.86	35	0	0	0
i	09-21 03:00	13.86	35	0	0	0
i	09-21 04:00	13.86	35	0	0	0
i	09-21 05:00	13.86	35	0.89	1.37	0.66
i	09-21 06:00	13.86	35	4.82	7.26	3.59
i	09-21 07:00	13.86	35	15.5	22.84	10.52
i	09-21 08:00	13.86	35	33.28	47.8	22.01
i	09-21 09:00	13.86	35	47.45	67.9	31.84
i	09-21 10:00	13.86	35	57.68	80.77	38.92
i	09-21 11:00	13.86	35	65.04	94.27	42.15
i	09-21 12:00	13.86	35	79.54	138.07	50.35
i	09-21 13:00	13.86	35	66.3	97.83	44.17
i	09-21 14:00	13.86	35	58.68	83.87	38.54
i	09-21 15:00	13.86	35	44.2	64.66	29.74

i	09-21 16:00	13.86	35	28.28	40.91	18.61
i	09-21 17:00	13.86	35	10.39	15.79	7.3
i	09-21 18:00	13.86	35	3.06	4.67	2.27
i	09-21 19:00	13.86	35	0.37	0.64	0.27
i	09-21 20:00	13.86	35	0	0	0
i	09-21 21:00	13.86	35	0	0	0
i	09-21 22:00	13.86	35	0	0	0
i	09-21 23:00	13.86	35	0	0	0
i	09-22 00:00	13.86	35	0	0	0
l	09-21 00:00	7.05	21	0	0	0
l	09-21 01:00	7.05	21	0	0	0
l	09-21 02:00	7.05	21	0	0	0
l	09-21 03:00	7.05	21	0	0	0
l	09-21 04:00	7.05	21	0	0	0
l	09-21 05:00	7.05	21	1.68	9.88	0
l	09-21 06:00	7.05	21	6.82	33.91	0
l	09-21 07:00	7.05	21	14.84	59.37	0
l	09-21 08:00	7.05	21	28.21	99.28	0
l	09-21 09:00	7.05	21	29.11	102.6	0.01
l	09-21 10:00	7.05	21	25.25	100.4	0
l	09-21 11:00	7.05	21	28.77	114.73	0

l	09-21 12:00	7.05	21	33.92	129.78	0
l	09-21 13:00	7.05	21	40.16	143.5	0.01
l	09-21 14:00	7.05	21	63.04	164.86	0.25
l	09-21 15:00	7.05	21	48	152.76	0
l	09-21 16:00	7.05	21	43.26	133.84	0
l	09-21 17:00	7.05	21	20.03	53.74	0
l	09-21 18:00	7.05	21	4.53	23.18	0
l	09-21 19:00	7.05	21	0.51	2.93	0
l	09-21 20:00	7.05	21	0	0	0
l	09-21 21:00	7.05	21	0	0	0
l	09-21 22:00	7.05	21	0	0	0
l	09-21 23:00	7.05	21	0	0	0
l	09-22 00:00	7.05	21	0	0	0
m	09-21 00:00	9.44	25	0	0	0
m	09-21 01:00	9.44	25	0	0	0
m	09-21 02:00	9.44	25	0	0	0
m	09-21 03:00	9.44	25	0	0	0
m	09-21 04:00	9.44	25	0	0	0
m	09-21 05:00	9.44	25	15.88	21.07	9.07
m	09-21 06:00	9.44	25	76.09	101.3	42.86
m	09-21 07:00	9.44	25	325.44	411.84	239.91

m	09-21 08:00	9.44	25	899.63	1402.41	497.97
m	09-21 09:00	9.44	25	683.01	1092.13	401.12
m	09-21 10:00	9.44	25	383.34	496.12	266.35
m	09-21 11:00	9.44	25	305.54	372.48	226.1
m	09-21 12:00	9.44	25	264.53	315.09	190.22
m	09-21 13:00	9.44	25	247.51	285.98	197.15
m	09-21 14:00	9.44	25	275.41	313.24	225.41
m	09-21 15:00	9.44	25	238.06	276.12	173.66
m	09-21 16:00	9.44	25	136.68	163.51	91.24
m	09-21 17:00	9.44	25	74.01	86.13	49.19
m	09-21 18:00	9.44	25	32.72	43.63	19.74
m	09-21 19:00	9.44	25	4.24	5.74	2.65
m	09-21 20:00	9.44	25	0	0	0
m	09-21 21:00	9.44	25	0	0	0
m	09-21 22:00	9.44	25	0	0	0
m	09-21 23:00	9.44	25	0	0	0
m	09-22 00:00	9.44	25	0	0	0
n	09-21 00:00	20.91	51	0	0	0
n	09-21 01:00	20.91	51	0	0	0
n	09-21 02:00	20.91	51	0	0	0
n	09-21 03:00	20.91	51	0	0	0

n	09-21 04:00	20.91	51	0	0	0
n	09-21 05:00	20.91	51	13.88	21.28	3.86
n	09-21 06:00	20.91	51	54.4	70.41	15.98
n	09-21 07:00	20.91	51	143.31	183.27	57.41
n	09-21 08:00	20.91	51	400.31	903.23	111.29
n	09-21 09:00	20.91	51	5142.19	41281.67	250.98
n	09-21 10:00	20.91	51	4338.01	49271.81	262.32
n	09-21 11:00	20.91	51	2561.91	55777.45	165.99
n	09-21 12:00	20.91	51	305.45	525.15	124.47
n	09-21 13:00	20.91	51	265.63	367.48	94.21
n	09-21 14:00	20.91	51	262.61	367.93	91.14
n	09-21 15:00	20.91	51	225.69	303.85	86.53
n	09-21 16:00	20.91	51	188.05	327.88	93.02
n	09-21 17:00	20.91	51	100.89	170.25	43.35
n	09-21 18:00	20.91	51	48.25	78.78	11.7
n	09-21 19:00	20.91	51	6.34	10.04	1.58
n	09-21 20:00	20.91	51	0	0	0
n	09-21 21:00	20.91	51	0	0	0
n	09-21 22:00	20.91	51	0	0	0
n	09-21 23:00	20.91	51	0	0	0
n	09-22 00:00	20.91	51	0	0	0

p	09-21 00:00	19	45	0	0	0
p	09-21 01:00	19	45	0	0	0
p	09-21 02:00	19	45	0	0	0
p	09-21 03:00	19	45	0	0	0
p	09-21 04:00	19	45	0	0	0
p	09-21 05:00	19	45	5.54	11.89	2.08
p	09-21 06:00	19	45	23.77	43.88	8.99
p	09-21 07:00	19	45	317.79	451.78	172.5
p	09-21 08:00	19	45	502.7	984.04	222.34
p	09-21 09:00	19	45	1908.25	39485.47	95.27
p	09-21 10:00	19	45	2349.22	48732.06	103.84
p	09-21 11:00	19	45	261.97	470.97	144.96
p	09-21 12:00	19	45	166.21	250.09	88.7
p	09-21 13:00	19	45	142.33	224.75	59
p	09-21 14:00	19	45	126.13	211.47	56.7
p	09-21 15:00	19	45	107.25	189.57	49.28
p	09-21 16:00	19	45	153.04	576.84	67.21
p	09-21 17:00	19	45	64.15	92.61	36.2
p	09-21 18:00	19	45	15.1	36.91	4.96
p	09-21 19:00	19	45	1.93	4.28	0.69
p	09-21 20:00	19	45	0	0	0

p	09-21 21:00	19	45	0	0	0
p	09-21 22:00	19	45	0	0	0
p	09-21 23:00	19	45	0	0	0
p	09-22 00:00	19	45	0	0	0
q	09-21 00:00	4.84	9	0	0	0
q	09-21 01:00	4.84	9	0	0	0
q	09-21 02:00	4.84	9	0	0	0
q	09-21 03:00	4.84	9	0	0	0
q	09-21 04:00	4.84	9	0	0	0
q	09-21 05:00	4.84	9	1.56	3.17	0.44
q	09-21 06:00	4.84	9	5.8	11.09	2.15
q	09-21 07:00	4.84	9	16.37	22.67	8.26
q	09-21 08:00	4.84	9	32.47	43.25	18.35
q	09-21 09:00	4.84	9	41.46	52.33	26.88
q	09-21 10:00	4.84	9	48.76	68.88	33.02
q	09-21 11:00	4.84	9	53.89	78.11	37.39
q	09-21 12:00	4.84	9	57	73.62	38.03
q	09-21 13:00	4.84	9	55.55	75.33	37.5
q	09-21 14:00	4.84	9	51.8	64.5	33.44
q	09-21 15:00	4.84	9	43.45	57.86	26.54
q	09-21 16:00	4.84	9	34.18	45.64	18.89

q	09-21 17:00	4.84	9	17.92	29.42	7.44
q	09-21 18:00	4.84	9	7.65	15.38	1.62
q	09-21 19:00	4.84	9	0.81	1.53	0.18
q	09-21 20:00	4.84	9	0	0	0
q	09-21 21:00	4.84	9	0	0	0
q	09-21 22:00	4.84	9	0	0	0
q	09-21 23:00	4.84	9	0	0	0
q	09-22 00:00	4.84	9	0	0	0
r	09-21 00:00	5.84	21	0	0	0
r	09-21 01:00	5.84	21	0	0	0
r	09-21 02:00	5.84	21	0	0	0
r	09-21 03:00	5.84	21	0	0	0
r	09-21 04:00	5.84	21	0	0	0
r	09-21 05:00	5.84	21	2.27	9.69	0.26
r	09-21 06:00	5.84	21	11.52	50.22	1.13
r	09-21 07:00	5.84	21	130.85	489.08	12.4
r	09-21 08:00	5.84	21	362.93	1910.48	49.03
r	09-21 09:00	5.84	21	2037.27	38833.02	55.96
r	09-21 10:00	5.84	21	70.33	287.03	7.67
r	09-21 11:00	5.84	21	53.13	228.09	5.17
r	09-21 12:00	5.84	21	42.44	169.97	5.01

r	09-21 13:00	5.84	21	34.76	126.24	4.79
r	09-21 14:00	5.84	21	27.98	99.79	5.25
r	09-21 15:00	5.84	21	25.04	86.35	6.32
r	09-21 16:00	5.84	21	32.57	83.28	13.77
r	09-21 17:00	5.84	21	38.77	62.43	21.13
r	09-21 18:00	5.84	21	4.98	19.22	1.38
r	09-21 19:00	5.84	21	0.65	2.75	0.15
r	09-21 20:00	5.84	21	0	0	0
r	09-21 21:00	5.84	21	0	0	0
r	09-21 22:00	5.84	21	0	0	0
r	09-21 23:00	5.84	21	0	0	0
r	09-22 00:00	5.84	21	0	0	0
s	09-21 00:00	6.85	15	0	0	0
s	09-21 01:00	6.85	15	0	0	0
s	09-21 02:00	6.85	15	0	0	0
s	09-21 03:00	6.85	15	0	0	0
s	09-21 04:00	6.85	15	0	0	0
s	09-21 05:00	6.85	15	3.21	25.66	0.69
s	09-21 06:00	6.85	15	17.35	135.9	3.77
s	09-21 07:00	6.85	15	863.74	4098.02	349.78
s	09-21 08:00	6.85	15	464.22	2270.06	245.97

s	09-21 09:00	6.85	15	87.67	400.42	29.35
s	09-21 10:00	6.85	15	46.68	257.08	13.06
s	09-21 11:00	6.85	15	40.84	215.29	11.29
s	09-21 12:00	6.85	15	40.99	200.94	10.66
s	09-21 13:00	6.85	15	39.97	192.69	11.1
s	09-21 14:00	6.85	15	36.87	172	10.22
s	09-21 15:00	6.85	15	32.41	163.46	10.46
s	09-21 16:00	6.85	15	32.73	139.66	13.16
s	09-21 17:00	6.85	15	63.26	118.44	44.73
s	09-21 18:00	6.85	15	5.72	35.77	1.81
s	09-21 19:00	6.85	15	0.69	4.68	0.2
s	09-21 20:00	6.85	15	0	0	0
s	09-21 21:00	6.85	15	0	0	0
s	09-21 22:00	6.85	15	0	0	0
s	09-21 23:00	6.85	15	0	0	0
s	09-22 00:00	6.85	15	0	0	0
t	09-21 00:00	8.42	15	0	0	0
t	09-21 01:00	8.42	15	0	0	0
t	09-21 02:00	8.42	15	0	0	0
t	09-21 03:00	8.42	15	0	0	0
t	09-21 04:00	8.42	15	0	0	0

t	09-21 05:00	8.42	15	82.4	108.79	53.74
t	09-21 06:00	8.42	15	343.47	488.01	175.86
t	09-21 07:00	8.42	15	2034.96	3850.64	766.83
t	09-21 08:00	8.42	15	6515.1	29387.92	935.74
t	09-21 09:00	8.42	15	1162.9	1551.12	772.31
t	09-21 10:00	8.42	15	990.2	1364.39	665.72
t	09-21 11:00	8.42	15	811.25	1027.88	565.13
t	09-21 12:00	8.42	15	775.86	983.11	562.82
t	09-21 13:00	8.42	15	743.56	908.07	574.34
t	09-21 14:00	8.42	15	700.7	838.91	541.35
t	09-21 15:00	8.42	15	636.97	764.38	537.66
t	09-21 16:00	8.42	15	569.65	660.09	469.92
t	09-21 17:00	8.42	15	302.77	378.35	220.78
t	09-21 18:00	8.42	15	129.5	178.95	86.35
t	09-21 19:00	8.42	15	16.28	22.77	10.8
t	09-21 20:00	8.42	15	0	0	0
t	09-21 21:00	8.42	15	0	0	0
t	09-21 22:00	8.42	15	0	0	0
t	09-21 23:00	8.42	15	0	0	0
t	09-22 00:00	8.42	15	0	0	0
u	09-21 00:00	7.03	15	0	0	0

u	09-21 01:00	7.03	15	0	0	0
u	09-21 02:00	7.03	15	0	0	0
u	09-21 03:00	7.03	15	0	0	0
u	09-21 04:00	7.03	15	0	0	0
u	09-21 05:00	7.03	15	0.27	0.97	0.06
u	09-21 06:00	7.03	15	0.72	2.39	0.22
u	09-21 07:00	7.03	15	3.9	10.62	1.27
u	09-21 08:00	7.03	15	5.77	11.59	1.92
u	09-21 09:00	7.03	15	13.79	43.7	4.53
u	09-21 10:00	7.03	15	11.18	32.06	4.11
u	09-21 11:00	7.03	15	7.7	24.22	2.68
u	09-21 12:00	7.03	15	8.22	28.62	2.6
u	09-21 13:00	7.03	15	7.38	29.67	1.35
u	09-21 14:00	7.03	15	7.42	25.51	2.3
u	09-21 15:00	7.03	15	5.51	20.25	2.12
u	09-21 16:00	7.03	15	6.28	24.62	2.21
u	09-21 17:00	7.03	15	11.65	16.92	7.24
u	09-21 18:00	7.03	15	0.67	2.25	0.25
u	09-21 19:00	7.03	15	0.08	0.23	0.02
u	09-21 20:00	7.03	15	0	0	0
u	09-21 21:00	7.03	15	0	0	0

u	09-21 22:00	7.03	15	0	0	0
u	09-21 23:00	7.03	15	0	0	0
u	09-22 00:00	7.03	15	0	0	0
x	09-21 00:00	99.2	242	0	0	0
x	09-21 01:00	99.2	242	0	0	0
x	09-21 02:00	99.2	242	0	0	0
x	09-21 03:00	99.2	242	0	0	0
x	09-21 04:00	99.2	242	0	0	0
x	09-21 05:00	99.2	242	244.89	366.69	63.41
x	09-21 06:00	99.2	242	943.19	1425.94	274.2
x	09-21 07:00	99.2	242	2325.52	5886.99	1011.68
x	09-21 08:00	99.2	242	12330.63	34518.42	1388.54
x	09-21 09:00	99.2	242	24209.32	49693.27	1645.91
x	09-21 10:00	99.2	242	36804.04	62810.98	1812.68
x	09-21 11:00	99.2	242	44703.65	69278.11	2072.31
x	09-21 12:00	99.2	242	41195.01	71065.69	2109.55
x	09-21 13:00	99.2	242	35649.73	67401.51	2094.17
x	09-21 14:00	99.2	242	27786.26	61906.68	1932.33
x	09-21 15:00	99.2	242	18179.14	50613.29	1619.73
x	09-21 16:00	99.2	242	7097.34	33093.52	1122.67
x	09-21 17:00	99.2	242	1786.1	3059.33	438.4

x	09-21 18:00	99.2	242	770.13	1194.29	160.75
x	09-21 19:00	99.2	242	91.81	138.78	19.56
x	09-21 20:00	99.2	242	0	0	0
x	09-21 21:00	99.2	242	0	0	0
x	09-21 22:00	99.2	242	0	0	0
x	09-21 23:00	99.2	242	0	0	0
x	09-22 00:00	99.2	242	0	0	0
y	09-21 00:00	3.51	9	0	0	0
y	09-21 01:00	3.51	9	0	0	0
y	09-21 02:00	3.51	9	0	0	0
y	09-21 03:00	3.51	9	0	0	0
y	09-21 04:00	3.51	9	0	0	0
y	09-21 05:00	3.51	9	2.23	7.29	0.92
y	09-21 06:00	3.51	9	8.37	26.23	3.77
y	09-21 07:00	3.51	9	24.57	64.6	13.55
y	09-21 08:00	3.51	9	47.01	102.65	29.12
y	09-21 09:00	3.51	9	56.89	119.99	34.19
y	09-21 10:00	3.51	9	60.86	114.85	39.03
y	09-21 11:00	3.51	9	76.54	131.74	43.86
y	09-21 12:00	3.51	9	92.91	155.34	49.7
y	09-21 13:00	3.51	9	87.95	143.42	50.43

y	09-21 14:00	3.51	9	86.47	142.03	47.61
y	09-21 15:00	3.51	9	87.56	151.53	48.66
y	09-21 16:00	3.51	9	100.77	180.96	53.56
y	09-21 17:00	3.51	9	67.11	133.08	40.75
y	09-21 18:00	3.51	9	14.37	51.69	5.38
y	09-21 19:00	3.51	9	1.73	6.43	0.59
y	09-21 20:00	3.51	9	0	0	0
y	09-21 21:00	3.51	9	0	0	0
y	09-21 22:00	3.51	9	0	0	0
y	09-21 23:00	3.51	9	0	0	0
y	09-22 00:00	3.51	9	0	0	0

Table 5. (B2) Hourly illuminance data of the different rooms.

Appendix C – List of technical terms

BIM (Building Information Modeling) – A digital representation of a building’s physical and functional characteristics used for design and analysis.

LiDAR (Light Detection and Ranging) – Remote sensing method that uses laser pulses to capture precise 3D spatial data.

Photogrammetry – Technique for generating measurements or 3D models from overlapping photographs.

RealityCapture – Photogrammetry software used to process and scale image-based 3D models.

Point Cloud – A collection of 3D data points representing visible features, often created via LiDAR or photogrammetry.

CloudCompare – Open-source software for processing and aligning point clouds and meshes.

Light Stanza – Cloud-based Autodesk Revit add-on for daylighting simulation.

Radiance Suite – Lighting simulation software using ray tracing for accurate light modeling.

Daylight Factor (DF) – Ratio of indoor to outdoor illuminance under overcast sky conditions, expressed as a percentage.

Illuminance – Light falling on a surface, measured in lux (lx).

Lux (lx) – SI unit of illuminance, equal to one lumen per square meter.

Lumen (lm) – SI unit of luminous flux, indicating total light output.

CIE (Commission Internationale de l’Éclairage) – The International Commission on Illumination, an organization setting international lighting standards. Founded in 1900 and currently based in Vienna,

Austria.

Clear Sky Model – Simulation assuming a cloudless sky for maximum daylight availability.

Ray Tracing – Rendering technique in 3D computer graphics that calculates light paths for realistic simulation.

Reflectance – Proportion of light reflected by a surface, expressed as a percentage.

Illuminance Grid Analysis – Mapping of light levels across a defined floor grid (e.g., 1 × 1 m).

Works Cited

- Campanaro 2023a** Campanaro, D.M. (2023a) “Coming to light: Illuminating the house of the Greek Epigrams in Pompeii”, *American Journal of Archaeology*, 127(2), pp. 263–292. Available at: <https://doi.org/10.1086/723393>.
- Campanaro 2023b** Campanaro, D.M. (2023b) *Illumination matters. Revisiting the Roman house in a new light*. Doctoral Dissertation. Lund University.
- Carcopino 2003** Carcopino, J. (2003) *Daily life in Ancient Rome: the people and the city at the height of the empire*. 2nd ed. New Haven (Conn.): Yale Nota Bene - Yale university press.
- Chartered Institution of Building Services Engineers (1999)** Chartered Institution of Building Services Engineers (ed.) (1999) *Daylighting and window design*. London: CIBSE (Lighting guide / CIBSE, Chartered Institution of Building Services Engineers, 10).
- Ellis 1995** Ellis, S. (1995) “Lighting in late Roman houses”, *Theoretical Roman Archaeology Journal*, 0(1994), pp. 65–71. Available at: https://doi.org/10.16995/TRAC1994_65_71.
- Haan 2007** Haan, N. de (2007) “Luxus Wasser. Privatbäder in der vesuvregion”, in *Luxus und Dekadenz Römisches Leben am Golf von Neapel*. Mainz am Rhein: Verlag Philipp von Zabern, pp. 123–137.
- Haan 2010** Haan, N. de (2010) *Römische Privatbäder: Entwicklung, Verbreitung, Struktur und sozialer Status*. Frankfurt am Main ; New York: Peter Lang.
- IEC 60050** No author *IEC 60050 - International Electrotechnical Vocabulary - Details for IEC number 845-21-060: ‘illuminance’* (no date). Available at: <https://www.electropedia.org/iev/iev.nsf/display?openform&ievref=845-21-060>. (Accessed: 18 July 2024).
- Mills and Borg 1999** Mills, E. and Borg, N. (1999) “Trends in recommended illuminance levels: An international comparison”, *Journal of the Illuminating Engineering Society* [Preprint]. Available at: <https://www.tandfonline.com/doi/abs/10.1080/00994480.1999.10748262>. (Accessed: 24 July 2024).
- Molar Orozco 2022** Mollar Orozco, M. (2022) “The role of architecture to achieve well-being”, in *Architecture for Health and Well-Being: A Sustainable Approach*. Oxon, UK: Apple Academic Press, pp. 1–94.
- Monteoliva et al. 2019** Monteoliva, J.M. et al. (2019) “Ancient Romans and daylighting: the case of Villa of the mysteries in Pompeii”, *Journal of Cultural Heritage*, 43, pp. 204–218. Available at: <https://doi.org/10.1016/j.culher.2019.12.008>.
- Monteoliva n.d.** Monteoliva, J.M. et al. (No date) “Dynamic cubic illuminance: An example of application of a new paradigm for daylight analysis in an ancient Pompeian Domus”, in *Building Simulation 2019*, Rome, Italy, pp. 1106–1113. Available at: <https://doi.org/10.26868/25222708.2019.210761>.
- Moullou, Doulos, and Topalis (2018)** Moullou, D., Doulos, L.T., and Topalis, F.V. (2018) “Artificial light sources in Roman, Byzantine, and Post- Byzantine eras: An evaluation of their performance”, in *Chronos*, 32, pp. 119–132. Available at: <https://doi.org/10.31377/chr.v32i0.115>.
- Müeller 2013** Müller, H.F.O. (2013) “Chapter 9 - Daylighting”, in A. Sayigh (ed.) *Sustainability, Energy and Architecture*. Boston: Academic Press, pp. 227–255. Available at: <https://doi.org/10.1016/B978-0-12-397269-9.00009-8>.
- Phillips 2004** Phillips, D. (2004) *Daylighting: natural light in architecture*. Oxford: Architectural Press.
- Pollard 2020** Pollard, N. (2020) *Bombing Pompeii: World heritage and military necessity*. Ann Arbor, MI: University of Michigan Press. Available at: <https://doi.org/10.3998/mpub.11377428>.
- Rea and Figueiro 2018** Rea, M. and Figueiro, M. (2018) “Light as a circadian stimulus for architectural lighting”, *Lighting Research & Technology*, 50(4), pp. 497–510. Available at: <https://doi.org/10.1177/1477153516682368>.
- Serra 1998** Serra, R. (1998) “Chapter 6 — Daylighting”, *Renewable and Sustainable Energy Reviews*, 2(1), pp. 115–155.

Simm and Coley 2011 Simm, S. and Coley, D. (2011) "The relationship between wall reflectance and daylight factor in real rooms", *Architectural Science Review* [Preprint]. Available at: <https://www.tandfonline.com/doi/full/10.1080/00038628.2011.613642>. (Accessed 17 July 2024).

Smith (ed.) 2006 Smith, I.F.C. (ed.) (2006) *Intelligent computing in engineering and architecture: 13th EG-ICE Workshop 2006, Ascona, Switzerland, June 25-30, 2006: revised selected papers. EG-ICE Workshop*, Berlin ; New York: Springer (Lecture notes in computer science, Lecture notes in artificial intelligence, 4200).

Spano 1915 Spano, G. (1915) "Scavi durante il mese di luglio", *Notizie degli Scavi di Antichit*, pp. 336–341.

Spano 1916 Spano, G. (1916) "Pompei. Continuazione degli scavi lungo la Via dell'Abbondanza", *Notizie degli Scavi di Antichità*, pp. 231–235.

Spinazzolo 1916 Spinazzolo, V. (1916) "Pompei. Continuazione degli scavi in via dell'Abbondanza", *Notizie degli Scavi di Antichità*, pp. 148–151.

Spinazzolo 1953 Spinazzolo, V. (1953) *Pompei alla luce degli scavi nuovi di Via dell'Abbondanza (Anni 1910-1923)*. Rome: Libreria della Stato.

Van Creveld and Mansfield 2020 Van Crevelde, K. and Mansfield, K. (2020) "Lit environments that promote health and well-being", *Building Services Engineering Research and Technology*, 1(2), pp. 193–209. Available at: <https://doi.org/10.1177/0143624419896250>.

Recommendations

DHQ is testing out three new article recommendation methods! Please explore the links below to find articles that are related in different ways to the one you just read. We are interested in how these methods work for readers—if you would like to share feedback with us, please complete our short evaluation survey. You can also visit our documentation for these recommendation methods to learn more.

SPECTER Recommendations

Below are article recommendations generated by the SPECTER model:

1. The case of the golden background, a virtual restoration and a physical reconstruction of the medieval Crucifixion of the Lindau Master (c. 1425), 2023, Liselore Tissen, Leiden University and Delft University of Technology; Sanne Frequin, Utrecht University; Ruben Wiersma, Delft University of Technology
2. Renaissance Remix. Isabella d'Este: Virtual Studiolo, 2018, Deanna Shemek, University of California, Irvine, USA; Antonella Guidazzoli, VisitLab - Cineca Interuniversity Consortium, Italy; Maria Chiara Liguori, VisitLab - Cineca Interuniversity Consortium, Italy; Giovanni Bellavia, VisitLab - Cineca Interuniversity Consortium, Italy; Daniele De Luca, VisitLab - Cineca Interuniversity Consortium, Italy; Luigi Verri, VisitLab - Cineca Interuniversity Consortium, Italy; Silvano Imboden, VisitLab - Cineca Interuniversity Consortium, Italy
3. An Integral Web-map for the Analysis of Spatial Change over Time in a Complex Built Environment: Digital Samos, 2023, Estefanía López Salas, Universidade da Coruña
4. Cervantes Project: The Digital Quixote Iconography Collection, 2009, Eduardo Urbina, Texas A&M University; Richard Furuta, Texas A&M University; Steven E. Smith, Texas A&M University
5. Recording invisible proofs to compose stone narratives. Applications of Near Infrared Spectroscopy in provenance studies., 2018, Claudia Sciuto, Umeå University

DHQ Keyword Recommendations

Below are article recommendations generated by DHQ Keywords:

1. Teaching Spatial Literacy in the Classical Studies Curriculum, 2016, Rebecca K. Schindler, DePauw University
2. Humanities Approaches to Graphical Display, 2011, Johanna Drucker, Breslauer Professor of Bibliographical Studies Department of Information Studies, UCLA
3. A Historical Geographic Information System (HGIS) of Nubia Based on the William J. Bankes Archive (1815-1822), 2017, Daniele Salvoldi, Dahlem Research School, Freie Universität Berlin
4. Introduction: Digital Humanities & Colonial Latin American Studies, 2020, Hannah Alpert-Abrams, Independent Scholar; Clayton McCarl, University of North Florida
5. Modeling Amerindian Sea Travel in the Early Colonial Caribbean, 2020, Emma Slayton, Carnegie Mellon University

TF-IDF Recommendations

Below are article recommendations generated by the TF-IDF Model:

1. Stretched Skulls: Anamorphic Games and the memento mortem mortis, 2012, Stephanie Boluk, Vassar College; Patrick LeMieux, Duke University
2. Renaissance Remix. Isabella d'Este: Virtual Studiolo, 2018, Deanna Shemek, University of California, Irvine, USA; Antonella Guidazzoli, VisitLab - Cineca Interuniversity Consortium, Italy; Maria Chiara Liguori, VisitLab - Cineca Interuniversity Consortium, Italy; Giovanni Bellavia, VisitLab - Cineca Interuniversity Consortium, Italy; Daniele De Luca, VisitLab - Cineca Interuniversity Consortium, Italy; Luigi Verri, VisitLab - Cineca Interuniversity Consortium, Italy; Silvano Imboden, VisitLab - Cineca Interuniversity Consortium, Italy
3. Somewhere Nearby is Colossal Cave: Examining Will Crowther's Original "Adventure" in Code and in Kentucky, 2007, Dennis G. Jerz, Seton Hill University
4. Because It's Not There: Ekphrasis and the Threat of Graphics in Interactive Fiction, 2011, Aaron Kashtan, Department of English, University of Florida
5. Reviving Classical Drama: virtual reality and experiential learning in a traditional classroom, 2018, Eleni Bozia, University of Florida



This work is licensed under a Creative Commons Attribution-NoDerivatives 4.0 International License.