PHOTOGRAMMETRY AS A TOOL FOR CHRONOLOGICAL DATING OF FIRED BRICKS STRUCTURES IN GENOA AREA

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ABSTRACT:

The aim of this paper is to explore the applications of photogrammetry in the field of archaeology of architecture. Specifically, to test possible advantages in adopting this tool for undertaking brick measurements for chronological dating of fired bricks historic structures. Mensiochronology analysis is a direct and non-destructive method providing an absolute dating of stratigraphic units. It is based on direct inspection and survey of bricks. Depending on the accessibility of the surface being studied, mensiochronology is suitable for vertical structures of limited height or relies on the availability of scaffolding and lifting equipment. There are several advantages in applying photogrammetry to brick measurement, among them: the possibility to undertake measurements of every kind of surface; the reduction of on-site survey time; the opportunity to repeat measurements off-site; the possibility to increase the number of measured elements in subsequent phases and by different operators. To explore the application of photogrammetry for mensiochronology three case studies are analyzed, testing the effectiveness of this tool on buildings displaying diverse features (e.g. handmade and industrial bricks) and dating back to different periods.

1. INTRODUCTION

This paper presents the first results of a study aimed at exploring one possible application of photogrammetry in the field of archaeology of architecture. Specifically, to test the precision of this tool for mensiochronology, that is the chronological dating of brickwork based on the analysis of dimensions and composition of the elements.
Considering every construction as the primary documental source of its own history, mensiochronology is among the preferred tools for the investigation of buildings. In fact, cross checking data provided by this method with information made available by other disciplines (investigation on archival and bibliographical sources, or material and construction techniques) allows gaining a deep understanding of the history regarding the first construction of the building and its subsequent transformations (Mannoni, Boato, 2002).
The possibility of dating parts or elements of an historic building allows the previously identified stratigraphic sequences to be situated in time. This is critical not only to formulate new hypothesis regarding modifications occurred to the building over time, but also to prove existing assumptions or solve chronological inconsistencies.
Moreover, the opportunities provided by this method go beyond a single and specific case study. In fact, it can offer a crucial contribution to the study of the whole material culture that created one building (Musso, 2015). Finally, information gathered may serve not only to the purpose of expanding knowledge about its constructive history, but are also crucial for conservation. For example, information regarding the time a material has been exposed to decay agents, or whether a structural element dates back to the first construction or to subsequent phases, is fundamental to calibrate the most appropriate conservation interventions.
However, to have access to its whole potential, this dating method needs to be supported by a high number of samples, and by very precise and reliable measurements. These requirements often collide with the actual characteristics of the building, that may not display a sufficient amount of measurable bricks, being covered by one or more layers of mortar, or located in areas that have difficult or no access. Based on direct inspection and survey of the wall elements and on the accessibility of the surface being studied, mensiochronology is therefore suitable for vertical structures of limited height or relies on the availability of scaffolding and lifting equipment.
This considered, there are several advantages in applying photogrammetry to brick measurement. First, the possibility to undertake measurements of every kind of surface, regardless to its position and geometry. Second, the reduction of survey time on site, this representing an obvious advantage in case of damaged structures. Third, the opportunity to repeat measurements off-site, involving more than one operator and giving the chance of several checking. Then, the possibility to increase the number of measured elements in subsequent phases, to improve the accuracy of the reference curves. Finally, the use of already available or historic pictures (if showing a metric reference) to create new point clouds.
This paper is aimed at investigating the possibilities provided by the most recent and advanced 3D digital photogrammetric techniques. Digital measurement on point cloud is proposed as an alternative to direct measurement of bricks for chronological dating purposes. First outcomes are presented, focusing on easily accessible stratigraphic units (to minimize measurement error on site) and involving the phase of data gathering (therefore not

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considering chronological attribution based on measurements). If the reliability of photogrammetry is demonstrated, it may be profitably used to apply mensiochronology also to architectural portions that are not directly accessible. Both the quality improvement of measurements referred to elements far from the operator, and the possibility to keep precision and accuracy of measures will be tested in a subsequent phase.

2. MAIN BODY

2.1 Mensiochronology as a dating method

Mensiochronology represents one important dating method for fired bricks historic structures developed within the wide field of archaeology of architecture in the last decades. It is a direct analysis based on inspection and survey of the blocks and it is non-destructive since no sampling is required.
Mensiochronology was developed by ISCUM (Institute of the History of Material Culture, Genoa) in the early 1970s. ISCUM verified that, after the fall of the Roman Empire (when most parts of Europe and around the Mediterranean shared the same brick module), an abrupt change in bricks dimensions happened, followed by a series of small local changes, up to the current UNI standardization (Pittaluga, 2009a).
The method follows several subsequent phases. First, the physical dimensions of the blocks (length, width, and thickness) are recorded with a caliper. The most appropriate precision for measurements is millimeter: a lower precision implies dating error, whereas a greater one is not achievable due to block irregularites.
Then, the collected data are processed statistically. The mean value for each dimension (length, width, and thickness) and the distribution curve trend are evaluated (Pittaluga, 2009a). Results are compared with unique curves relating measurements trends to production periods. Each curve is valid for a specific geographical, social, or economic context of production and use and it is known as "local key".
Mensiochronology is an absolute dating method: in fact, the result is a precise chronological segment, that is a time interval with variable length. The time span of the chronological segment decreases with the increase of the number of measured elements and the quantity of additional information gathered (Pittaluga, 2009a).
It is not possible to apply mensiochronology to every geographical or historical context because it relies on the possibility of identifying a recurring and recognizable transformation path when considering bricks production characteristics over centuries. This method has proved to be reliable for dating of fired bricks historic constructions in Genoa area.

2.1 Photogrammetry for mensiochronology: proposed methodology

The measurement of bricks through digital imaging in Genoa area was first investigated by a Master's Degree thesis (Pertica, 2002-2003). Automated detection of the edges in an image resulting from a digital rectified photography was experimented. However, this system did not consider some of the bricks features like color and decay that, if not properly assessed, may lead to dating errors.
To explore the application of photogrammetry for bricks measurement three case studies were analyzed. Buildings displaying diverse features (e.g. handmade and industrial bricks) and dating back to different periods were selected.
The first one – case A – is a wall on the ground floor of an historic house in Novi Ligure (Piedmont, North of Genoa). This case, easily accessible for direct inspection and survey, was intended to demonstrate the reliability of the procedure. A comparison between direct and digital measurements was developed to test the accuracy of the point cloud for the purpose of this study.
The second one – case B – is an historic house in the center of Genoa. The external wall on Vico Fate displays a complex stratigraphy, with several stratigraphic units (US). Most of the bricks are handmade. This structure had previously been studied by the DAD Department (Department of Architecture and Design, Polytechnic School, University of Genoa) and by a Master's Degree thesis, that also conducted brick measurements analysis for chronological dating (Forgione, 2011-2012).
The third one – case C – is located in the kitchens of the *Albergo dei Poveri* (Hospice for the Poor) in Genoa, a construction dating back to the 17th century. The wall studied is part of the ovens and is made of industrial 19th century bricks. This example was chosen to verify the application of photogrammetry in the case of more standardized elements, checking the deviations of the resulting curve.
In case A and B, the bricks were identified on site with numbered labels to compare the results of direct and digital measurements and to prove the effectivity of photogrammetry for mensiochronology.

	n. of photos	camera	point cloud
CASE A	25	Iphone 6	11304833
	30	Nikon D300	30410772
CASE B	44	Iphone 6	9661806
CASE C	95	Nikon D300	44380708

Table 1. Number of photos, model of camera, and point cloud. Data for case C are referred not only to the studied wall but to the whole oven room.

Pictures of the walls were taken with two different cameras: the first is a Nikon D300 (CMOS sensor, 23.6 x 15.8 mm; 13.1 MP), the second is the camera of an iPhone 6 (8 MP). The set of picture taken with iPhone 6 displayed an acceptable accuracy, thus demonstrating the wide applicability of the system.

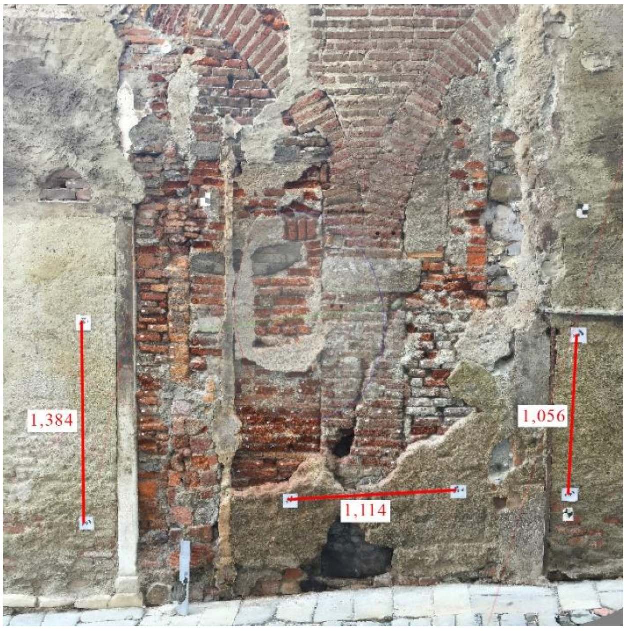

Figure 2. The digital model created by Agisoft PhotoScan software is scaled inserting the distance between couples of coded targets placed on site.

Six coded target (CTs)[1] were placed on the wall. The length between couples of targets was measured manually on site to scale the digital model. In case A and B coded targets were measured topographically with a total station Leica TS-15. This allowed to compare the difference between the point cloud resulting from longimetric survey and the one resulting from topographic survey. The gap between the two sets of measurements (longimetric and topographic) resulted to be less than one millimeter.
Photogrammetric point clouds, mesh, texture, and tiled model of the case studies were created with the software Agisoft PhotoScan. Bricks measurements and additional features (e.g. color and peculiarities such as cracks) were recorded on site (direct measurement) and on the digital model using the tiled model view of Agisoft PhotoScan software (digital measurement). Measurement was done inserting two markers at the endpoints of the desired segment and creating a *scalebar* giving the estimated distance between the two.
Given the irregularity of bricks, each dimension (length, width, and thickness) may display different values. For each dimension, the largest measured value was recorded. This is a common practice in mensiochronology. Doing so, measurements are closer to the dimension of the mold used for block production.

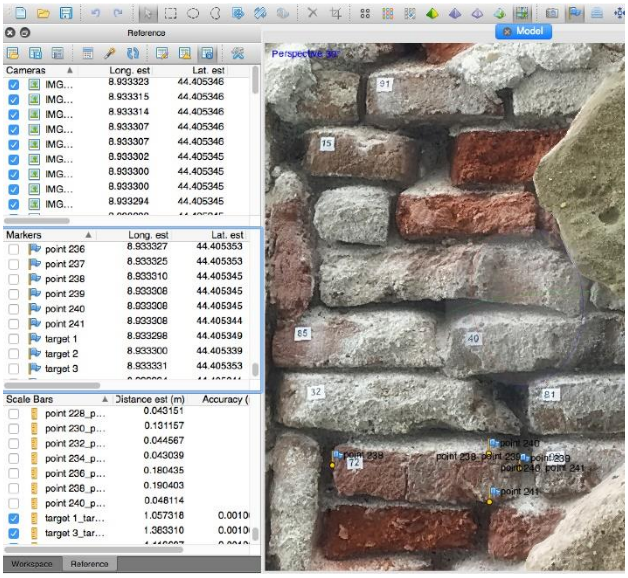

Figure 3. In case A and B, the bricks were identified on site with numbered labels to compare the results of direct and digital measurements block by block. The image displays inserted markers for brick n. 72.

2.2 Results

To consider the human factor during the survey, a comparison between measurements conducted by different operators was developed. Homogenous types of measurements (on site and on digital models) were compared obtaining mean difference and standard deviation in mm.
The position of the block (in front, above or below the operator sight) can affect the measurements error on site. This inconvenience does not exist in the case of photogrammetry. In fact, the use of photogrammetry is limited by the possibility of taking photos from a sufficient number of points of view in order to create the digital model. For the presented case studies, photos were taken from street or floor level and the model covers an area up to about 3.5 m high. It should be considered that it is often possible to take pictures from points of view at higher level (for example, from the windows of a building in front of the studied wall), whereas scaffolding would be needed for direct measurement.
After this, a comparison between direct and digital measurement was developed to test the reliability of photogrammetry for the purpose of this study.
In mensiochronology a divergence of less than 1 mm is normally accepted. Larger errors affect the dating.
Since more thickness measures were available due to the exposed bricks in the different case studies, observations were mainly deduced from the comparison of this measure. Further data may be gathered if comparison is extended to length and width for all the case studies.

2.2.1 Case A: One operator undertook measurements on site and one on the digital model and their results on individual bricks were compared.
The comparison between direct and digital measurements on single elements showed that 25 measurements of 72 total have a difference of less than 1 mm and that the mean difference is 2.33 ± 1.99 mm.

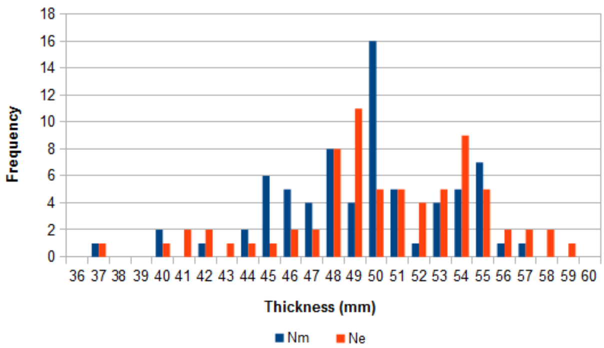

Figure 4. Graph regarding the distribution curve trend of bricks thickness in case A. Nm: direct measurements on site; Ne: measurements on digital model. As previously stated, the larger available number for each dimension was recorded for each of the dimensions, to deal with block irregularities. For example, if one element presented parts with different thicknesses, the larger value among the two was the one recorded. Both direct and digital systems allowed the identification of color and characteristics of all the bricks (such as color and cracks).

2.2.2 Case B: Five previously identified stratigraphic units were analyzed: US 15, US 17, US 152, US 153, and US 221 (Forgione, 2011-2012). Measurements on these US was conducted by C. Forgione and R. Vecchiattini and dating results were available.
Two different operators undertook measurements on site and three on the digital model (33 bricks for US 15, 30 bricks for US 17, 6 bricks for US 152, 15 bricks for US 153, and 11 bricks for US 221).
First, the measurement values were processed through IBM SPSS running a t-test. Direct measurement on site were compared with measurement on the digital model. The difference between the

[1] Agisoft PhotoScan functionality includes automatic detection and matching of CTs on source photos, which allows to benefit from marker implementation in the project while saving time on manual marker placement. Moreover, automatic CTs detection and marker placement is more precise then manual marker placement (Agisoft, 2013).

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means of direct and digital measurements resulted to be not significant, being the difference less than 1 mm, and the confidence interval 95%.

Then, data were analyzed to investigate whether a linear trend linking the difference between direct and digital measurements with brick thickness could be identified. To do this, the two sets of direct measurements were compared between them, using the second set to check the reliability of the first one. Elements displaying a difference of more than 3 mm between the two direct measurements were discarded. After this, direct measurements on single elements were compared with the corresponding measurement on each digital set, calculating the mean difference and standard deviation. Considering the first digital set, the mean difference is 2.14 ± 1.64 mm (76 measurements); for the second one, the mean difference is 2.00 ± 1.44 mm (79 measurements); for the third one, the mean difference is 1.54 ± 1.25 mm (63 measurements).

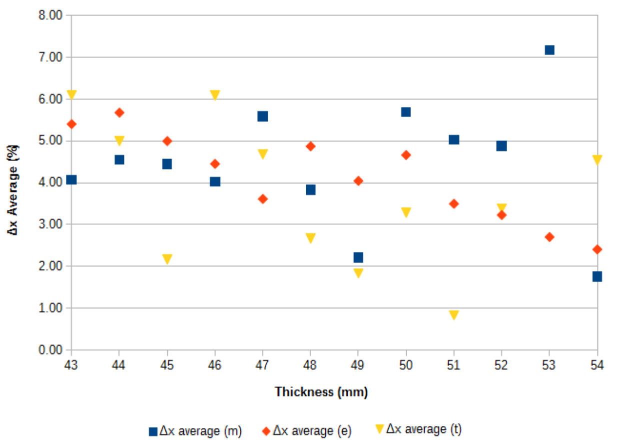

Figure 5. Graph regarding the difference between direct measurement on site by one operator, and digital measurement by three operators (m, e, t). This graph includes bricks of all stratigraphic units. Direct measurement is considered here as reference, since mensiochronology curves are usually developed based on measurements on site. Brick thickness is represented on x-axis: the range 43-54 mm is selected since it includes most measurements. The mean difference in absolute value is weighted on the brick thickness (from direct measurement on site), giving a percentage that is represented on y-axis. It is not possible to recognize a linear trend linking the difference between direct and digital measurements and brick thickness, nor considering the measurements by each operator alone working on the digital model. Further observation may be done by increasing the number of operators.

2.2.3 Case C: One stratigraphic unit was analyzed, identified as US 14 during a previous campaign aimed at the archeological analysis of that area of the building (D. Pittaluga, M. Casanova, S. Acacia).

One operator undertook measurements on site and two on the digital model (11 bricks). As for the previous case, since more measurements were available for thickness, this dimension was considered for further observation.

In case of the first operator, the difference between digital and direct measurements is less than 1 mm for 4 measurements of 11 total, and mean difference is 1.40 ± 1.13 mm. In case of the second operator, the difference between digital and direct measurements is less than 1 mm for 5 measurements of 11 total, and the mean difference is 1.96 ± 1.76 mm.

Despite the smaller number of measured elements, the difference resulted lower than in case A and B. This may be related to the use of industrial vs. handmade bricks. In fact, being more standardized, industrial bricks present a smaller variation in their size range.

Figure 6. Tiled model view of case C, a wall of the ovens in the kitchen of the *Albergo dei Poveri*.

3. CONCLUSIONS

It should be remarked that this paper presents the very first results of the application of photogrammetry for mensiochronology and further investigation is needed to test the outcomes, both increasing the number of operators involved and including new case studies.

At the moment, photogrammetry demonstrated to potentially reliable to undertake measurements for chronological dating, specifically for industrial bricks. Considerable divergences between direct and digital measurements emerged for stratigraphic units made of handmade bricks. However, it must be noted that the human factor highly affects the survey in both cases (measurements on site and on digital model): as showed, the difference between measurements by different operators happens also when considering homogenous type of data.

The main advantage highlighted by this study is that, even decreasing the time for on-site survey, it is possible to create a digital model suitable to be used for measurements later on, involving more operators, and without the need for all of them to go on site. One of the limitations of digital measurement is that it is not possible to manually clean the bricks before measuring them, and this operation is sometimes needed to understand their actual size, when they are partially covered by mortar joints or incoherent deposit.

There are several opportunities to further deepen the research in the future.

First, the inaccuracies emerged between direct and digital measurements showed that more investigation is needed to prove the reliability of photogrammetry in case of objects that are located far from the operator (for example the upper part of walls or vaults).

Second, it is fundamental to further compare dating results from direct and digital measurement and see whether they may lead to

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divergent dates. For case B, dating results developed from digital measurement were compared with the ones by C. Forgione and R. Vecchiattini. In both cases a specialist provided the dating frame based on statistic evaluations, and the results obtained were quite divergent between digital and direct measurement, and between these results and the ones by C. Forgione and R. Vecchiattini. It would be decisive to understand whether this should be attributed to the measurement or to other elements considered by the consulted specialist.
Finally, it would be crucial to further expand the number of case studies and to involve more operators. Among them, the Palazzo San Giorgio in Genoa could be the next case study. Some stratigraphic units of this construction were built with salvaged bricks. Those elements cannot be distinguished by their mean measurements, but only by the standard deviation of their curve (Pittaluga, 1997) and (Pittaluga, 2009b). This example may serve as an additional test to verify the reliability of the system on surfaces with even more complex stratigraphy.

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