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Research article

Estimating the Ratios of Masonry Wall and Wall Finishing Work to the Building Area, Considering Only the Area within the Building's Boundaries: A Case Study of a Two-story Reinforced Concrete House

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Abstract: This research aims to study the ratios of the quantity of masonry wall and wall finishing per unit of a major factor that can be easily calculated: the building area, considering only the area that falls within the building's boundaries. A two-story reinforced concrete residential house is used as a case study. Building area calculation and detailed quantity takeoff of masonry wall and wall finishing are implemented for the house designs of 56 samples. Pearson's correlation coefficient determines the relationship between the major factor and the quantity of work studied to identify a major factor's practicality. The ratios of the quantities of work studied to the major factor are examined using mean statistics and the distribution range according to the Empirical Rule with a 95% coverage probability. The results indicate that the size of the floor area within the building's boundaries is suitable as a major factor for a rough estimation of masonry wall and wall finishing, as it shows a very high correlation with the quantities of work studied. When testing the results against three house designs, it was found that the ratios calculated from the detailed takeoffs of the three houses fell within the range of the study's results and that the differences from the average study results were within the acceptable accuracy range of the rough estimation method, which could vary by 20-30%.

Keywords: Ratio; Rough estimation; Masonry wall; Wall finishing work

1. Introduction

Masonry walls are widely used in construction due to their strength, durability, and aesthetic appeal. Additionally, they bond well with the structural systems of buildings, often made of reinforced concrete, as cement is a key component in both [1]. Calculating the quantity of masonry walls is the most critical task in the architectural category, as it serves as a reference for estimating the quantity of wall finishing work, which includes plastering and painting, as well as various wall cladding materials such as wall tiles [2].

Estimating the quantity of masonry walls in a building project is a complex and time-consuming process [3]. At the same time, quantifying the finishing work on walls is equally challenging. To conduct a detailed quantity takeoff for both types of work, information from various construction drawings is required, including floor plans, elevations, sections, and details for doors, windows, as well as bathrooms and stairs, which are necessary because there may be bathroom or storage walls located underneath the stairs. Consequently,

there is a significant chance of errors, whether from inaccurate measurements or counts, incorrect calculation formulas, or simply forgetting items. One common approach to verify the accuracy or identify discrepancies in detailed quantity takeoffs is to compare the calculations with rough estimates [4].

Rough or preliminary estimation is used when speed is essential, but high accuracy is not yet required. It is based on the idea that various constructions have a single major factor that determines the price, and this variable is directly proportional to the construction cost. This estimation method yields approximately accurate results within a range of 20-30% [4]. Examples of the aforementioned key factors include building area or volume and usage quantity, such as the number of hotel rooms and the number of hospital beds. This approach serves for direct price estimation and is applied to roughly estimate the quantities of various significant tasks in construction work.

The rough estimation of work quantities using a single major factor has been widely used for a long time in the structural category, particularly in reinforced concrete structures. Reference ratio figures are from various sources, including textbooks and research studies [5-8]. In the architectural category, there are only masonry wall works, often presented as linear regression equations with the building area as the major factor [3, 9-10]. However, no information could be found in any sources, including books, manuals, or research studies for wall finishing work.

Wall finishing work involves plastering, painting, or applying decorative materials on the surface of masonry walls [4]. Generally, the total area of wall finishing work is equal to twice the area of the masonry wall [2], depending on whether both sides of the wall are finished. Nevertheless, this relationship is sufficient to demonstrate that the total quantity of wall finishing is related to the area of the masonry. Therefore, if the building area can be defined as a major factor for estimating the masonry area, it is reasonable to estimate the total wall finishing work area.

The Valuers Association of Thailand [11] has provided guidelines for calculating the area of a building, stating that only the area within the structural boundaries of the building should be considered. Roof areas are not included. Areas that extend from the building, such as washing areas, balconies, and parking spaces, will only be included if they are under the roof of the building or have a structure that is integral to the building's structure. Examples of areas that should be included are washing areas or parking spaces under the building's roof and upper-level balconies structurally connected to the building. Some areas that should not be included are external washing areas and parking lots that are not under the building's roof. However, the area calculation based on this concept aims to use the obtained area size to estimate the preliminary construction costs. Therefore, it includes the overhanging areas of the building that are not within the boundary of the wall construction work, such as upper balconies, which may not be necessary for a rough estimate of the masonry wall and wall finishing quantities. This has led the researcher to wonder whether removing the overhanging areas and using only the area within the building's boundaries would be reasonable as a major factor for a rough estimate of the masonry wall and wall finishing work quantities. If this can be done, it would make the work process easier and more efficient.

According to the above argumentations, this study examines the ratios of masonry wall and wall finishing to a unit of the major factor, which can be easily calculated, i.e., building area, considering only the area within the building's boundaries. This refers to the area of the building that lies within the confines of its structure or the building itself. The overhanging area is included only when there are surrounding walls. The study focuses specifically on the case of two-story reinforced concrete residential houses and has the following specific objectives:

1) To study the relationship between the significant factor, i.e., building area, considering only the area within the building's boundaries, and the quantity of masonry wall and wall finishing, to identify the practicality of using it as a significant factor for rough quantity estimation of masonry wall and wall finishing.

2) To study the average and range of distribution of the ratios of masonry wall and wall finishing to the building area, considering only the area within the building's boundaries.

2. Materials and Methods

The study method consists of three main steps: (1) sample selection, (2) quantity measurement, and (3) data analysis.

2.1 Sample Selection

The two-story house designs studied consist of 56 samples, selected using purposive sampling from the free house designs, the Ban Yim, for the public project, phase 3, by the Bangkok Metropolitan Administration. This number is sufficient as it aligns with the Central Limit Theorem, which states that if there are more than 30 samples, the sample group will exhibit a normal distribution [12]. In addition, it is a number greater than 28 samples, which is the minimum required sample size for testing the significance of the correlation between two variables, with a large expected effect size (r=0.5), a significance level (α) of 0.05, and a power of the test equal to 0.8 [13]. The criteria for selecting samples of two-story houses are as follows:

1) It must be a two-story residential house with complete architectural and structural engineering work details.

2) All house walls, exterior and interior, must be made of one type of masonry material, such as brick, lightweight block, concrete block, etc.

3) All masonry panels must have the characteristics of standard masonry panels, meaning they should be laid in a straight line without any curved lines, and the panels must be positioned vertically without tilting.

2.2 Quantity Measurement

2.2.1 Building area

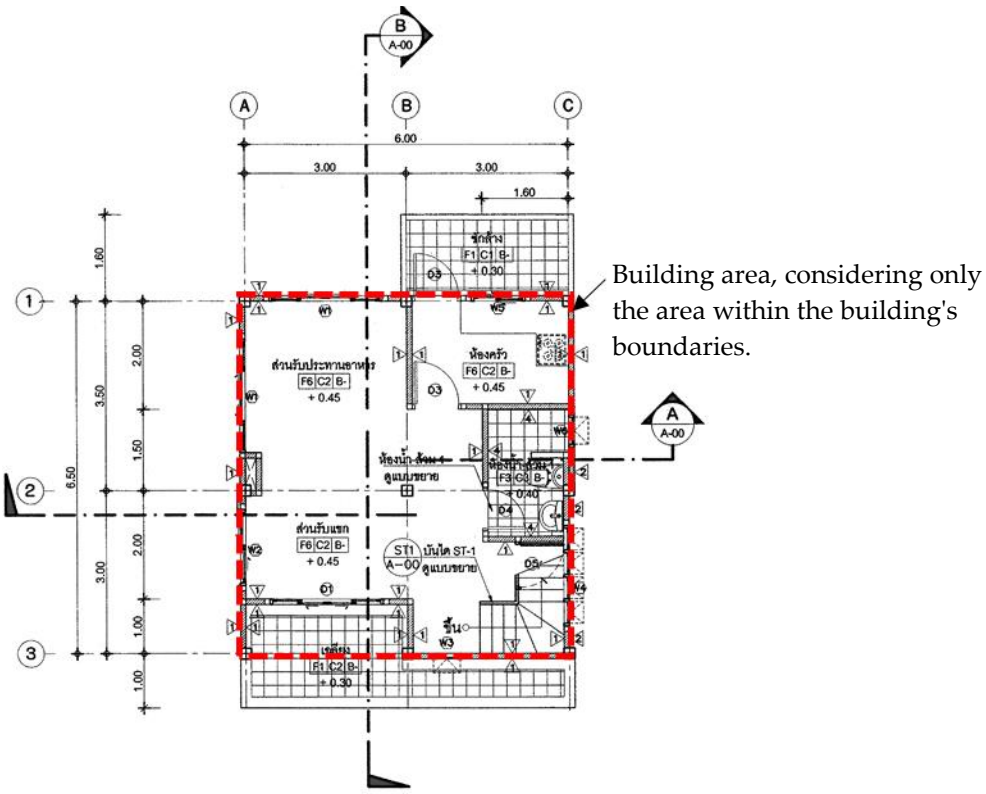

Figure 1. Guidelines for measuring the area of a building, considering only the area within the building's boundaries.

Considering only the area that falls within the building's boundaries, the building area is proposed to be a significant factor for rough quantity estimation of masonry wall and wall finishing. This refers to the area of the building that lies within the confines of its structure or the building itself. The overhanging area is included only when there are surrounding walls. The size of the area is calculated in square meters, and the measurements of the various sides will be taken from the outer edge to the outer edge of the columns or beams, as shown in Figure 1; it is adapted from the free house design, ID33, of the Ban Yim for the public project, phase 3, by the Bangkok Metropolitan Administration [14].

2.2.2 Quantity of masonry wall

The quantity of masonry walls will be calculated from the square-meter net wall area. This can be determined by summing the whole area of each wall panel and subtracting the total area of all openings or door and window frames without deducting the area of columns and lintels. Smaller than 0.1 square meter openings won't be considered [15] since it has a minimal effect on the overall quantity of masonry wall. The length of the wall panels will be measured without deducting the size of the columns, as this is more convenient and yields a calculation result that does not differ significantly from deducting the size of the columns [2] (p. 56), especially for buildings with columns not exceeding 0.25 meters in size [16]. For the height of the walls, consider the underside of the beams or floors as applicable [16]. As for measuring the size of openings or doors and windows, consider the outer edges of the frames [2] (pp. 63-64).

In buildings, the masonry wall can be either single-layer or double-layer. Therefore, the quantity takeoff must be calculated separately for each part. However, to simplify the overall study, the quantity of double-layer masonry walls is converted into single-layer masonry walls by multiplying by two [17]. Next, merge it with the quantity of single-layer masonry wall, known as equivalent single-layer masonry wall. Therefore, the quantity of masonry wall work in this study is divided into three parts: 1) single-layer masonry wall, 2) double-layer masonry wall, and 3) equivalent single-layer masonry wall. The details of the calculation formula are as shown in equations (1) – (3).

$$\text{SB} = \text{Total area of single-layer masonry wall panel} - \text{Total area of openings on single-layer masonry} \quad (1)$$

$$\text{DB} = \text{Total area of double-layer masonry wall panel} - \text{Total area of openings on double-layer masonry} \quad (2)$$

$$\text{eqSB} = \text{SB} + 2 \cdot \text{DB} \quad (3)$$

When: SB = The quantity of single-layer masonry wall, m^2
DB = The quantity of double-layer brick wall work, m^2
eqSB = The quantity of equivalent single-layer masonry wall, m^2

2.2.3 Quantity of wall finishing work

The quantity of wall finishing will be calculated in square meters. The types of finishing can be divided into two categories: 1) finishing with cement or plaster to prepare for painting or coating, and 2) finishing with wall cladding materials, such as tiles [2]. The finishing area not only includes the surface of the wall panels but also extends to the surfaces of the structure and other materials that need to be finished with the same type of material to create a continuous surface. Calculating the quantity of wall finishing is divided into two parts: 1) external wall finishing and 2) internal wall finishing, for convenience in using the information for verification and reference when calculating the area of wall surface finishing according to various sub-items [2].

The total quantity of external wall finishing is estimated from the sum of the surface area of the outer side of the exterior walls and the outer surface of the reinforced concrete structure. Since the length of the walls has already included the size of the columns, the surface of the reinforced concrete structure is only calculated for the beam sections. The total quantity of internal wall finishing is estimated from the sum of the inner surface area of the exterior walls and both sides of the interior walls. The details of the calculation formula are as shown in equations (4) – (5)

$$\text{FNex} = \text{Outer surface area of exterior masonry wall} + \text{Outer surface area of reinforced concrete beam} \quad (4)$$

$$\text{FNin} = \text{Inter-surface area of exterior masonry wall} + \text{Surface area of both sides of inner masonry wall} \quad (5)$$

When: FNex = The quantity of exterior wall finishing work, m^2
FNin = The quantity of interior wall finishing work, m^2

2.3 Data Analysis

Data analysis is divided into four main parts, namely:

1) The analysis of general characteristics of data using descriptive statistics includes frequency (N), percentage (%), mean ($\overline{X}$), and standard deviation (SD).

2) The relationship between the significant factor, i.e., building area, considering only the area within the building's boundaries, and the quantity of masonry wall and wall finishing, is analyzed using Pearson's Correlation Coefficient. Among the relationships examined are:

2.1) The relationship between the major factor and equivalent single-layer masonry wall quantity.

2.2) The relationship between the major factor and exterior wall finishing work quantity.

2.3) The relationship between the major factor and the interior wall finishing work quantity.

In this regard, the consideration of the correlation coefficient (r) for interpreting the level of correlation uses the following criteria [18]:

r equals 0 means no correlation.

r is between 0.01 – 0.09, which means it is deficient.

r is between 0.10 – 0.29, which means it is low.

r is between 0.30 – 0.49, which means moderate.

r is between 0.50 – 0.69, which means it is high.

r is between 0.70 – 0.89, which means it is very high.

r is between 0.90 – 1.00, which means it is almost perfect.

3) The analysis to find the mean and the distribution range of the ratios of the quantities of work studied to the significant factor consists of 1) calculating the mean ($\overline{X}$) and the standard deviation (SD), and 2) determining the range of distribution of the ratios according to the Empirical Rule with a 95% coverage probability, which states that if the data is usually distributed, approximately 95% of the data will be in the range of $\overline{X} \pm 2SD$ [19]. Among the ratios studied include:

3.1) The ratio of equivalent single-layer masonry wall quantity to the building area, considering only the area within the building's boundaries.

3.2) The ratio of the quantity of exterior wall finishing work to the building area, considering only the area within the building's boundaries.

3.3) The ratio of the quantity of interior wall finishing work to the building, considering only the area within the building's boundaries.

4) Testing the mean and range of the ratios obtained from the study by comparing them with those calculated from 3 other two-story houses that are not part of the sample group.

3. Results and Discussion

The results of this research study are divided into four main topics: 1) general characteristics of the data, 2) the relationship between the main factor and the quantities of work studied, 3) the mean and range of the distribution of the ratios of the quantities of work studied to the major factor, and 4) testing of the mean and range of the distribution of the ratios obtained from the study.

3.1 General Characteristics of the Data

The preliminary data analysis of the selected two-story house designs, totaling 56 samples (details as shown in Table 1), reveals that:

1) The area of the building, considering only the part within the building's boundaries, ranges from 62.32 to 317.04 square meters; the mean ($\overline{X}$) is equal to 162.39 square square meters (SD = 44.50).

2) The quantity of single-layer masonry walls has an area ranging from 101.74 to 416.54 square meters; the mean ($\overline{X}$) is equal to 234.23 square square meters (SD = 60.81).

3) The quantity of double-layer masonry wall has an area ranging from 0.00 to 243.78 square meters; the mean ($\bar{X}$) is equal to 53.54 square square meters (SD = 55.90).

4) The quantity of masonry wall, when converted to equivalent single-layer masonry walls, has an area ranging from 200.58 to 700.82 square meters; the mean ($\bar{X}$) is equal to 341.31 square square meters (SD = 106.24).

5) The quantity of work for exterior wall finishing has an area ranging from 153.08 to 352.58 square meters; the mean ($\bar{X}$) is equal to 239.62 square square meters (SD = 49.82).

6) The quantity of work for interior wall finishing ranges from 187.11 to 627.37 square meters. the mean ($\bar{X}$) is equal to 352.09 square square meters (SD = 89.61).

Table 1. The building area and the quantities of work studied for 56 sample house designs.

Descriptions	Min. (m^2)	Max. (m^2)	$\bar{X}$ (m^2)	SD (m^2)
Building area, only the area within the building's boundaries (Abb), m^2	62.32	317.04	162.39	44.50
The quantity of single-layer masonry wall (SB), m^2	101.74	416.54	234.23	60.81
The quantity of double-layer masonry wall (DB), m^2	0.00	243.78	53.54	55.90
The quantity of equivalent single-layer masonry wall (eqSB), m^2	200.58	700.82	341.31	106.24
The quantity of exterior wall finishing work (FNex), m^2	153.08	352.58	239.62	49.82
The quantity of interior wall finishing work (FNin), m^2	187.11	627.37	352.09	89.61

3.2 Relationship between the Main factor and the Quantities of Work Studied

The analysis of the relationship between the major factor, which is the area of the building specific to the boundaries of the structure, and the quantities of work studied (details as shown in Table 2) reveals that the major factor has a very high positive correlation with all three quantities of work studied, with statistical significance at the 0.01 level. The quantity of interior wall finishing work has the highest correlation coefficient with the major factor (r = 0.840), followed by the quantity of equivalent single-layer masonry wall and the quantity of exterior wall finishing work, respectively (r = 0.773 and r = 0.725). Therefore, it is practical to use the area of the building specific to the boundaries of the structure as the major factor for a rough estimation of the quantity of equivalent single-layer masonry wall, exterior wall finishing work, and interior wall finishing work.

Table 2. Relationship between the main factor and the quantities of work studied.

Pairs of Relationships	r	Correlation Interpretation
Building area, only the area within the building's boundaries (Abb) and The quantity of equivalent single-layer masonry wall (eqSB)	0.773**	Very high positive
Building area, only the area within the building's boundaries (Abb) and The quantity of exterior wall finishing work (FNex)	0.725**	Very high positive
Building area, only the area within the building's boundaries (Abb) and The quantity of interior wall finishing work (FNin)	0.840**	Very high positive

** Correlation is a significant level at the 0.01 (2-tailed).

3.3 Mean and Range of the Distribution of the Ratios of the Quantities of Work Studied to the Major Factor

The analysis of the ratios of the quantities of work studied to the major factor, which is the size of the building area, specifically within the boundaries of the building (details as shown in Table 3), reveals that:

1) The ratio of the quantity of equivalent single-layer masonry wall to the building area, considering only the area within the building's boundaries (eqSB/Abb), has a mean ($\bar{X}$) of 2.07 (SD = 0.43) and a distribution range that covers 95% of the data according to empirical rules, between 1.21 and 2.93.

2) The ratio of the quantity of exterior wall finishing work to the building area, considering only the area within the building's boundaries (FNex/Abb), has a mean ($\bar{X}$) of 1.49 (SD = 0.27), and the range of distribution covers 95% of the data, according to empirical rules, is between 0.95 and 2.03.

3) The ratio of the quantity of interior wall finishing work/area of the building area, considering only the area within the building's boundaries (FNin/Abb), has a mean ($\bar{X}$) of 2.14 (SD = 0.36) and a distribution range that covers 95% of the data according to empirical rules, which is 1.42 – 2.86.

Table 3. Mean and range of the distribution of the ratios of the quantities of work studied to the major factor.

Ratios	N	$\bar{X}$ (m²)	SD (m²)	Distribution range with a 95% coverage probability	
				$\bar{X}$ - 2SD (m²)	$\bar{X}$ + 2SD (m²)
The quantity of equivalent single-layer masonry wall (eqSB)/ Building area, only the area within the building's boundaries (Abb)	56	2.07	0.43	1.21	2.93
The quantity of exterior wall finishing work (FNex)/ Building area, only the area within the building's boundaries (Abb)	56	1.49	0.27	0.95	2.03
The quantity of interior wall finishing work (FNin)/ Building area, only the area within the building's boundaries (Abb)	56	2.14	0.36	1.42	2.86

3.4 Testing of the Mean and Range of the Distribution of the Ratios Obtained from the Study

Three additional two-story reinforced concrete residential houses that are not part of the sample group are selected to test the results obtained from the study. The area of the building is measured precisely for the parts within the building's boundaries, and a detailed quantity takeoff is conducted for the masonry and wall finishing work. The details of the quantity takeoff are shown in Table 4. Subsequently, essential ratios were calculated: 1) the quantity of single-layer masonry work per the area of the building within the building's boundaries, 2) the quantity of exterior wall finishing work per the area of the building within the building's boundaries, and 3) the quantity of interior wall finishing work per the area of the building within the building's boundaries. These calculated values are then compared with the mean and range of ratios obtained from the study results. Overall, the comparison reveals that the ratios calculated from the three houses fell within the range of the study results, with the most significant difference from the average study result being 27.52%, which is within the acceptable margin of error for rough estimation methods that may vary by 20-30% [4]. The details of the comparison are in Table 5.

Table 4. The building area and the quantities of work were studied for three additional house designs.

House no.	Building area, only the area within the building's boundaries (Abb), m²	The quantity of single-layer masonry wall (SB), m²	The quantity of double-layer masonry wall (DB), m²	The quantity of equivalent single-layer masonry wall (eqSB), m²	The quantity of exterior wall finishing work (FNex), m²	The quantity of interior wall finishing work (FNin), m²
1	128.32	279.76	18.31	316.38	243.95	333.42
2	169.70	278.73	26.41	331.54	236.72	379.81
3	220.96	277.49	54.34	386.18	245.69	426.58

Table 5. Comparing the ratios of the selected houses with the mean and range of the ratios from the study.

House no.	eqSB/Abb			FNex/Abb			FNin/Abb		
	Ratio of selected house	**Diff. from Derived Mean $\bar{X}$ = 2.07**	**Compare with Derived Range [1.21, 2.93]**	**Ratio of selected house**	**Diff. from Derived Mean $\bar{X}$ = 1.49**	**Compare with Derived Range [0.95, 2.03]**	**Ratio of selected house**	**Diff. from Derived Mean $\bar{X}$ = 2.14**	**Compare with Derived Range [1.42, 2.86]**
1	2.47	19.32%	within the range	1.90	27.52%	within the range	2.60	21.50%	within the range
2	1.95	– 5.80%	within the range	1.39	– 6.71%	within the range	2.24	4.67%	within the range
3	1.75	– 15.46%	within the range	1.11	– 25.50%	within the range	1.93	– 9.81%	within the range

4. Conclusions

The detailed quantity of masonry wall and wall finishing work is complex and challenging, with a significant chance of errors. This research study investigates the ratios, both in average and distribution range, of the quantities of masonry and wall finishing work per unit of a major factor that can be easily calculated, i.e., the building area, considering only the area that falls within the building's boundaries. This is intended for use in rough estimates of the quantities of masonry and wall finishing work in the case of a two-story concrete residential house. Estimators or stakeholders can utilize the ratio values from this study to compare or verify any discrepancies in the detailed quantity takeoff of building projects comparable to the sample under study. However, this study's methodology applies to other construction projects. The findings of the study can be summarized as follows:

1) The area of the building, considering only the area within the building's boundaries, is suitable to be a primary variable for a rough estimate of the quantity of single-layer brickwork, external wall finishes, and internal wall finishes, as it has a very high correlation with all three tasks (with r values ranging from 0.7 to 0.89).

2) The ratio of the quantity of equivalent single-layer brick walls to the area of the building, considering only the area within the building's boundaries, has an average value of 2.07, with a distribution range that covers 95% of the data between 1.21 and 2.93.

3) The ratio of the quantity of work for exterior wall finishing to the area of the building, considering only the area within the building's boundaries, has an average value of 1.49, with a distribution range that covers 95% of the data between 0.95 and 2.03.

4) The ratio of the quantity of interior wall finishing work to the area of the building, considering only the area within the building's boundaries, has an average value of 2.14, with a distribution range that covers 95% of the data between 1.42 and 2.86.

5) The testing of the average and range of the ratios obtained from the study, compared to the ratios calculated from the detailed measurements of three two-story houses, found that the ratios from all three houses fell within the range of the study results and differed from the average study result by no more than 30%, which is within the accuracy limits of the preliminary estimation method.

However, when considering the usage of double-layer masonry walls in the sample house designs, it is found that the minimum value is 0 square meters. There is no usage, while the maximum value is 243.78 square meters. This shows that the sample house designs utilize double-layer masonry walls in varying quantities, which may affect the ratio of equivalent single-layer masonry work relative to the building area. Therefore, in future studies, guidelines should address this issue, such as standardizing the sample house designs to have similar proportions of double-layer masonry work.

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