Long Paper

Shadows Analysis and Viewshed Georeferencing for Dating of Historical Photographs

New Possibilities for Chronology Studies of Lost Built Heritage

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Abstract: To facilitate the use of historical photography in studies of lost heritage and its modifications over time, it is crucial to have dated images, in order to chronologically organize the visual information they contain. Although there are dating methods based on optical metadata for digital images, little attention has been paid to historical photographs, where no optical information is available, and there is insufficient data redundancy to infer them by automatic means. To address this problem, the present work proposes a method to date historical photographs based on the analysis of the shadows contained in the image, as they are known to evidence a measurable position of the sun. The key observation is that, having recovered the volumetry of the scene and its georeferencing by photogrammetric means, it is possible to project the visual information of the shadows on this geometry and thus obtain magnitudes and angles that, with the help of an astronomical formula, allows determining the time of day and the day of the year associated with them. Based on this principle, a processing workflow is proposed and validated in a case study. The results show that the method generates consistent and replicable results in different scenarios and photographic material, exhibiting a fairly low and constant margin of error. This confirms the validity of the proposed approach, and its feasibility to complement existing dating methods, thus improving the use of historical photography in studies on lost heritage and the chronology of its modifications.

Keywords: *Historical photograph—Photograph dating—Shadows analysis—Lost built heritage*

CHNT Reference: Suazo, A. (2025). ‘Shadows Analysis and Viewshed Georeferencing for Dating of Historical Photographs: New Possibilities for Chronology Studies of Lost Built Heritage’, *Proceedings of the 26th International Conference on Cultural Heritage and New Technologies*, Vienna and online, November 2021. Heidelberg: Propylaeum. doi: 10.11588/propylaeum.1449.c20745.

Introduction

In recent years, the possibility of recovering from historical photography information on the past condition of buildings and infrastructures that have disappeared, has gained momentum among studies of the built heritage. This potential is more noticeable in the case of buildings that have undergone interventions over time, where photography could be used to reconstruct the history of modifications. However, despite this potential, the information on the date of capture, stored with each photograph by the respective archives and repositories, presents a series of inconsistencies in practice. The main obstacles are the lack of original metadata, inaccurate date attribution or very long periods, and confusion between the date of actual capture and the date of entry into the photographic collection, among others. As a result, the information contained in the images cannot be used to know the temporal sequence in the history of modifications, and the possibility of taking advantage of the latent potential in the photograph is lost.

The problem of dating historical photographs, and the relevance of their use in built heritage studies, has so far received little attention. As a way of moving away from simplistic approaches to dating from archival science, which infer an estimated time range based on the presence of known objects in the image (i.e. buildings of known years), it is of particular interest to establish a way of exploiting information about the shadows that objects cast, as these are known to evidence a specific and measurable position of the sun. While recent advances have proved satisfactory in exploiting the correlation between shadow analysis and some geometrical aspects, such as optical metadata in image sets (Wehrwein, Bala and Snavely, 2015), or camera position obtained by GPS (Abdelrahim and Mansour, 2018), new methods require to be defined for the case of historical photography, where those parameters are not known and where different photographs often show different states of the studied object.

Methods

The present study then focuses on addressing this problem based on fundamental principles of shadow analysis and astronomical formulas known for a long time (Meyer and Shane, 1936), already mentioned in treatises on astrology and architecture as old as Vitruvius' De Architectura (written between 30–20 BC, where formulas for sundials already appear). Assuming a vertical surface of known height, and the measurement of the corresponding shadow it casts on a horizontal surface, it would be possible to infer the day of the year (DoY) if the time of day (ToD) is known, or the ToD if the DoY is known. Moreover, by knowing the geographic orientation of the scene, it would be possible to obtain both data simultaneously (Fitzpatrick, 2008).

To access these possibilities and following the ever-present suggestion of deploying all this information through a virtual reconstruction (Farid, 2016), the notion of using a three-dimensional format to represent the visual information contained in the photographs is explored. To this end, we aim to obtain these essential pieces of information (scene volumetry and orientation) using photogrammetric techniques to project the image data onto the recovered geometry, which is visible from the camera's field of vision and has known dimensions and geographical orientation.

The proposed processing method is based on the following workflow (Figure 1). In the first step, the local camera position and orientation are obtained using vanishing points (Guillou et al., 2000), while recovering the volumetry by auxiliary parallelepipeds (Tan, Sullivan and Baker, 1995). In the second step, the scene is globally located and oriented using known control points in the image by resection (Bruschke et al., 2017). In the third step, the image is projected onto the geometry, canceling the perspective distortion and obtaining the actual magnitudes (Suazo, 2020). Then, in the fourth step, the values associated with the length of the gnomon (object casting the shadow) are collected, as well as the length and azimuthal angle of the shadow projected horizontally. Finally, in the fifth step the recovered values feed the dating equation, mainly based on available astronomical formulas (Agafonkin, 2019).

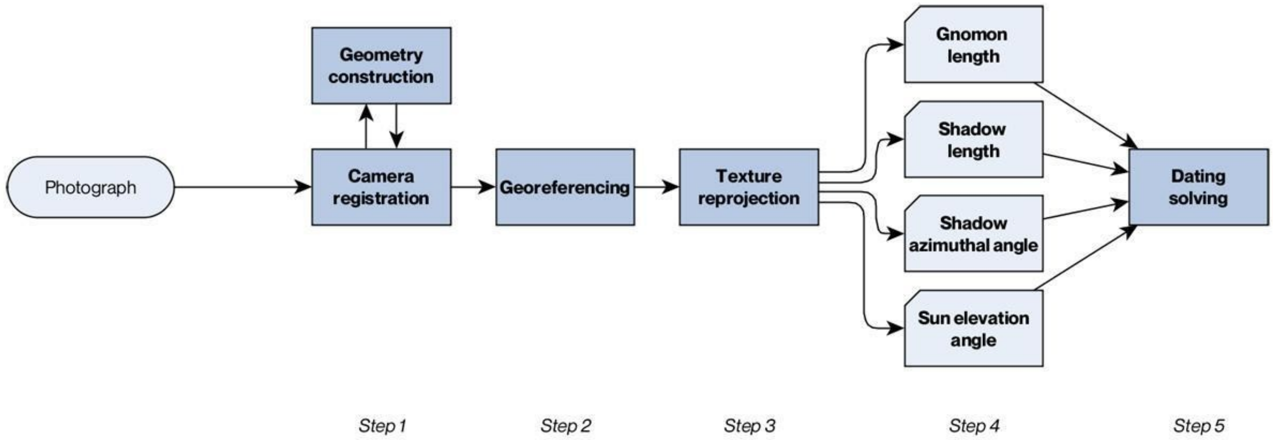

Fig. 1. Proposed workflow and processing steps (© Antonio Suazo).

Case study

For purposes of evaluation, the proposed system has been applied to a case study, the construction process of the Civic District in Santiago, Chile -which took almost a decade to complete- and the reconstruction of its chronology from a set of historical photographs, without known dating, collected from different archives and digitized repositories. From the first set of selected images, a subset that met the aforementioned requirements was used (Figure 2): the presence of identifiable straight and parallel converging lines (for camera registration); at least three control points with known geographical coordinates (for georeferencing); and under illumination with direct sunlight, with accurate and defined shadows, where at least one gnomon of known vertical geometry (or reconstructable by photogrammetric means) casts a shadow with a straight side on a horizontal surface (for dating calculation).

The results are shown following the proposed workflow. From a total of 83 collected photographs attributable to the period, 48 were pre-selected where the urban complex being studied is depicted. Of these, in 36 it was possible to identify in the image the requirements to perform the camera registration, georeferencing, and dating calculation based on shadows. Thus, the complete set of 36 images was processed and their ToD and DoY solutions were obtained (Figure 3).

In the last step of the proposed workflow, the astronomical formula is fed with the obtained physical quantities. Usually, the most common use would be to calculate the sun position of the sun from ToD and DoY values, but here it is used the other way around, which generates, from a single sun position, two valid solutions of time and day. This is due to the fact that, in its path, the earth orients itself twice a year in the same direction towards the sun, on dates and hours that are symmetrical to each other with respect to the nearest solstice.

As a result, for each processed photograph, the two possible values of ToD and DoY were calculated and stored, together with the magnitudes obtained for solar azimuth and elevation, as shown in Table 1.

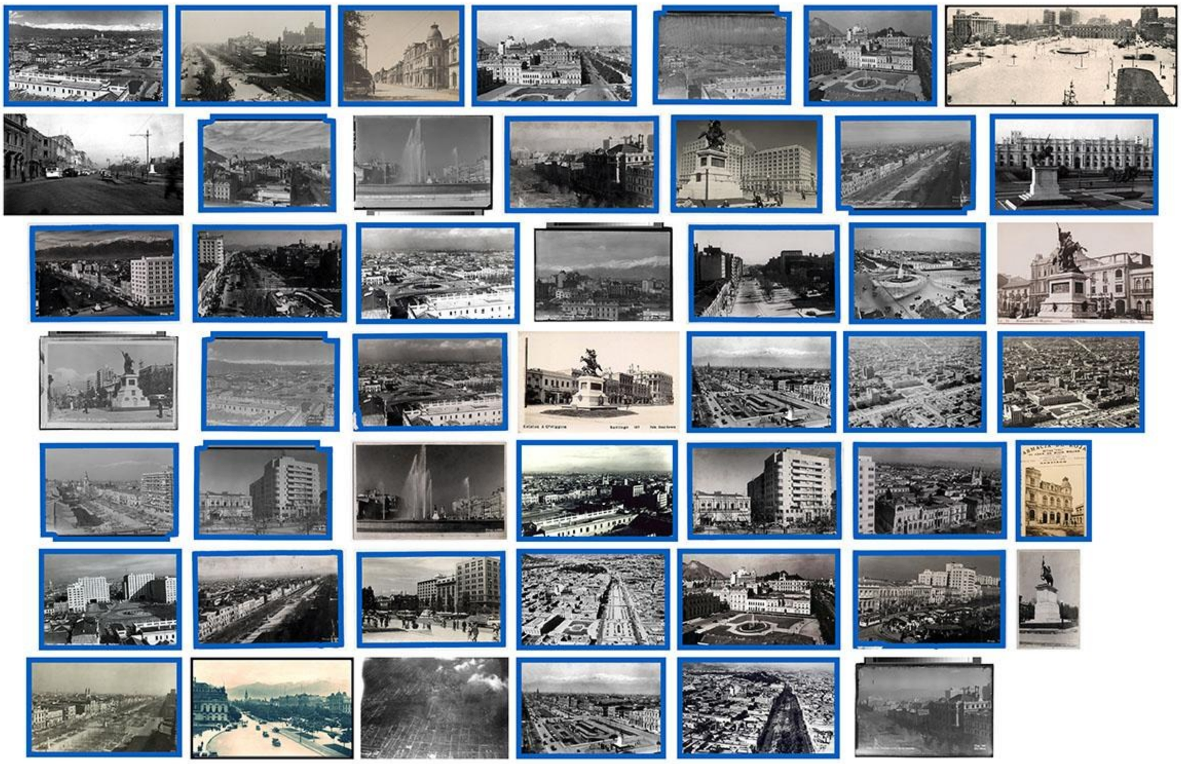

Figure 2. Photographic set, from which 36 images were selected for processing, marked by blue frames (© Antonio Suazo).

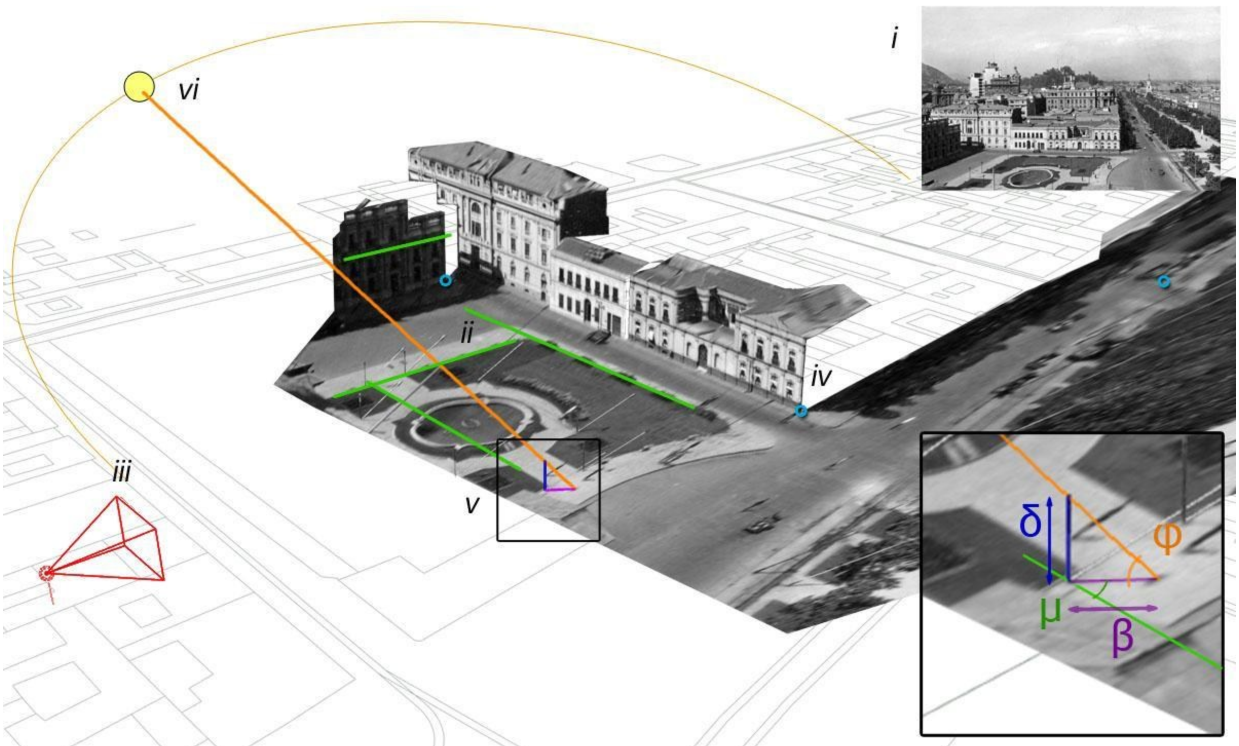

Fig. 3. Processing example in detail. Starting from the original photograph (i), in-image detected parallel lines (ii) were used to obtain camera position and orientation (iii), further georeferenced with the aid of control points (iv). This was used to generate basic scene geometry, including the chosen element to act as gnomon (v), allowing to recover the four main measures (enlarged image section marked by a black frame): gnomon length(δ), shadow length (β), sun elevation angle (φ), and shadow azimuthal angle (μ), to feed with them the astronomical formula, ultimately obtaining values of Time of Day and Day of Year (vi). (© Antonio Suazo).

Table 1. Dating results (extract). In each case, the two possible dates were stored

		Shadow	Sun	Date A		Date B	
N°	ID	Azimuth	Elevation	DoY	ToD	DoY	ToD
1	108870833	14.45°	33.43°	14 jul	11:57	31 may	11:48
2	108960614	-48.53°	25.79°	13 aug	15:45	02 may	15:36
3	108962064	-45.51°	52.16°	05 oct	14:15	10 mar	14:38
4	154011350	50.47°	73.01°	02 dec	11:35	11 jan	11:46
5	163472390	-38.02°	58.27°	12 oct	13:45	03 mar	13:58
6	16enrique	-46.70°	43.29°	18 sep	14:45	26 mar	14:49
7	176279816	-26.73°	63.15°	17 oct	13:15	26 feb	13:07
8	1Alameda1	-44.45°	48.32°	26 sep	14:25	16 mar	14:29
9	201080523	19.74°	30.47°	21 jun	11:30	23 jun	11:22
10	281961624	-51.53°	42.92°	23 sep	14:55	22 mar	15:06
11	329274868	-16.43°	56.37°	26 sep	15:10	19 mar	15:16
12	418958025	26.36°	67.06°	27 oct	11:45	16 feb	11:37
13	447243080	-33.67°	44.33°	07 sep	14:15	06 apr	14:21
14	455606337	-59.20°	46.85°	9 oct	14:54	04 mar	15:20
15	479022034	-41.99°	64.30°	29 oct	13:35	14 feb	13:26
16	503653143	-63.20°	45.51°	13 oct	15:05	02 mar	15:17
17	524818544	-49.11°	19.70°	28 jul	16:05	17 may	13:58
18	579824662	-11.16°	62.44°	10 oct	12:50	05 mar	13:04

Validation, findings and error analysis

To account for a validation step, a dedicated tool was developed to represent the values obtained in a three-dimensional environment, in combination with the respective *analemma* associated with the dates, the position of the sun, and the shadows cast. In this way, it was possible to visualize and check the consistency of the results, and eventually to better interpret the values obtained (Figure 4).

The main findings obtained with the application of the processing in the case study are shown below:

I. Dating solution

- In relation to inferring photograph date, the proposed procedure generates consistent and replicable dating results, exceeding initial expectations. For all photographs processed, it was possible to obtain the values of i) ToD and ii) DoY.
- This was possible not only for photographic material (positives and negatives), but also for other indirect media such as photographic postcards and images included in advertising posters.

II. Results precision & margin of error

- The accuracy of the dating solution depends on the shadow angles identified. Azimuth angle impacts -mostly- to ToD; elevation angle impacts to DoY. It was observed that a variation of 1° degree is already distinguishable, which in the case of the elevation angle generates differences of 5 days on average (Figure 5).
- Successive steps of the proposed workflow do not contribute with significant errors, and none of them is greater than, for example, the variations produced by the geometric distortion of the lens, already studied in the literature.

III. Absolute year determination

- Spanning different values for year, the variation in the angle of the sun turned out to be even smaller than the margin of error, so the value alone is negligible.
- The determination of an absolute year remains an open issue, as it is difficult to establish a result solely from the astronomical formula used.
- Even so, ToD and DoY values obtained do provide additional information not previously available, which can be used to delimit the presumed year, in combination with other sources and conventional methods (i.e. by spotting events and or buildings depicted in the image associated with known ToD and DoY, please see below).

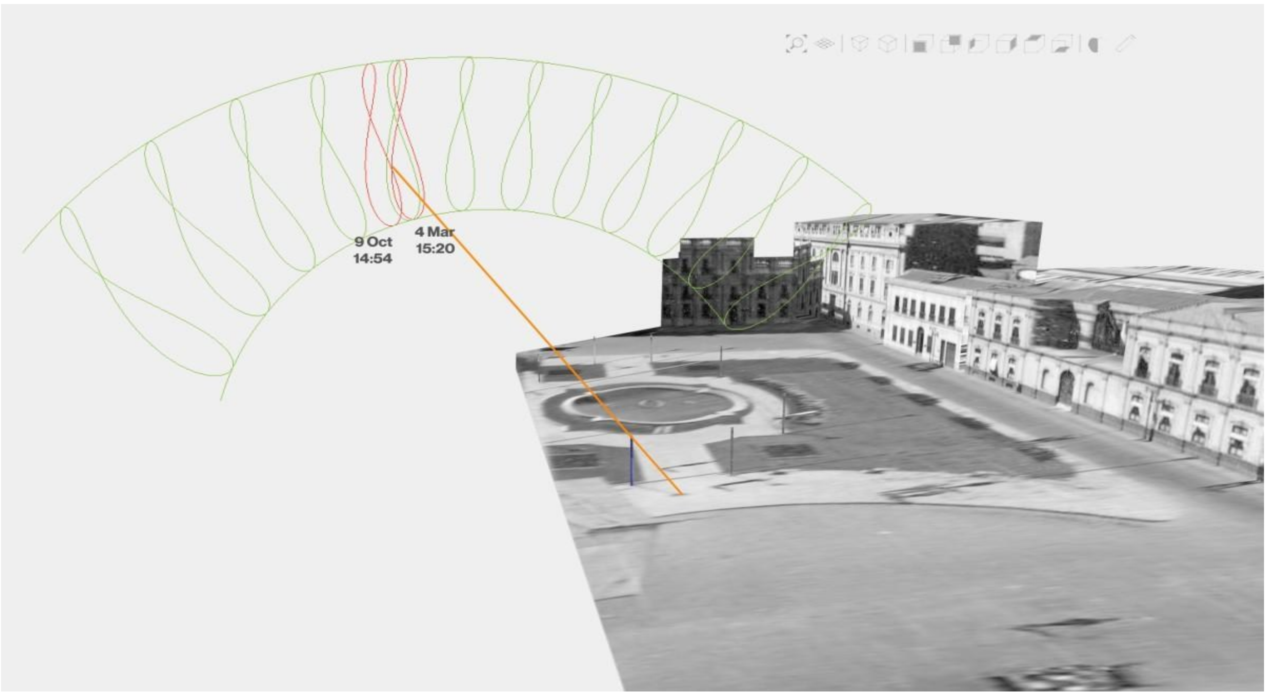

Fig. 4. Screenshot of a dedicated tool for visualizing and checking results consistency (© Antonio Suazo).

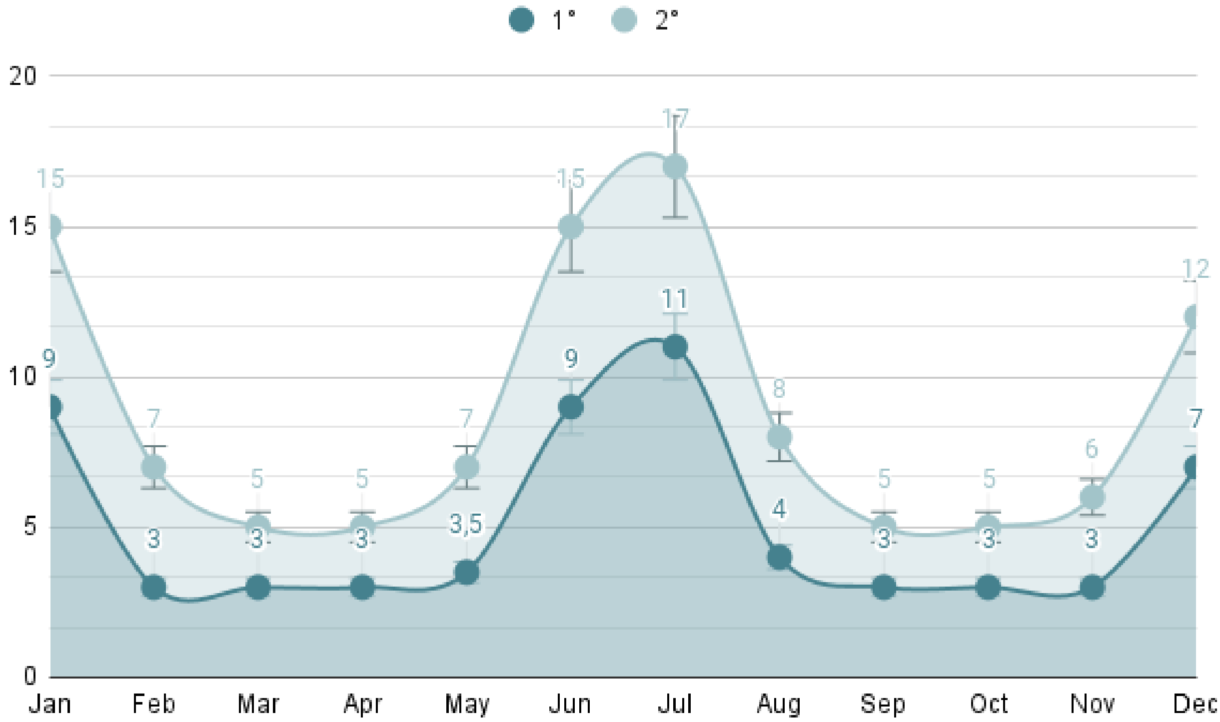

Fig. 5. Dating accuracy. Number of days according to variation of 1 and 2 degrees in shadow elevation angle. Peak values of 10 to 11 days of margin of error are observed at the end of June and December (coinciding with winter and summer solstices of extreme sun inclinations), although the rest of the year remains within 3 to 5 days on average (© Antonio Suazo).

Discussion

In summary, through the study, it was possible to formulate, design a workflow and apply in a case study, a procedure to date historical photographs and thus determine a date of capture. Having temporal capture data is very relevant to considering the documentary dimension of historical photography, and becomes a central issue for spot findings based on the information contained in it. This highlights the relevance of having modern methods to perform this dating, which is added to the methods already practiced for the recovery of the metadata associated with them, and to the study of built and missing heritage, especially with interest in the evolution and chronology of their interventions.

Future work could explore and expand upon the possibilities identified so far. The main one has to do with reducing the uncertainty surrounding the determination of an absolute year, using available contextual information in combination with the DoY and ToD results obtained. In one favorable example, the time interval found in the image metadata was checked against weather records for the day of the year obtained, identifying the only year in which the photograph could be taken. Applications like this are consistent enough to be used across image sets, given that photographs were often obtained in sequence, during full-day capture sessions.

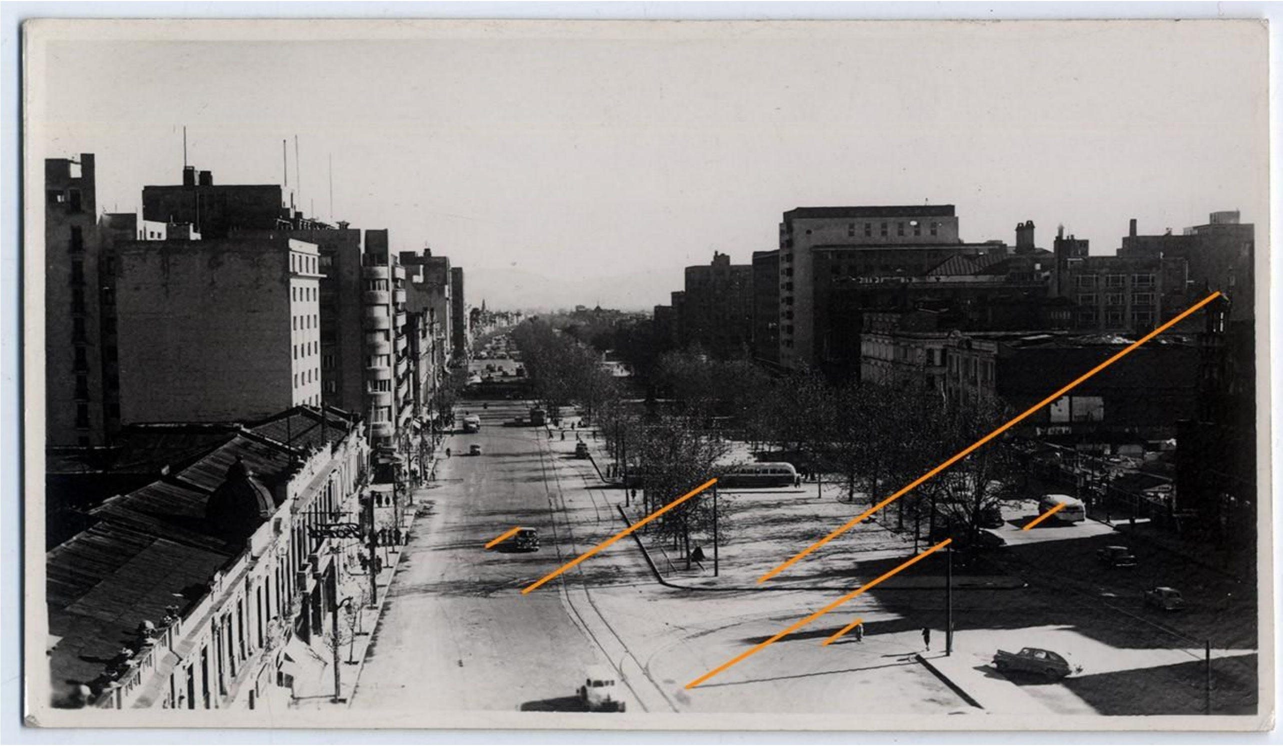

Fig. 6. Different measurements of shadows, evenly distributed on the photograph, can help to detect manipulations in the visual information. (© Antonio Suazo).

Similarly, future work will be able to analyze the impact of latitude on the obtained results. Since this implies having datasets from different locations, a collaborative research effort, with institutions at different latitudes, could comparatively evaluate situations with different sun inclinations, and determine how this factor affects the dating results and their error rate.

Finally, it is noted the high workload involved in analyzing each photograph. During the tests, it was necessary to enable different pieces of code to reduce manual work, both at the beginning (with a parallel line detection tool based on the Hough Transformation algorithm), and at the end (with a routine to convert and save the results to a .json file format). Future enhancements could turn the entire workflow into a semi-automated process, with dedicated tools to assist in the validation of each step. As a good example, it was observed that the visual validation tool ended up being very necessary for interpreting and converting raw values into useful information, especially for checking the consistency of the results with respect to the information already present in the photographs.

As complementary notes, and as a way to address the integrity of the image, it is suggested to carry out at least three measurements on shadows, located at different points of the photograph, in case of eventual alterations or manipulations to the visual information (Figure 6).

Funding

This work was partially funded by the National Fund for Arts and Cultural Development (Fondart) Grant N° 546668, within the research initiative “Alameda de Santiago 1910–2010: ¿El ocaso de un espacio público?” led by Carolina Quilodrán, with additional support from the Photographic Archive of the National Library of Chile, as well as the junior research group Evidencia Visual, Chile.

Conflict of Interests Disclosure

No potential competing interests have been reported by the authors.

Author Contributions

Investigation, Methodology, Software, Writing – original draft: Antonio Suazo

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