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Labor Productivity Improvement Obtained by Masonry Walls Project Design Implementation

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Abstract: This paper aims to quantify the labor productivity improvement reached by the implementation of a masonry wall project design to guide field construction. A masonry wall project design is an instrument of rationalization, developed to specify the layout and steps of a masonry walls execution. The methodology is of quantitative nature and involves a practical case. The work of an enterprise in Goiânia (Brazil) was tracked by the collection of productivity data, firstly of a crew that didn't have access to a masonry wall project design, and then of a crew that had access to the project. The evaluation of the productivity improvement was processed by means of statistical analysis, such as location and dispersion measures, average and variance, T-test, and F-value. Hypothesis tests were also performed to prove that the changes in productivity were caused by the implementation of the masonry project. The results showed that the project deployment optimized the production process in the field. There was a 26% increase in the team average productivity with access to the project design according to the hypothesis tests. The main contribution of this work is to present the beneficial impact of a masonry wall project design tailored for field construction, which allows a formal and rational approach to a heavily artisanal technique.

Keywords: Labor productivity, masonry, project design, statistical analysis.

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1. Introduction

In order to achieve greater efficiency and competitiveness, many companies began to invest in constructive rationalization processes. These new management actions can lead to changes in all phases of production (planning, design, execution, control, supplies, market, human resources, and technical assistance), implying the accomplishment of technical, administrative and financial activities, which need to be effectively coordinated to provide the expected result in terms of time, quality and cost demands (Hwang and Yeo, 2011).

In this manner, the old masonry execution processes, characterized by low productivity and unsatisfactory geometric uniformization has provided an opportunity for the rise of new production protocols. Zhang et al. (2018) affirm that the efficiency and quality of masonry structures could be improved, despite the evolution of regulations and requirements of the construction process.

One such changes are the use of masonry project designs, which considers aspects such as modulation of the blocks, interference with construction systems, such as plumbing and electrical, opening sizes, etc. (Parsekian et al. 2018). These decisions are now made in the project planning phase, ensuring a proper fit between the blocks and uniform mortar joints, which means increasing the integrity and stability of the masonry walls, as well as decreasing material waste, streamlining of production, higher quality, amongst other advantages (Parsekian et al. 2018, Zhang et al. 2018).

Projects for the execution of masonry walls provide rationalization of the construction, providing benefits such as reductions in cost, schedule, rework, workflow cycle time, and errors in contract documents (Love et al., 2013).

This paper seeks to show the importance of masonry projects that rationalize the building process of masonry walls, by portraying the types of blocks and shapes in their respective layers, the interaction with other systems, changes in direction and insertions of doors and windows, amongst other guidelines that help workers to improve the process. Usually, such project guidelines for masonry structures are only on focus when the system is structural (load-bearing). However, there are many applications for this technique for non-load bearing walls that should also get enough attention since its process is intricate and time-consuming when not properly planned ahead.

Therefore, this work aims to present the potential improvement of labor productivity values by providing a masonry wall layout project to the responsible crew, to guide field construction. With the use of statistical treatments (normality tests, hypothesis tests, T-test, Ficher test, and P-value) the productivity improvements obtained by the implementation of the layout project were tested and confirmed. Masonry modular solutions were not part of this scope, despite also being considered a form of rationalization. Productivity influence factors also were not part of the intended discussion. The intention of this case study was to prove how the simple presentation of the layout project to the responsible crew can improve productivity.

The goals are: (1) to collect labor productivity data from the crews responsible for constructing the masonry walls, with and without contact with the masonry wall project design; and finally, (2) to analyze this intervention of the masonry process by statistical means.

2. Literature Review

2.1. Labor Productivity

Productivity can be defined as the efficiency in transforming inputs into outputs that comply with the objectives set for a process (Thomas and Yiakoumis, 1987; Souza, 2006) being one of the main concerns of the construction industry. So, it is important that contractors and construction managers are familiarized with the main methods for assessing the productivity of equipment and workers (Shehata and El-Gohary, 2011).

Popular methods amongst the ones discussed in the literature include work sampling, which proposes to look at a composition of a workday, divided in productive time, in which the workers are actually performing the activity, and non-productive time, when the workers are waiting for instructions, having breaks, handling material and tools, etc. (Hajikazemi et al., 2017). Activity analysis, another method, is an extension of work sampling where continuous improvement is a demand (Gouett et al., 2011).

Yi and Chan (2014) discuss the indicator of hourly outputs to quantify productivity in a micro-perspective. According to them, the indicator is widely used at the level of world literature (Thomas and Yiakoumis, 1987; Sanders and Thomas, 1991; Hanna et al., 2008). In Brazil, this indicator is the most commonly used, going by the name Unitary Ratio of Production (RUP), which relates to the total amount of hours worked and the quantity of service performed by the teams during the same period, as shown in Eq. (1). Man-hours employed, and work produced are measured and compared to past records or to other firms to obtain measurements of efficiency (Enshassi et al., 2007; Thomas and Napolitan, 1995; El-Mashaleh et al., 2001).

$$\mathrm{RUP} = \frac{\text{Man} - \text{Hours (Mh)}}{\text{Service Quantity } (\mathrm{m}^2)} \tag{1}$$

Higher values indicate poor productivity, while lower values indicate good productivity measures. Therefore, according to Yi and Chan (2014), construction labor productivity (CLP) can be defined as shown in Eq. 2:

$$\mathrm{CLP} = \mathrm{RUP} = \frac{\text{Actual Work Hours}}{\text{Installed Quantity}} \tag{2}$$

RUP_{daily} indicates the factors outcomes in a working day. The cumulative indicator ($RUP_{cumulative}$) presents the accumulated amount of man-hours spent since the beginning of the process and the quantity produced in the same period, indicating the service performance, as shown in Eq. (3). The potential indicator ($RUP_{potential}$) is calculated by the median of values of RUP_{daily} that are lower than the $RUP_{cumulative}$ value, as shown in Eq. (4). This is defined as a daily RUP value that has translated well and is achievable based on the RUP values collected (Souza, 2005; Martins, 2013). Since the potential value reflects the best productivity of the period, it works as a first goal to have in mind when concerning productivity improvement. The productivity improvement is demonstrated by reducing the RUP rates (Yi and Chan, 2014).

$$\mathrm{RUP_{cum}} = \frac{\sum_{i=1}^{n} \text{Man} - \text{Hours (Mh)}}{\sum_{i=1}^{n} \text{Service Quantity } (\mathrm{m}^2)} \tag{3}$$

$$\mathrm{RUP_{pot}} = \frac{\sum \mathrm{RUP_{daily}}}{n(\mathrm{RUP_{daily}})} \left| \mathrm{RUP_{daily}} \leq \mathrm{RUP_{cum}} \right| \tag{4}$$

2.2. Masonry Walls Project Design as an Attempt to Improve Productivity

Masonry activities are usually studied with the aim of improving labor productivity since it is labor-intensive construction activity (Florez, 2017). As an example, Enshassi et al. (2007) measured the labor productivity for masonry works from nine construction projects in the Gaza Strip to acquire baseline productivity and apply a benchmarking method.

According to Sanders and Thomas (1991), understanding the factors that affect the masonry labor productivity would assist designers to create more efficient structures and enabling better estimations to manage masonry projects. After such an assessment, Naoum (2016) pointed out that design improvements show high potential for productivity improvement. Project complexity should be followed by a concern with design rationalization.

Zaki et al. (2017) commented that planning the modular layout of the blocks seeks the maximum use of them in order to reduce cutting wastes and minimize the impacts on productivity. Furthermore, the authors established that the planned design of the masonry allows better performance in the inter-location of the blocks.

In order to begin a masonry project design, the architecture, structure, and installations projects are analyzed and made compatible. Sanders and Thomas (1991) indicate that in a masonry project design the specific construction requirements and the construction methods used by the contractor to complete the work should be considered.

The masonry project must present a specification of all the necessary building materials, a description of the construction (how to rent the walls, how to perform the corners), and all the necessary graphic elements. Lordsleem Jr. (2000) highlight that most projects scopes include:

a) masonry components specification: type of blocks and mortar composition and dosage;

b) project plant marking the first line of blocks, incorporated to architectural, structural, installations and other projects, associated with horizontal disposal of blocks;

c) wall elevations, showing interferences with other systems components, like frames or switchboards;

d) complementary technical specifications of materials and other components, production method and application, structure preparation, fixation method, link components, pre-fabrication, execution sequence and connection to the structure of the building.

Given the potential increase of productivity rates and other improvements, by the use of masonry project designs in field construction, and the importance of assessing labor productivity in labor-intensive activities, this work analyzed the impact in the labor productivity of a construction site in Brazil after making available to the crew a masonry walls project design to guide field construction.

3. Methodology

This paper investigated a change of masonry-labor productivity in an enterprise after the implementation of a masonry-labor project. It also evaluated the impacts of the implementation of the project on construction sites and the difficulties encountered in its development. The main steps of the methodology used can be seen in Figure 1.

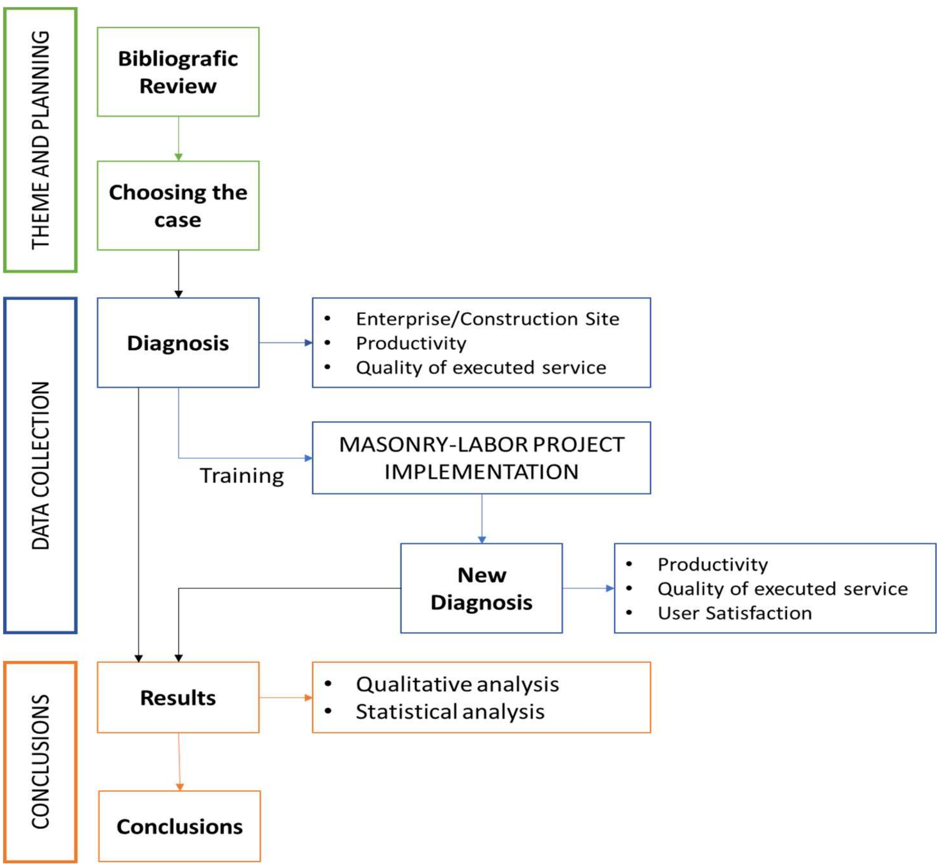


Fig. 1. Research method (source: the authors)

The company here portrayed was chosen because it already showed interest in using masonry layout projects, providing a layout project for the construction case, as shown in Figure 2, but did not use it in its full, lacking the implantation of the modulation solutions of the ceramic blocks. The modulation guarantees the rationalization of the construction and allows the achievement of high productivity, besides reducing the waste with adjustments. The interest of the company in adopting such a tool was ideal, as it expected to facilitate the acceptance of the research protocols in the field.

The project consisted of three residential buildings, with a total constructed area of 37,757.21 m², distributed in three towers. Only tower 3 was analyzed in this study, for this was the only tower going through the masonry phase of execution. Each tower has 24 standard floors, as well as a mezzanine, ground floor, basement, and roof. In order to collect the productivity data, a scorecard was elaborated as can be seen in Figure 3. This scorecard included the date, measurement time, employee identification, level number, and masonry place identification (internal or external). For this study, the information regarding the consumption of blocks will not be studied.

For the calculation of productivity, three types of data were required: labor expressed in Man-hours; the quantity of masonry (m²); and information regarding extraordinary daily occurrences. The quantity of service was obtained from the architectural plant, considering only the effective area, thus discounting all areas not filled by mortar or block and also not considering openings on walls.

Productivity was measured on a daily, cumulative, and potential basis. The data was collected through observation and recording of 57 consecutive days, being 27 days before the project implementation and 30 consecutive days after. The RUP of four teams was followed during the study, each team composed of one mason and one auxiliary. The observed teams remained the same throughout the observation period, and climate changes were not significant as to interfere with the activity since they were performed under covered spaces.

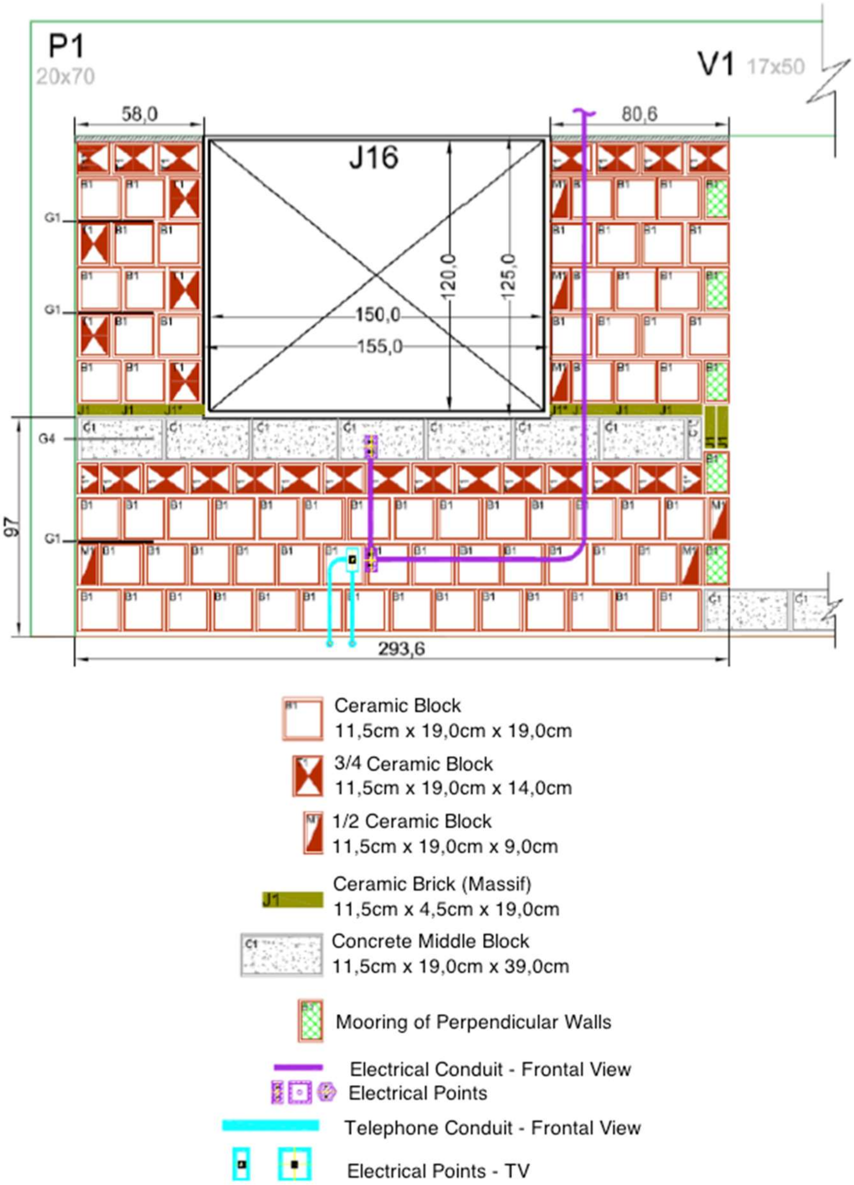


Fig. 2. Masonry-labor project of studied floors (source: the authors)

PRODUCTION AND CONSUPTION SCORECARD				
Construction site identification				
Block:		Floor:	Supervisor:	
Observation date and time				
Date: _____/_____/_____			Observation time:	
Production register				
Elevation ID	Elevation depth	Worker name	Internal masonry	External Masonry
Block consumption				
Type	*Standard consumption*		*Real consumption*	
Ceramic Block	Whole		Whole	
	¾		¾	
	½		½	
Ceramic Brick	Massif		Massif	
Middle Concrete	11,5x19x39		11,5x19x39	
Observations:				

Fig. 3. Scorecard for registering productivity in loco (source: the authors)

The statistical analysis proceeded with the intention to prove that the masonry-labor project interferes in the schedule, specifically reducing the execution period, as well as improving the quality of the executed service. According to Werkema (1996), in order to make a statistical inference, hypothesis tests should be performed. To achieve this objective, data were quantitatively treated by statistical tests using the IBM SPSS 24 statistical software. To evaluate the hypothesis studied, the following procedures were established:

- In order to obtain information on the corresponding populations, the population parameters were obtained, more specifically mean, median, confidence intervals and coefficient of variation, amongst others (Werkema, 1996);

- Verify that the sample values are within the specified limits, considering its confidence intervals and asymmetry compared to its histograms (Uddin et al., 2011);

- To evaluate whether the dataset complies with the principles of a normal distribution, which is essential to decide which hypothesis test to choose, the Kolmogorov-Smirnov and Shapiro-Wilk tests were performed;

- The productivity performance was analyzed by two tests (t-test and F-test) under a normal distribution (Arambula and Gharaibeh, 2014). The F-test is used to compare if daily productivity changes between the two samples and the t-test are used to compare whether the mean of the post-project-phase data is adjusted in relation to the data from the predecessor phase.

- For analysis of data variability and the RUP calculation parameters (service quantity and man-hour) influence, the Response Surface Methodology (RSM) was used, creating response surfaces with Statsoft® software for before and after the project implementation.

For all the statistical analyzes of this work, the confidence level used was 95%. The goal is therefore to demonstrate a relationship between productivity and project implementation.

4. Analysis and Results

In order to analyze the collected data, a comparison of RUPs calculated using data from before and after the implementation of the masonry-labor project was made, allowing it to trace a history of work in the construction site.

4.1. Productivity analysis

The variables analyzed in the tests are considered quantitative (assuming numerical values) and continuous (obtained by means of measurements and not counts). Values for daily, cumulative, and potential RUP values corresponding to the 27 days of data collection related to the stage prior to the project implementation, and the data corresponding to the 30 days period after the project implementation are both presented in Table 1.

Figure 4 is a graphical representation of the data collected. It indicates the high variability of daily RUP under the two conditions of research, which is in accordance with the model of factors presented by Thomas and Yakoumis (1987). This comparison led to the initial conclusion that there is an overall decrease in daily RUP values after the implementation of the masonry-labor project, which means there is an increase in productivity associated with this condition.

The values obtained for the central tendency and dispersion measurements are shown in Table 2. The asymmetry coefficient, for instance, is used to indicate how much the frequency distribution moves away from the symmetry. Asymmetry values equal to zero indicate that the distribution is symmetric; if it is positive, the distribution is asymmetric on the right and if it is negative, it is asymmetric on the left (Werkema, 1996).

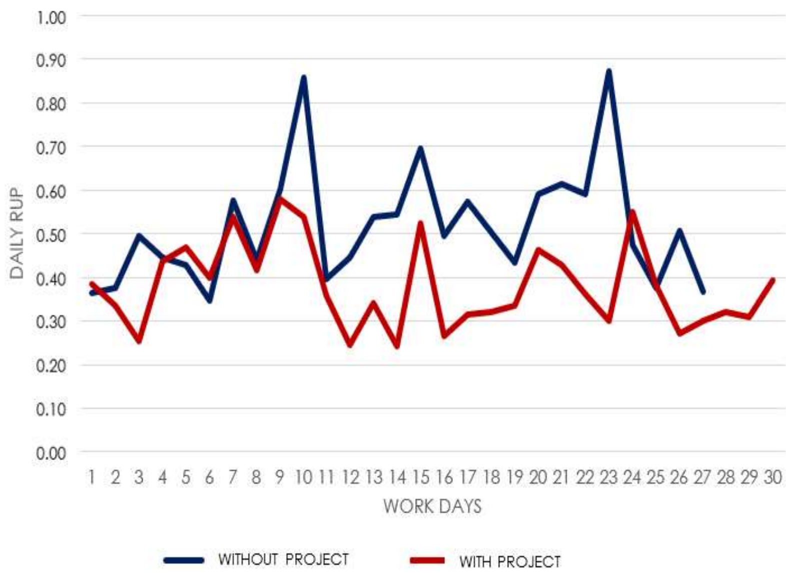


Fig. 4. Variability of RUP comparing conditions without a masonry wall project design and with a masonry wall project design. (source: the authors)

Table 1. Values for daily, cumulative, and potential RUP (source: the authors)

	Without a Masonry Wall Project Design			With a Masonry Wall Project Design		
Day	RUPd (Mh/m²)	RUPcum (Mh/m²)	RUPpot (Mh/m²)	RUPd (Mh/m²)	RUPcum (Mh/m²)	RUPpot (Mh/m²)
1	0.36	0.36		0.38	0.38	
2	0.38	0.37		0.34	0.36	
3	0.49	0.41		0.26	0.32	
4	0.45	0.42		0.44	0.34	
5	0.43	0.42		0.47	0.37	
6	0.35	0.40		0.40	0.40	
7	0.58	0.42		0.54	0.41	
8	0.44	0.43		0.42	0.41	
9	0.60	0.44		0.58	0.43	
10	0.86	0.44		0.54	0.43	
11	0.39	0.44		0.36	0.43	
12	0.44	0.44		0.24	0.39	
13	0.54	0.45		0.34	0.38	
14	0.55	0.45	0.495	0.24	0.36	
15	0.70	0.47		0.52	0.37	0.30
16	0.50	0.47		0.26	0.36	
17	0.57	0.48		0.31	0.35	
18	0.50	0.48		0.32	0.35	
19	0.43	0.48		0.34	0.35	
20	0.59	0.48		0.46	0.36	
21	0.61	0.49		0.43	0.36	
22	0.59	0.49		0.36	0.36	
23	0.87	0.51		0.30	0.36	
24	0.47	0.51		0.55	0.36	
25	0.38	0.50		0.38	0.36	
26	0.51	0.50		0.27	0.35	
27	0.37	0.49		0.30	0.36	
28	-	-	-	0.32	0.36	
29	-	-	-	0.31	0.36	
30	-	-	-	0.39	0.35	

Table 2. Descriptive analysis of data acquired. Source: Authors.

Aspect		Without a Masonry Wall Project Design	Without a Masonry Wall Project Design
Days (N)		27	30
Mean		0.5163	0.3789
Mean standard error		0.0259	0.0178
Median		0.4955	0.3601
Standard deviation		0.1346	0.0972
Variance		0.0180	0.0090
Asymmetry		1.205	0.441
Curtose		1.553	-0.860
Amplitude		0.52	0.34
Minimum		0.35	0.24
Maximum		0.87	0.58
Coefficient of variation		0.2606	0.2566
95% Confidence Interval for Average	Inferior Limit	0.4630	0.3432
	Superior Limit	0.5695	0.4230

For both pre-project sample and post-project sample, the distribution is positive asymmetric (right); with the second condition being closer to zero, thus indicating lower variance. This factor indicates that the post-implantation data present a more reliable average when compared to those obtained in the non-project phase. In the case of the post-project sample, the positive asymmetry is on the right, with a value closer to zero.

Another analysis of these data shows that the upper limit of the confidence interval from the mean to the post-implantation stage (0.423 Mh/m²) is inferior to the lower limit of the condition without the project (0.463 Mh/m²), indicating that there is no intersection, within the confidence interval, among the distributions. This allows the conclusion that the implementation of the project interferes with the productivity of the masonry service, with a high degree of confidence.

The histograms shown in Figure 5 are a result of the obtained data inserted in the SPSS program.

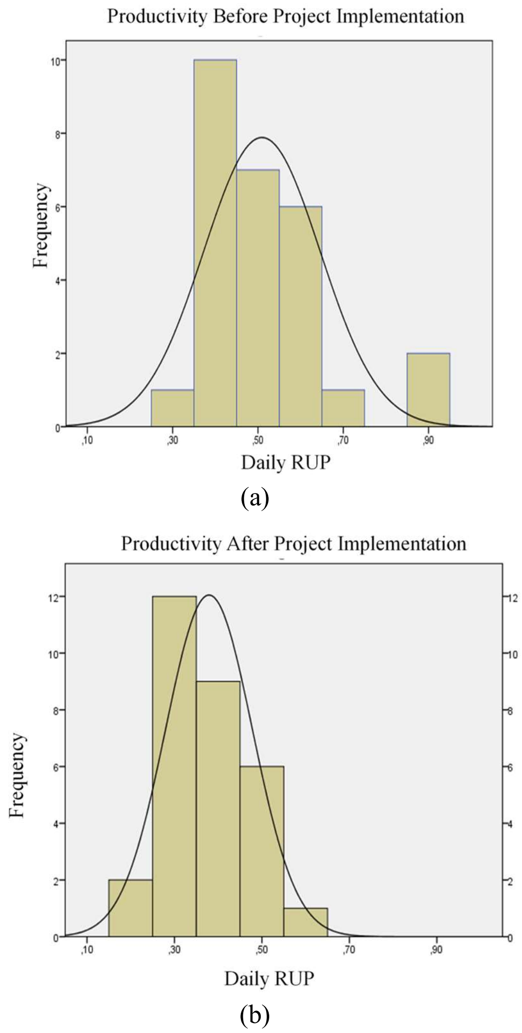


Fig. 5. Histograms of the productivity distribution in condition (a) without a masonry wall project design (b) with a masonry wall project design. (source: the authors)

According to Montgomery and Runger (2009, p. 127), histograms are visual dispositions of the frequency distribution. The histograms obtained and illustrated in Figure 5 are symmetrical and bell-shaped, thus helping conclude that they deal with normal distributions.

In order to decide which hypothesis test is appropriate for a population, it is first necessary to know if the sample truly presents normal distribution or not. The normality tests chosen for this procedure are the Kolmogorov-Smirnov (KS) and Shapiro-Wilk (SW) tests. Using the SPSS 24 statistical package, those normality tests were performed with a confidence level of 95% (significance level (α) of 5%). The significance level, or alpha, is the probability of rejecting the null hypothesis, given it's true, so, it should be kept as minimal as possible. According to Ross (2011), a 95% level is a well stablished number by statisticians after much work to achieve consistent reports.

The normality tests are also designed as a hypothesis test: the null hypothesis H_0 assumes normal distribution for the population under analysis, and the alternative hypothesis H_1 assumes nonnormal distribution. The p-value obtained from the tests, in table 3, is related to the cutoff on the distribution curve and it's the probability, given H_0 is true, of observing a value equal or bigger than what was really observed (Ross, 2011), which means it should be kept at a minimal value of α to comply with the standard settled for the problem. With those parameters in mind, there are two possibilities: (i) if p-value ≤ α, we reject H_0, so it cannot be assumed that the dataset in question has normal distribution; (ii) if p-value > α, we do not reject H_0, that is, the normal distribution is a possible distribution for the data set in question, that is, a low value of significance (Sig or p-value <0,05) indicates that the distribution of data differs significantly from a normal distribution.

Despite the asymmetry of data in the two stages, it can be seen in Tables 3 and 4, in the non-design stage, that the KS test does not reject the normality hypothesis H_0 (sig. = 0.200> 0.05, again for 95% confidence), but for the SW test, the sample without design rejected H_0 (Sig. equals 0.008 <0.05).

Table 3. Results for the Kolmogorov-Smirnov test. Source: Authors.

	Kolmogorov-Smirnov			
	Statistics	df	Sig.	Conclusion
Before Project	0.133	27	0.20*	**Not to reject H_0**
After Project	0.134	30	0.18	**Not to reject H_0**

*This is the inferior limit of true significance
*df – degrees of freedom

Table 4. Results for the Shapiro-Wilk test. Source: Authors.

	Shapiro-Wilk			
	Statistics	df	Sig.	Conclusion
Without a Masonry Wall Project Design	0.889	27	0.008	**Rejects H_0**
With a Masonry Wall Project Design	0.933	30	0.058	**Not to reject H_0**

For the post-project sample, the H_0 of Normality hypothesis is not rejected in both tests, since all cases presented values greater than the significance. Despite the rejection of the null hypothesis for the sample without project by the Shapiro-Wilk test, the histograms and the other results showed previously endorse the assumption of normal distribution. Also, as Montgomery and Runger (2009, p. 79) asserted, with the increase in the number of replicates of an experiment, these distributions tend to become normal. Presenting normal function gives credibility to the calculated RUP data. Next, hypothesis tests were used to evaluate if the verified change in means is related to the implementation of the masonry project.

4.2. Hypothesis tests on productivity parameters

Hypothesis tests are tools used for decision making, since engineering decisions are generally made about a population parameter, such as mean, standard deviation, or proportion. In this case, decision-making is performed based on sample values (Montgomery and Runger, 2009, p. 178). A population is represented, in statistical tests, by its mean or, more specifically, by the variance of its means. The lower the variance of a population, the more precisely limited the data was, and more concise is the data. When a significant interference in a population happens, the variance should reflect it. As the descriptive analysis indicated, there is a variability of the productivity measures with and without a masonry wall project design, which indicates that the population variances are unknown and unequal. To evaluate if the duration of the masonry service was affected by project implementation, the data presented in Table 2, more specifically its means, were used to perform a hypothesis test, adopting the level of significance of $\alpha = 5\%$, in which:

- μ_1 = productivity of masonry service without a masonry wall project design;
- μ_2 = productivity of masonry service with a masonry wall project design

A comparison of the means was carried out, in which the parameter of interest is the reduction of the production ratio (RUP) with the implementation of the masonry project. Therefore, in this study, the null hypothesis H_0 assumed that there was no significant change in the population, reflected by the relative maintenance of the mean ($\mu_1 = \mu_2$), and the alternative hypothesis H_1 assumed the impact on the productivity of the masonry service ($\mu_1 \neq \mu_2$). Usually, when comparing populations after interventions, the equality hypothesis is always the null hypothesis.

Once the normality of the data distribution was confirmed, the t-value and F-tests were performed, which should confirm by means of the variances of the samples, that both belong to the same sample population (Fonseca, 1996; Box et al., 2005, p. 47; Torman et al., 2012). Data from the productivity samples in the SPSS program yielded the hypothesis tests for T-test and F-test are presented in Table 5.

Table 5. Results for the t-test and F test. Source: Authors.

	Mean difference	Standard Error	t_0	df*
Non assumed equal variances	0.137	0.031	4.376	46.88
Hartley's test for equal variances: F = 1.918, Sig. = 0.0426				

*df – degrees of freedom

As to = 4.366> tα; υ = 1.676, the null hypothesis of H_0: $\mu_1 = \mu_2$ was rejected at the significance level $\alpha = 0.05$. As the p-value = 0.0426 < α = 0.05, the decision is also to reject the null hypothesis of H_0. In the analysis of the Hartley test with the hypothesis that, after the implementation of the project, the variability in production would be reduced, the F test also showed a strong tendency to reject H_0 because of the equal variances in the two samples, having $F_0 = 1.918 > F\alpha$; n1-1; n2-1 = 1.85.

Due to the results of the tests cited above, the rejection of the null hypothesis proves to be valid, indicating that the mean of the productivity was actually changed by the project implementation. Therefore, evidence was obtained to conclude the connection between the stages, that is, that the average productivity index of the sealing masonry service after the implementation of the project had an average increase of approximately 26% in relation to the phase without interventions, calculated according to the mean values shown in Table 2.

Figure 6 shows the response surface results for the collected data. In order to better understand the figure, the Z-axis data, RUP, were placed on the same scale. It allowed observing that the RUP after the project implementation has less variability compared to pre-project data, given the more regular format of the response surface. Although some data of the post-project stage is in the red zone, this zone is below 1 Mh/m², unlike the red area of the data surface prior to the implementation of the project, which is above 2 Mh/m². There is also a greater variability of colors in the axis referring to man-hour in relation to the axis of the daily quantity of services, which indicates a greater influence of the first on the RUP values.

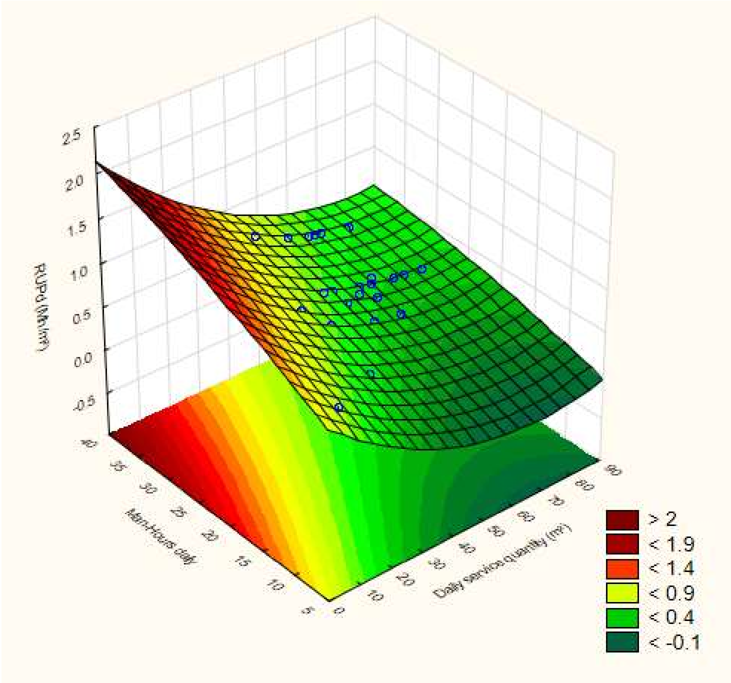
4.3. Further Discussions

Shen et al. (2011) carried out a series of statistical analyzes of the productivity data collected in the USA and China from various services, including masonry, in order to demonstrate the influence of different working conditions. The authors used as a method of measuring productivity an index inversely proportional to what was studied in this article (amount of service/hour). For the masonry service with blocks in the dimensions of 8 in. (approximately 20.32 cm), the authors found 0.9 m²/h in the USA and 1.3 m²/h in China. The average value found after the implementation of the project was 0.3789 h/m². Converting to the same unit of measure used in this study, these authors obtained 2.64 m²/h, indicating that the production was higher than in the surveyed countries than in the country of study.

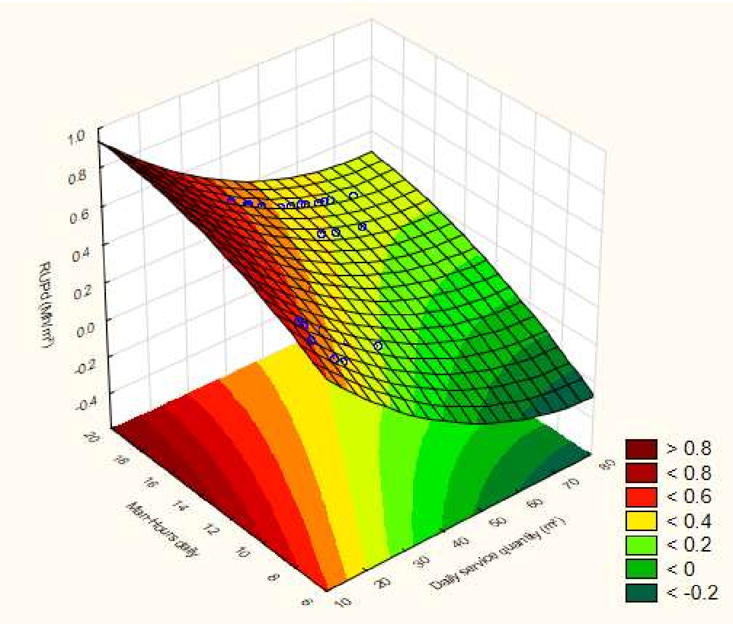
Regarding management failures, Mahamid (2013) showed that the lack of materials is one of the five factors perceived by contractors as contributing to the worsening of labor productivity, a problem also found in the work studied here. Poor management of space and logistics, another direct cause of productivity variation reported in this study, was also found to be the cause of delays in case studies conducted by Agyekum-Mensah and Knight (2017).

Zaki et al. (2017) continue a series of papers that discuss the modeling of masonry assembly in software such as BIM and Autodesk® Revit. They emphasize that masonry modeling, although previously mentioned in the literature, still requires the involvement of the designer in the process, due to the lack of tools that automate the necessary detail of the masonry assembly project.

Pace (2019) showed the importance of the researches that analyses project management from other perspectives, to find the real influences, of strong correlation, to project success. A masonry wall project design, as a tool mostly used for structural calculation purposes only, can be a great tool for project rationalization and for the successful execution of other artisanal techniques such as masonry.



(a)



(b)

Fig. 6. Surface results for the collected data (a) without a masonry project design (b) with a masonry project design (source: the authors)

5. Conclusions

This study aimed at portraying the importance of planning intricate and resource-demanding activities ahead of execution and providing the appropriate tools to aid execution in the field. Here, specifically, the building of masonry walls was aided by using a masonry wall layout project in the field, which guided the responsible crews. The knowledge gap fulfilled by this research is the actual implementation and intervention, with later quantification, of the benefits related to the use of a masonry-labor project in the productivity of such activity. The causes of such variations on the productivity data other than the project implementation were not explored.

The conclusion reached in this study indicated that the reduction of the RUP, which complies with the increase of productivity, was in the order of 26% due to the implantation of the masonry project, an instrument of rationalization of production. The variability between the studied conditions was confirmedly attributed to the intervention of the masonry project by the hypothesis tests. The improvement of masonry activity due to a management tool such as the masonry project shows the importance of enabling the crew with appropriate materials and information to achieve better results.

As a suggestion to future applications of the masonry layout project in the field, it is important to combine such tools with other management techniques, considering the gain of productivity and, consequently, the change in the workflow. Thus, with the implementation of the project to produce masonry walls, it is possible to contribute directly to the increase in productivity. This result has an impact on many practical aspects, such as crew sizes, changes in budgets, and schedules with the potential to relate to sustainability issues in the production. It can also be valuable to study different masonry modular solutions implemented in a construction site and how demanding each solution can be. The translation of this implementation process can be tracked by productivity improvement, as seen in this case study.

References

Agyekum-Mensah, G. and Knight, A. D. (2017). The Professionals' Perspective in the Causes of Project Delay in the Construction Industry. *Engineering, Construction and Architectural Management*, 24(5), 828-841.

Arambula, E. and Gharaibeh, N. (2014). Methods for Accumulating Construction and Material Quality Test Results and Their Effect on Acceptance Decisions. *Journal of Construction Engineering and Management*, 140(8).

Box, G. E. P., Hunter, S. and Hunter, G. V. (2005). *Statistics for experimenters: design. discovery, and innovation*. Hoboken, New Jersey: John Wiley & Sons, Inc., 2nd ed.

El-Mashaleh, M., O'Brien, W.J. and London, K. (2001). Envelopment methodology to measure and compare subcontractor productivity at the firm level. *Proceedings of the 9th Annual Conference of the International Group for Lean Construction*, Singapore.

Enshassi, A., Mohamed, S., Mayer, P. and Abed, K. (2007). Benchmarking masonry labor productivity. *International Journal of Productivity and Performance Management*, 56(4), 358-368.

Fonseca, J.S. (1996). *Curso de estatística*. São Paulo, São Paulo: Atlas, 6th ed.

Florez, L. (2017). Crew Allocation System for the Masonry Industry. *Computer-Aided Civil and Infrastructure Engineering*, 32, 874-889.

Gouett, M. C., Haas, C. T., Goodrum, P. M. and Caldas, C. H. (2011). Activity Analysis for Direct-Work Rate Improvement in Construction. *Journal of Construction Engineering and Management*, 137(12), 1117-1124.

Hajikazemi, S., Andersen, B. and Langlo, J. A. (2017). Analyzing Electrical Installation Labor Productivity through Work Sampling. *International Journal of Productivity and Performance Management*, 66(4), 539-553.

Hanna, A. S., Chang, C. K., Sullivan, K. T., and Lackney, J. A. (2008). Impact of shift work on labor productivity for labor intensive contractor. Journal of Construction Engineering and Management, 134(3), 197-204.

Hwang, B. and Yeo, Z. B. (2011). Perception on Benefits of Construction Waste Management in the Singapore Construction Industry. *Engineering, Construction and Architectural Management*, 18(4), 394-406.

Love, P. E. D., Simpson, I., Hill, A. and Standing, C. (2013). From justification to evaluation: Building information modeling for asset owners. *Automation in Construction*, 35, 208-216.

Lordsleem Junior, A. C. (2000). *Execução e Inspeção de Alvenaria Racionalizada*. São Paulo, São Paulo: O Nome da Rosa, 3rd ed.

Mahamid, Ibrahim (2013). Contractors Perspective Toward Factors Affecting Labor Productivity in Building Construction. *Engineering, Construction and Architectural Management*, 20(5), 446-460.

Martins, P. M. L. (2013). Avaliação da produtividade na construção no Brasil: O modelo de estratificação. *Working Paper*, Faculdade de Engenharia, Universidade do Porto, Porto, 2013.

Montgomery, D. C. and Runger, G. C. (2009). *Estatística Aplicada e Probabilidade para Engenheiros*. São Paulo, São Paulo: LTC, 4th ed.

Naoum, S. G. (2016). Factors influencing Labor Productivity on Construction Sites. *International Journal of Productivity and Performance Management*, 65(3), 401-421.

Pace, M. (2019). A Correlational Study on Project Management Methodology and Project Success. *Journal of Engineering, Project and Production Management*, 9(2), 56-65.

Parsekian, G. A., Medeiros, W. A. and Sipp, G. (2018). High-rise concrete and clay block masonry building in Brazil. *Mauerwerk: European Journal of Masonry*, 22(4), 260-272.

Ross, F. J. (2011). Statistics for the Clinician: Diagnostic Questionnaires. *Journal of Psychiatric Practice*, 17(1), 57-60.

Sanders, S. R. and Thomas, H. R. (1991). Factors affecting Masonry-Labor Productivity. *Journal of Construction Engineering and Management*, 117(4), 626-644.

Shehata, M. E. and El-Gohary, K. M. (2011). Towards improving construction labor productivity and projects' performance. *Alexandria Engineering Journal*, 50(4), 321–330.

Shen, Z., Jensen, W., Berryman, C. and Zhu, Y. (2011). Comparative Study of Activity-Based Construction Labor Productivity in the United States and China. *Journal of Management in Engineering*, 27(2), 116–124.

Souza, U. E. L. (2005). *Como Reduzir Perdas nos Canteiros de Obras: manual de gestão do consumo de materiais na construção civil*. São Paulo, São Paulo: Pini.

Souza, U. E. L. (2006). *Como Aumentar a Eficiência da Mão de Obra: manual de gestão da produtividade na construção civil*. São Paulo, São Paulo: Pini.

Torman, V. B. L., Coster, R. and Riboldi, J. (2012). Normalidade de variáveis: métodos de verificação e comparação de alguns testes não-paramétricos por simulação. *Revista HCPA*, 32(2), 227-234.

Thomas, R. H. and Napolitan, C.L. (1995). Quantitative effects of construction changes on labor productivity. *Journal of Construction Engineering and Management*, 121(3), 290-6.

Thomas, H. R. and Yiakoumis, I. (1987). Factor Model of Construction Productivity. *Journal of Construction Engineering and Management*, 113(4), 623-638.

Uddin, M., Mahboub, K. C. and Goodrum, P. M. (2011). Effects of Nonnormal Distributions on Highway Construction Acceptance Pay Factor Calculation. *Journal of Construction Engineering and Management*, 137(2), 108–118.

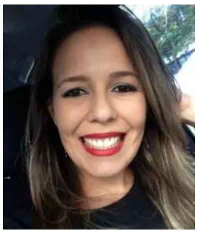
Werkema, M. C. C. (1996). *Como estabelecer conclusões com confiança*. Belo Horizonte, Minas Gerais: Fundação Christiano Ottoni.

Yi, W. and Chan, A. P. C. (2014). Critical Review of Labor Productivity Research in Construction Journals.

Journal of Management in Engineering, 30(2), 214-225.

Zaki, T., Nassar, K. and Hosny, O. (2017). Parametric Blockwall-Assembly Algorithms for the Automated Generation of Virtual Wall Mockups Using BIM. *Proceedings of Architectural Engineering Conference 2017*, Oklahoma City, Oklahoma.

Zhang, Y., Liu, Y. and Cai, P. (2018). Research on masonry structure layout design based on BIM technology. *Proceedings of the 2018 International Conference in Advanced Mechatronic Systems*, Zhengzhou, China.



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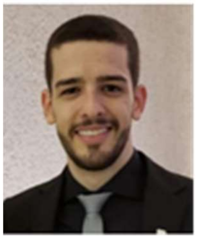

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