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## Quantitative analysis of brick-faced masonry: examples from some large imperial buildings in Rome

### *Análisis cuantitativo de paramentos de ladrillo: ejemplos de algunos grandes edificios imperiales en Roma*

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#### ABSTRACT

This paper aims to present some preliminary results of an ongoing study which started from the analysis of the external brick facing of the Aurelian Walls. The methodology employed was to analyse the brick facing by sampling the brick wall surfaces, drawing consistent areas of 1x1 m<sup>2</sup> in CAD, based on rectified photographs. These samples were then measured in detail to make a quantitative-statistical analysis of the elements constituting the brick facings, in order to yield standard parameters which could meaningfully describe their features. In this first part of the work, we tried to compare some of the most important imperial brick buildings, each with its own characteristic features. Sampling has covered the Aurelian Walls extensively, focusing on the early periods of Aurelian and Honorius. After were sampled brick-faced walls from a Neronian building facing the Valley of the Colosseum; the substructures of the Baths of Trajan; and some sectors of the *Domus Tiberiana*, towards the north slope of the Palatine Hill.

*Keywords:* Aurelian Walls; Palatine Hill; Baths of Trajan's; *Domus Tiberiana*.

#### RESUMEN

El objetivo de este documento, es presentar resultados de un estudio en curso, comenzando con el análisis de la cortina externa en ladrillos de los muros Aurelianos. Como metodología de estudio, las capas de ladrillos fueron inspeccionadas a través de muestras de sus superficies, seleccionando partes de 1x1m<sup>2</sup> dibujados en CAD, utilizando fotos sin distorsión. Dichas muestras, fueron medidas en detalle, para generar análisis de estadísticas cuantitativas de los elementos constituyentes de éstas cortinas, para obtener standars, que pueden describir sus características. En esta primera fase, tratamos de comparar algunas de los más importantes fabricantes de ladrillos imperiales, cada una con características específicas. El muestrario ha cubierto extensivamente los muros aurelianos, concentrándose en los periodos de Aureliano y Honorio. Luego, fueron estudiadas paredes de ladrillos de edificios de época neroniana, frente al valle del Coliseo; subestructuras de las termas de Trajano; sectores de la *Domus Tiberiana*, en dirección a la falda norte del Palatino.

*Palabras clave:* Muralla Aureliana; Palatino; Termas de Trajano; *Domus Tiberiana*.

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## INTRODUCTION

This study started from the analysis of the external brick facing structures of the Aurelian Walls in Rome, focusing on the early periods of Aurelian (271-275 d.C.) and Honorius (400-402 e 417 d.C.). The main purpose was to argue whether the towers and curtains of the Walls were built using new or recycled bricks. Scholars who have dealt with the Aurelian Walls have not agreed: Lanciani (1892) stated that new bricks were used, Richmond (1930) that new and recycled bricks were mixed, and Heres (1982) and then Mancini (2001), that only recycled ones were used. Given this uncertainty and lack of agreement, based merely on superficial aspects, we have tried to find a safer way for evaluating the data more objectively. For this purpose, we have created a rigorously analytical sampling system, which would allow brick-faced walls to be compared in detail<sup>1</sup>.

## ROMAN BRICKS: SIZE AND PIECES

As is known, brick thickness has been considered indicative of the chronology since the first pioneering quantitative studies by Giuseppe Lugli. Together with the thickness of the mortar beds it constitutes Lugli's «*modulo*», corresponding to the thickness of 5 bricks+5 mortar beds (Lugli 1957); moreover, the length of pieces visible in the wall facing should allow the size of the bricks originally made for the construction to be determined (Bukowiecki 2010), that is to say the three standard sized bricks produced in Rome since the Neronian-Flavian period: *bessalis*, *sesquipedalis* and *bipedalis*.

Completely new, instead, are the evaluation parameters introduced through measuring the rate of coverage of the wall surface, divided into constitutive material, i.e. bricks, and binding material, i.e. mortar. Moreover, as verified, the estimate of the two mentioned parameters must be correlated to the reconstructed number of pieces in the sampled 1sqm area, because only by comparing both values is the quality of the building as it has been projected really perceivable.

<sup>1</sup> This is a work in progress that requires an assortment of skills. The working group is composed of: Maura Medri, coordinator; Valeria Cola who performed the field work, in collaboration with Federico Cirocchi; Giorgia Pasquali who performed the calculations in CAD and generated the quantitative tables; Samuele Mongodi who analyzed the data and produced the histograms. The translation of this text from Italian to English was done by Valeria Di Cola.

## METHOD OF SAMPLING

The method of sampling (Fig. 1) consists of taking measurements from a uniform 1sqm section surface of the wall. Afterwards, the sample is drawn in CAD, by digitising the details from rectified scaled photographs. For each sample, an Excel-sheet is drawn out recording the following numerical data:

- A. Estimate of pieces uncut by the sample frame
    - Number of uncut pieces in the facing
    - Thickness and length, measured as distances between midpoints of opposite sides, and CAD area
    - Total area of uncut pieces
    - Thickness and median length of uncut pieces, median area of uncut pieces
  - B. Estimate of pieces cut by the sample frame:
    - Numbers of pieces cut by the frame
    - CAD area of single cut pieces
    - Total area of cut pieces
  - C. Sample global estimate for 1 sqm of masonry:
    - Reconstructed number of pieces for 1 sqm (= area of cut pieces : median area of uncut pieces)
    - Total number of bricks (= number of uncut pieces + reconstructed number)
    - Brick area of coverage in the facing
    - Mortar area of coverage in the facing
- Finally, elements compared are:
- The thickness and lengths of only uncut pieces visible in the facing;
  - The rate of coverage between bricks and mortar;
  - The reconstructed total number of pieces used in 1 sqm.

## AURELIANIC WALLS

For the Aurelian Walls (Fig. 2), many sectors were sampled choosing particularly from those masonry parts where evidence of the two principal building phases had been already detected (see Dey 2011): the Aurelian phase, less well-preserved, was sampled in sectors A, B (Fig. 3 a-b), and C, the Honorian phase in the sectors G, J and K (Fig. 4 a-b), where it is clearly visible over the Aurelian structures (sectors by Mancini 2001).

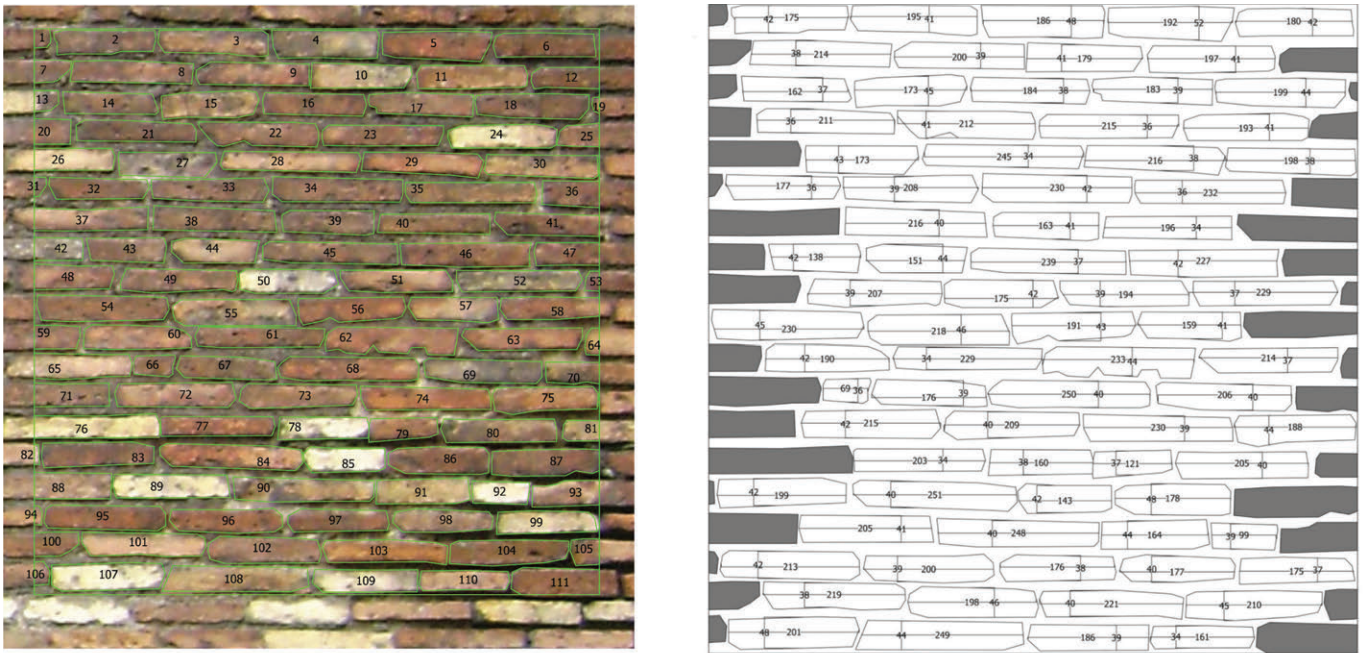


Fig. 1. Aurelian Walls, brick faced external structures, quantitative analysis of 1 sqm sample; left, rectified scaled photograph and CAD drawing; right, estimate of uncut and cut pieces.

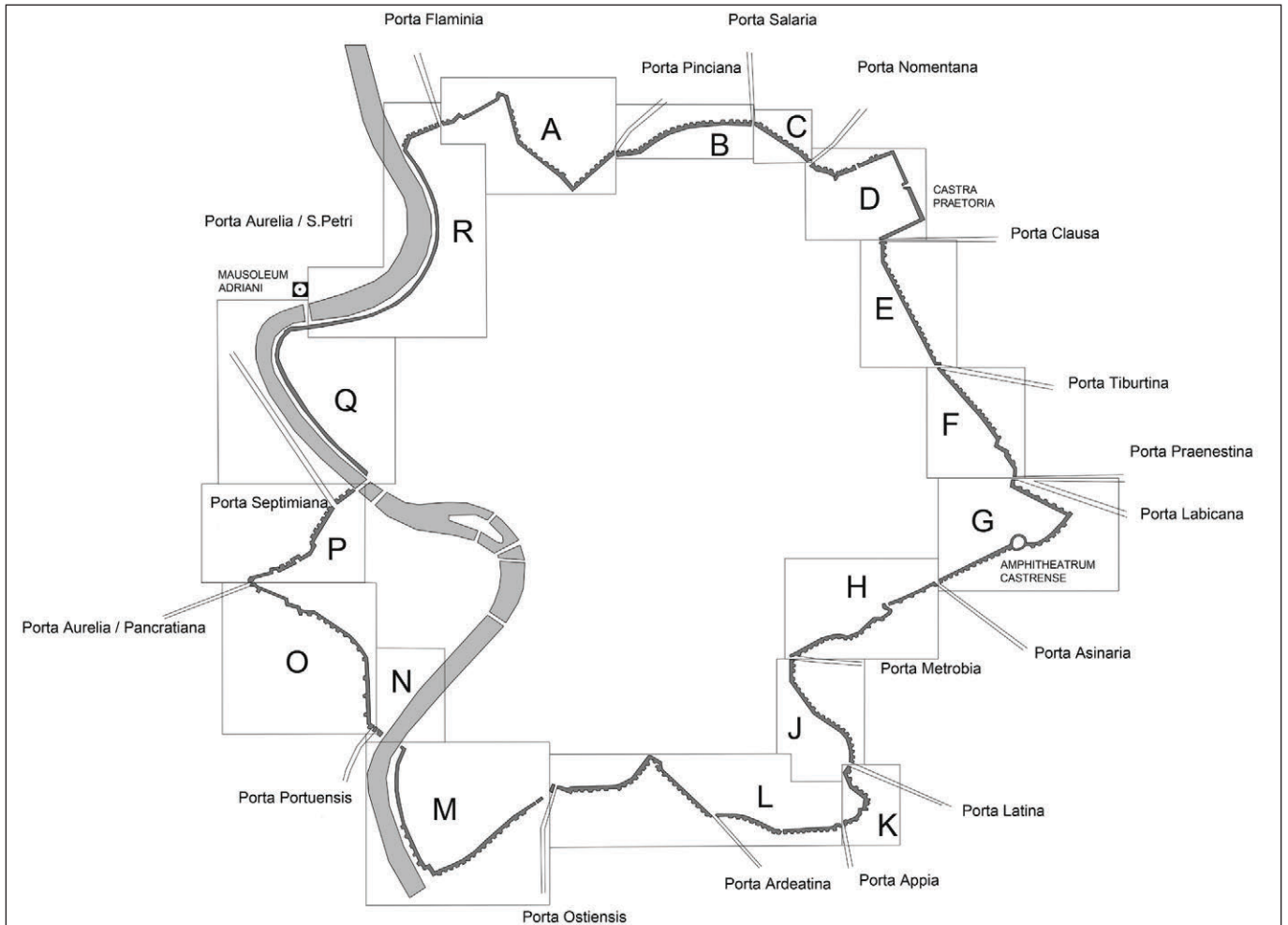


Fig. 2. The circuit of the Aurelian Wall with the sectors from Richmond 1930.





Fig. 3. Aurelian Walls, sampling of tower B17. Right: general view; left: right side, samples 01-02.



Fig. 4. Aurelian Walls, sampling of tower K07. Right: general view; left: central side, samples 01-04.

### IMPERIAL BUILDINGS IN ROME

Data gathered from the structures of the Aurelian Walls were compared with ones collected from other buildings, different in chronology and function but all belonging to large imperial projects, yielding the possibility to analyse how the quantitative parameters would have performed in different contexts. For now, the buildings faced in brick which have been compared to the Aurelian Walls are: two different rooms, A03 (Fig. 5) and A04, from a

Neronian building towards the Palatine Hill north slope, facing the valley of the Colosseum; the substructures of the Baths of Trajan’s (Fig. 6); the Hadrianic substructures alongside the *Via Tecta*, a building dating to the same period (Fig. 7), and another of the Flavian age, all in the area of the *Domus Tiberiana*.

This comparison has yielded some significant data; nevertheless, continuing research will be necessary to broaden the database to possibly confirm these statements.





Fig. 5. Palatine Hill north slope, facing the valley of the Colosseum, Neronian building, room 03, sample 01.

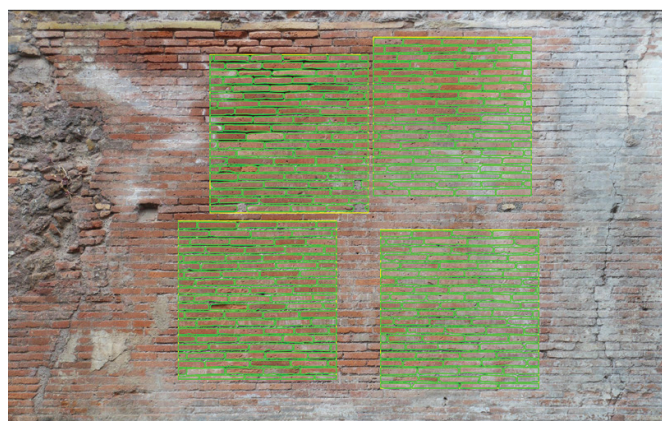


Fig. 6. Baths of Trajan's, substructures, samples 01-04.



Fig. 7. Palatine Hill north slope, *Domus Tiberiana*, the Hadrianic substructures alongside the *Via Tecta*, samples 01-03.

## QUANTITATIVE ANALYSIS: CONCLUSIONS

About the bricks, it is possible to affirm that (see Figs. 8, 9, 10):

- for both the projects, Aurelianic and Honorian, the brick materials are recycled and perhaps chosen according to the length of brick pieces to be used in the facing, mainly in the Honorian structures, which seem to reach a greater homogeneity in the construction (Fig. 8.4);
- the analysis of the thickness has proved to be a real criterion for arguing whether the structure are built with new or recycled materials, because in the recycled pieces we observed widely spread thickness measurements (i.e. with high variance), often with varying peak values, whereas new ones have a single peak value, coinciding with the mean, around which all observations are distributed with relatively small variance (Fig. 8.1-2);
- the length of pieces in the wall facing seems to yield the same range of variability in all the structures analysed (Fig. 9): the dimensions of the pieces visible in the facing concentrate between >14 cm and <26 cm, perhaps in relation to the use of cuts which are smaller than the ones currently considered standard (see above); at the time, the only exception is the Baths of Trajan where the average length of the brick facing is = or < 24 cm (Fig. 8.6).

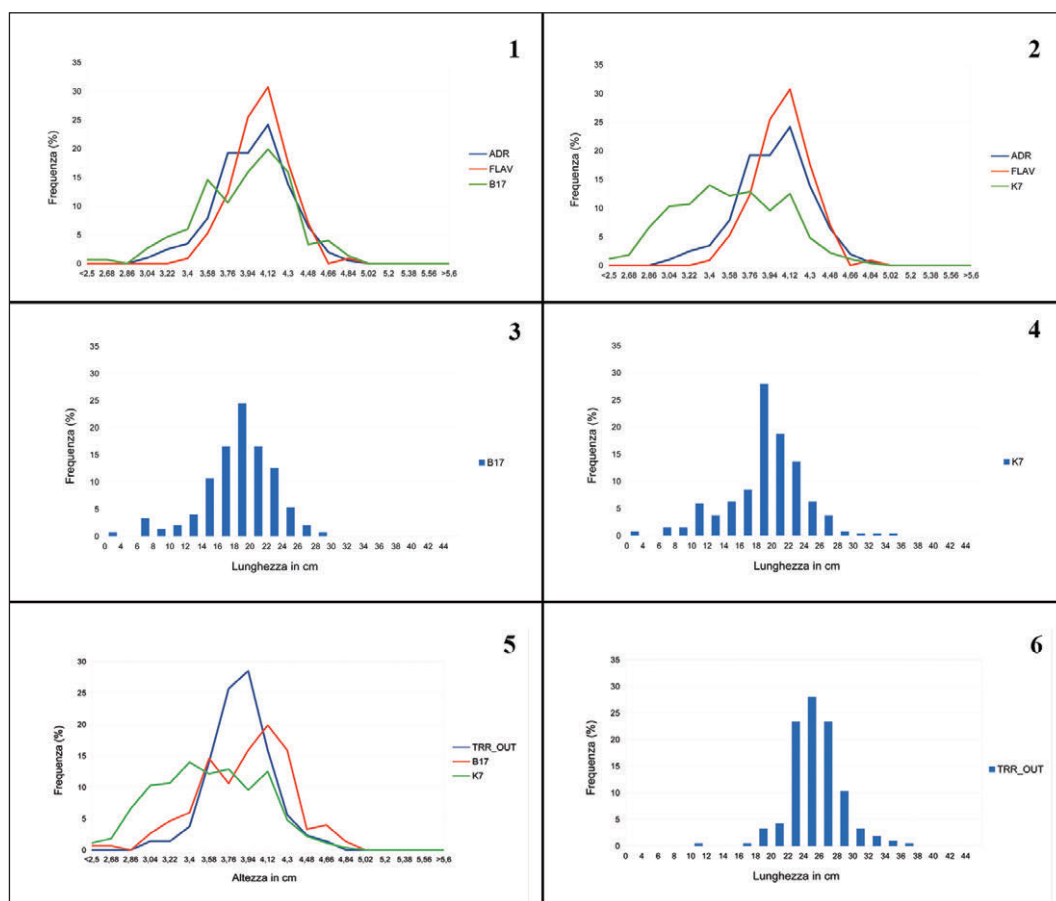


Fig. 8. Quantitative analysis.

1. Thickness of pieces: Aurelianic sample of tower B17 in comparison with Flavian and Hadrianic structures.
2. Thickness of pieces: Honorian sample of the tower K07 in comparison with Flavian and Hadrianic structures.
3. Length of pieces: Aurelianic sample of tower B17.
4. Length of pieces: Honorian sample of the tower K07.
5. Thickness of pieces: structures of the Bath of Trajan in comparison with Aurelianic sample of tower B17, and Honorian sample of the tower K07.
6. Length of pieces: structures of the Bath of Trajan.



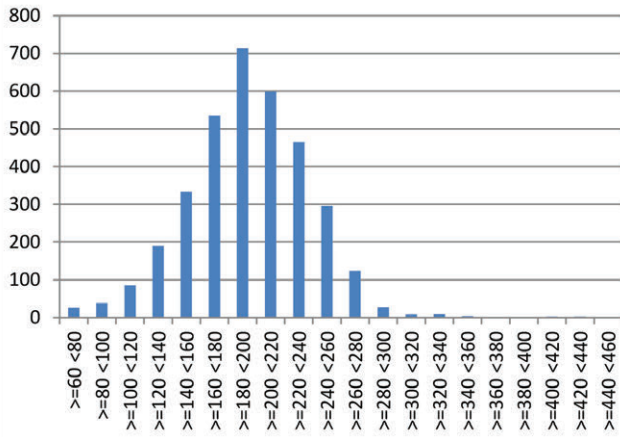


Fig. 9. Length of pieces: all samples, except structures of the Bath of Trajan.

Generally, about the Walls it is possible to state that (see Fig. 10):

- the quality of the Aurelianic masonry is different in each sector;

- in the structures of the Aurelianic phase the systematic use of small-sized pieces has presumably produced areas of collapse, mainly in the lower part of the Wall facings, which appear to be particularly reshaped (Fig. 10.1);
- it is still not certain whether the rate of coverage of the constitutive material, which is less than 60%, was provided by the Honorian builders in order to save materials or to reduce the strain on the underside wall, or both; nevertheless, at present this appears to be a recurring element (Fig. 10.2).

Generally, in relation to brick masonries of large imperial buildings in Rome (Fig. 10.3), it might be said that:

- the rate of the constituent material, i.e. bricks, which is greater than 75%, appears to be an extraordinary value; it needs to be verified, through other samplings, whether there are other structures where the use of brick reaches the same rate;

Campione	Nr pezzi interi esistenti	Nr pezzi interi ricostruiti	% area copertura paramento	% area copertura materiale legante	Campione	Nr pezzi interi esistenti	Nr pezzi interi ricostruiti	% area copertura paramento	% area copertura materiale legante
A18_c_01	73	90	59	41	DT_via_nova_US387	67	87	67	33
A18_c_02	64	84	55	45	DT_via_nova_adr01	72	96	73	27
A18_c_03	66	82	55	45	DT_via_nova_adr02	65	94	78	22
A18_c_04	63	78	55	45	DT_via_nova_adr03	66	87	74	26
A18_c_05	66	80	52	48	DT_via_nova_flav01	54	76	67	33
A18_c_06	56	70	52	48	DT_via_nova_flav01	60	82	69	31
A22_c_01	70	84	59	41	PSP_A03_N_01	64	83	65	35
A22_c_02	68	84	66	34	PSP_A03_N_02	68	85	63	37
A23_c_01	70	89	65	35	PSP_A03_S_01	69	87	64	36
A23_c_02	78	92	71	29	PSP_A03_S_02	70	89	64	36
A23_c_04	77	96	72	28	PSP_A03_S_03	65	84	64	36
B16_s_01	81	101	63	37	PSP_A03_S_04	69	88	64	36
B16_s_02	85	104	62	38	PSP_A04_N_01	70	94	65	35
B17_d_01	76	92	63	37	PSP_A04_N_02	72	91	70	30
B17_d_02	75	91	62	38	PSP_A04_N_03	69	90	66	34
B16_B17_s_01	52	71	56	44	PSP_A04_N_04	71	89	68	32
B16_B17_s_02	55	69	54	46	TTr_out_01	54	74	71	29
C02_c_01	60	82	53	47	TTr_out_02	50	72	72	28
C02_c_02	57	73	55	45	TTr_out_03	56	78	70	30
C02_c_03	63	82	53	47	TTr_out_04	54	78	71	29
C02_c_04	56	76	52	48					
Minimo			52	28	Minimo			63	22
Massimo			72	48	Massimo			78	37
Media			59	41	Media			68	32

**1. Aurelianic samples**

**2. Other imperial buildings samples**

Campione	Nr pezzi interi esistenti	Nr pezzi interi ricostruiti	% area copertura paramento	% area copertura materiale legante
J8f_onor_01	62	77	54	46
J8f_onor_02	61	74	55	45
J11_onor_01	61	80	53	47
J11_onor_02	62	77	54	46
K2K3_onor_01	51	66	51	49
K2K3_onor_02	60	76	53	47
K7_onor_01	69	84	55	45
K7_onor_02	67	85	56	44
K7_onor_03	69	86	55	45
K7_onor_04	67	88	57	43
Minimo			51	43
Massimo			57	49
Media			55	45

**3. Honorian samples**

Fig. 10. Quantitative analysis, reconstructed number of pieces for 1 sqm, bricks area and mortar area of coverage in the facing.

- the quality of a masonry can be judged only by matching both the parameters: number of pieces used and materials rate of the constitutive material.

In this regard, the difference observed between structures made with a medium of 75 pieces/sqm visible in the facing in order to have a coverage of about 70% - as in the Baths of Trajan - and those that reach or exceed the value, but using up to 90 pieces/sqm in the facing, clearly emerges. This difference is obviously in the size of the brick cuts, but also in how far the triangular pieces go into the masonry concrete core, which affects considerably the amount of material used (Fig. 11).

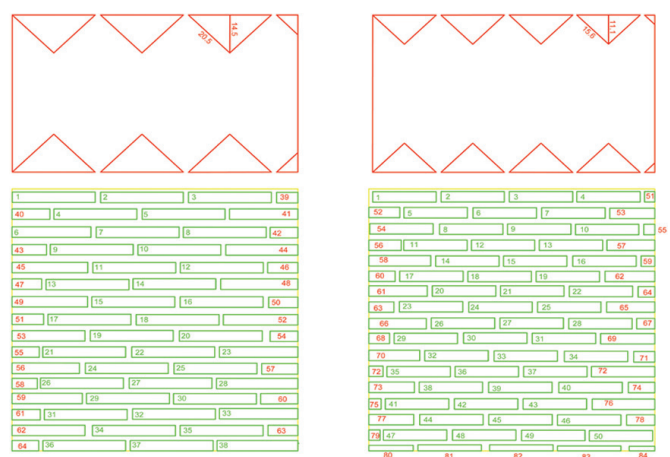


Fig. 11. Ideal samples. Left: 1 sqm with 52,5 pieces 29 x 0,40 cm, 61,7% coverage of bricks, needed 6,5 sesquipedalis. Right: 1 sqm with 68 pieces 22,2 x 0,40 cm, 59,6,3% coverage of bricks, needed 4,5 sesquipedalis.

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