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A framework for selection criteria of wet mortar pumping systems in Brazil

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Abstract

Despite presenting several advantages in relation to the mortar coating performed by hand labor traditionally carried out in Brazil, there is little knowledge available about mortar pumping systems. Thus, selecting a mortar pump system is not a trivial procedure, and there are no significative studies published in the specialized literature to fully understand the decision criteria applying to this equipment selection. Therefore, the present study aimed to identify the relevant criteria and quantify their importance in the selection of this equipment, by developing a framework combining both mortar pump specialists expertise and fuzzy analytic hierarchy process method to aid this decision making process. Results showed that acquisition cost and quality are the most relevant criteria, representing together around 2/3 of the decision weight, while technical and operational aspects account for approximately 1/10 of relevance in the equipment selection.

Keywords: mortar pump, decision making, Delphi, Fuzzy AHP, equipment selection.

1. Introduction

In the last decade, the Brazilian civil construction industry has been seeking to optimize its processes, improving productivity, reducing and reusing material waste as well as replacing traditional labor processes with technological innovation solutions (Boubaaya *et al.*, 2023; Borges *et al.*, 2019; Santos, Morais and Lordsleem, 2018). Mortar coating and displacement into the construction sites are some of the most labor-intensive processes in the Brazilian construction industry, with low productivity and a wide variation in quality because it is traditionally performed

manually. Using mortar pumps, represents a great potential for rationalization and cost reduction, when compared to the transport of raw materials and mortars by the traditional means as wheelbarrows, pushcart, buckets, cranes, elevators and forklifts (ABCP, 2002).

Initially created to enable concrete projection, wet mortar pumps were developed in the first half of the twentieth century. Early equipment was designed using piston pump systems, but only in the 1950s did this technology become viable, using different types of pumps, such as screw pumps

(Morgan, 1996). Screw pumps promote a continuous flow of materials without causing deterioration, which is not possible to achieve with piston pumps (Cholet, 1997).

In Brazil, the introduction of the mortar projection systems began in the 1970s, but it was not initially successful due to the lack of labor training and engineering knowledge. It was only in the late 1990s, when some of these problems were gradually solved that this equipment was reintroduced in the market (Crescêncio *et al.*, 2000). These pumps present themselves as a solution to optimize construction performance

by improving deadline conditions, quality, rationalization, productivity, sustainability and costs in mortar coating process (Amaral, Oliveira and Lima, 2023). Studies show significant gains in execution deadlines with the implementation of mechanization in the civil construction industry (Cichinelli, 2010) in which there is special emphasis on the process of transporting mortar inside the construction site. Despite all these reported advantages,

this technological innovation in Brazil still remains being applied by a relatively small number of companies (Santos, Morais and Lordsleem, 2018).

In the specialized literature, the mortar pump research published is scarce, being the few existing articles focusing solely on mortar composition and pumping (Ha *et al.*, 2017; Jacobsen *et al.*, 2008; Pérez, Costa and Golçalves, 2017). No research was found regarding the criteria

that determine the selection of mechanized wet mortar pumping systems with screw pumps available in the Brazilian market.

Therefore, this literature gap emboldens the present study, whose goal is to identify the relevant criteria and quantifying their importance in the selection of wet mortar pumping systems in Brazil. In order to accomplish this task, a framework combining the Delphi and Fuzzy Analytic Hierarchy Process (FAHP) methods were used.

2. Materials and methods

2.1 Mortar pumping system

The mortar pumping system is a set of equipment for designing the mortar, consisting of: electrical control system, mortar reservoir, connections, mortar pump (component responsible for promoting the displacement of the mortar in the pumping system) and other accessories. It has a high performance, used for the mechanized transport of materials intended for the execution of plaster, subfloor, grout, mortar and other materials (M-TEC, 2023a). In Brazil, manufacturers provide different models

that carry distinguishable characteristics, dimensions, and capacities. The length of the screw pump (type of component commonly used in mortar pumping system design) determines the number of rotor pitches, which is responsible for determining the pump output pressure. The greater the length of the pump, the greater the pressure (Cholet, 1997). The dimensions of the gaps between the rotor and the stator define the dimension limit of the aggregate. The mortar pumping system composed of a screw pump can displace

mortar up to 100 meters vertically and 300 meters horizontally, depending on the pump output flow, hose gauge and the rheological properties of the mortar (Austin, 1995). In addition to facilitating cleaning and maintenance, it pumps mortar for coatings containing fine aggregates, from 0 to 8 mm, continuously and without oscillations, facilitating the precise dosage of additives (Cook, 1990).

In the image in Figure 1, a model of a mortar pumping system manufactured with a screw pump is shown.

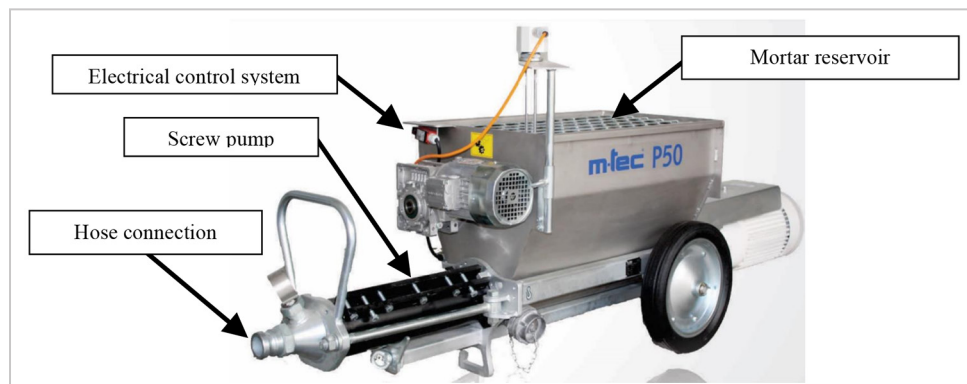


Figure 1 – Mortar pumping system with screw pump (Source: Elaboration based on M-TEC (2023a)).

2.1.1 Screw pump

The screw pumps, which are part of the mortar pumping system, are composed of two main parts: the internal steel rotor and a stator, external part, produced in petroleum-derived elastomer. The geometries of these parts are not identical, forming precise empty spaces between them, which are responsible for generating negative pressure at the inlet as the rotor rotates inside the stator (Maidl, 1995; Cholet, 1997). According to Valge (2023), this type of pump requires low Net Positive Suction Head - NPSH, avoiding the risk of cavitation; operates with continuous flow, which allows greater control of flow and operating pressure; and produces smooth pumping, which

poses no risk of altering the properties of the pumped material. Also known as a progressive cavity pump, this kind of pump is employed where other sorts of pumps are unfit to operate, as it allows the pumping of high-viscosity products that may even retain abrasives. According to Netzsch (2023), the helical movement, through the combination of the axial and radial movements of the fluid inside the pump, provides speed, direction and direction imposed by the rotors, generating chambers that advance continuously, producing the positive displacement, continuous, without pulsations and proportional to the movement of the elements of the pump, making the pump

flow constant and proportional to the rotor speed. This type of pump has the advantage of preserving the physical and chemical characteristics of the fluid, since there is low friction between the parts of the pump and the pumped product, due to the shape of the cavities being constant, meaning that the pumped product is not compressed, allowing the pumping of liquids and solids, including due to the lack of shear forces.

In Figure 2, a working diagram of a double equipment is presented, which accumulates the functions of mixing and pumping the mortar. In this diagram, the positioning of the screw pump can be seen as a component of the system.

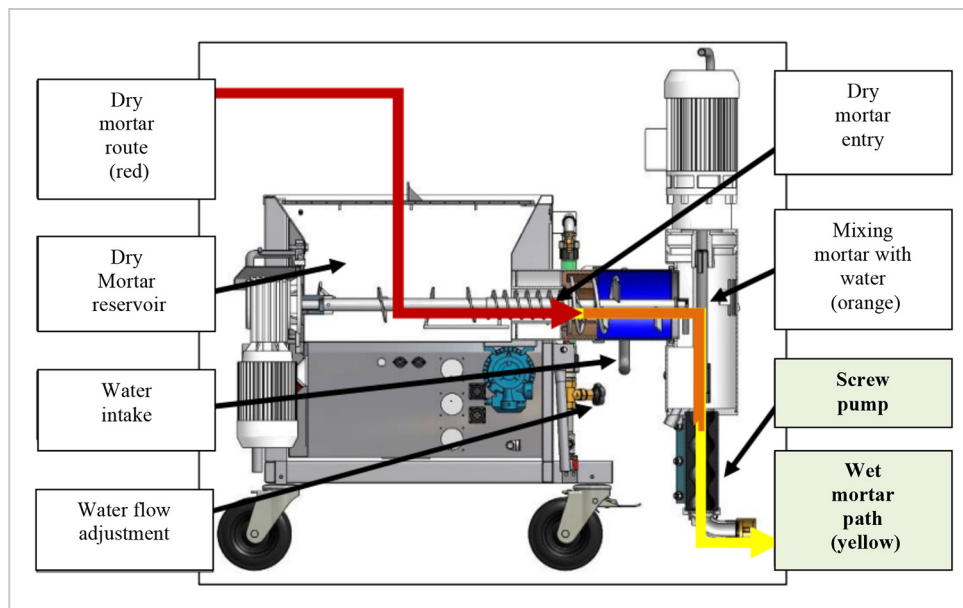


Figure 2 – Illustrative scheme of mixing and pumping equipment (Source: Elaboration based on M-TEC (2023b)).

2.2 Research data

All the data for this study were obtained from the responses of questionnaire application and interviews carried out with a set of specialists for decision making in the subject: mortar pump manufacturers and buyers from construction companies and contractors.

The following characteristics that

configured the class of wet mortar pumping systems that were part of the study were established: rotor-stator pumping operating principle, consisting of a single geared motor, vat for receiving the wet mortar, horizontal axis, coupled electrical control panel and outlet with 50 mm diameter hoses.

Decision makers had to analyze the

established criteria, based on a possible acquisition process for this specific class of equipment. In the interviews, fifteen questions were answered in an trade-off process, based on the relative importance scale for each criteria by ten decision makers between November 2022 and January 2023.

2.3 Framework

To carry out this work, the development of the framework presented in Figure 3 was proposed.

The algorithm consisted of completing five stages to achieve the purpose established in the study:

Stage 1: after setting the intent of the study, this step consisted of defining the groups of experts and decision-

makers surveyed, the methodology, and the effectiveness of the initial contacts.

Stage 2: using the Delphi method, with the participation of experts in the area of mortar pumping systems, the tested criteria were selected.

Stage 3: development of the form, containing the 15 questions in the trade-off format.

Stage 4: conducting interviews structured by questionnaire, with decision-making groups of suppliers and buyers to obtain judgments of the criteria.

Stage 5: the decision makers' responses were used in the application of the FAHP to obtain the importance weight vectors of the established criteria.

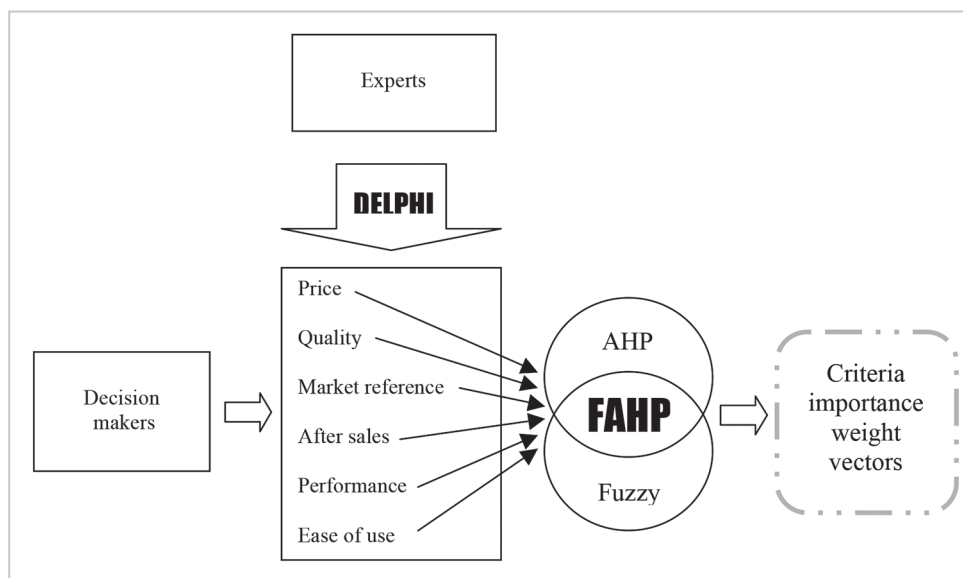


Figure 3 – Framework for selection criteria of wet mortar pumping systems.

2.3.1 Delphi method

The Delphi method, developed by researchers from the Rand Corporation Olaf Helmer and Norman C. Dalkey, in the 1960s, for research in the area of military defense during the Cold War period, is a technique used to make predictions, in order to know in advance the probability of future events through the systematic collection of expert opinions,

being indicated, for example, for cases where quantitative data are lacking for the resolution of a study (Oliveira *et al.*, 2008). Its use is widespread in several different areas. According to Helmer (1966), it is a systematic method that seeks to obtain opinions from experts in obtaining their consensus on a given subject, taking care not to be influenced

by groups, trends and public opinion (Hasson, Keeney and McKenna, 2000). The implementation of this study included meetings with three experts in mortar pumping systems, with the aim of identifying the criteria that could be part of the field research and investigating their relevance for decision-makers in the process of acquiring equipment.

2.3.2 Fuzzy AHP method

The Hierarchical Analysis Method, better known as AHP, created by Professor Thomas L. Saaty in 1980, is recognized as one of the first methods developed in the Discrete Multicriteria Decisions environment, possibly being the most popular method in this category of decision making used worldwide (Gomes,

Araya and Carignano, 2011). It was proposed as a decision analysis technique with the objective of evaluating, by one or more decision makers, complex alternatives that contain multiple attributes (Ho, 2008; Emrouznejad & Marrab, 2017).

In the AHP method, complex problems are decomposed into smaller

parts, organizing the decision criteria into hierarchical levels and then compared at each level in a paired way, according to the decision maker's judgment, creating a judgment matrix using the fundamental scale of relative importance, developed by Saaty and presented in Table 1.

Table 1 – Fundamental scale of relative importance.

Relative importance	Linguistic importance	Description
1	Equal importance	Both alternatives contribute equally to the objective.
3	Little or moderate importance of one over the other	Experience and judgment favor one alternative over the other.
5	Great or essential importance	Experience and judgment strongly favor one alternative over the other.
7	Very great or demonstrated importance	One alternative is very strongly favored over the other. Can be demonstrated in practice.
9	Absolute or extreme importance	The evidence favors one alternative over the other, with the highest degree of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgments	When looking for a compromise condition between two definitions.
1/2,1/3,1/4,1/5, 1/6,1/7,1/8, 1/9	Values for reverse comparison	Adopted directly to the opposite alternative in the analysis.

Source: Elaboration based on Saaty (1987).

Fuzzy AHP, or FAHP, was conceived as an extension of the AHP method (Jaiswal *et al.*, 2015). In this method, diffuse numbers, or fuzzy numbers, are integrated into the AHP to appropriately express linguistic evaluation, making it possible to deal with subjective perceptions and inaccuracies (Calabrese *et al.*, 2016). Developed by Zadeh (1965), with the aim of resolving the imprecision and ambiguity of human cognition and judgment, Fuzzy Set Theory makes it possible to process uncertainties associated with thought and

reasoning, working on human preferences, which in turn are sometimes subjective, uncertain and ambiguous and making it possible to represent them in exact numerical values (Kannan *et al.*, 2013).

The first FAHP method was proposed by Van Laarhoven and Pedrycz in 1983, using triangular fuzzy numbers in the pairwise comparison matrix (Emrouznejad & Ho, 2017). Subsequently, fuzzy numbers were used with the trapezoidal membership function (Onar *et al.*, 2016) and Gaussian (Paul, 2015).

The FAHP method is carried out by a four step algorithm:

Step 1 - Consists of identifying the criteria for selecting a wet mortar pump, the decision makers who will be part of the study and modeling the problem as a hierarchy.

Step 2 - Make comparisons between pairs, referring to the importance of the selection criteria for mortar pumping systems, using the geometric mean to integrate the decision makers' judgments according to Equation 1:

$$l = (l_1 * l_2 * ... * l_k)^{1/k}, m = (m_1 * m_2 * ... * m_k)^{1/k}, u = (u_1 * u_2 * ... * u_k)^{1/k} \quad (1)$$

Where, (l,m,u) – triangular fuzzy number; (1,2,...,K) – number of decision makers.

Step 3 – Develop a decision matrix, synthesizing the judgments of the decision

makers to prepare a set of general priorities for the hierarchy.

Define the pairwise comparison matrix, by applying the relative importance

scale, as shown in Table 1.

Perform fuzzyfication (expression

that refers to the action of transforming a numeric value into a fuzzy number)

through the diffuse scale of relative importance, shown in Figure 4.

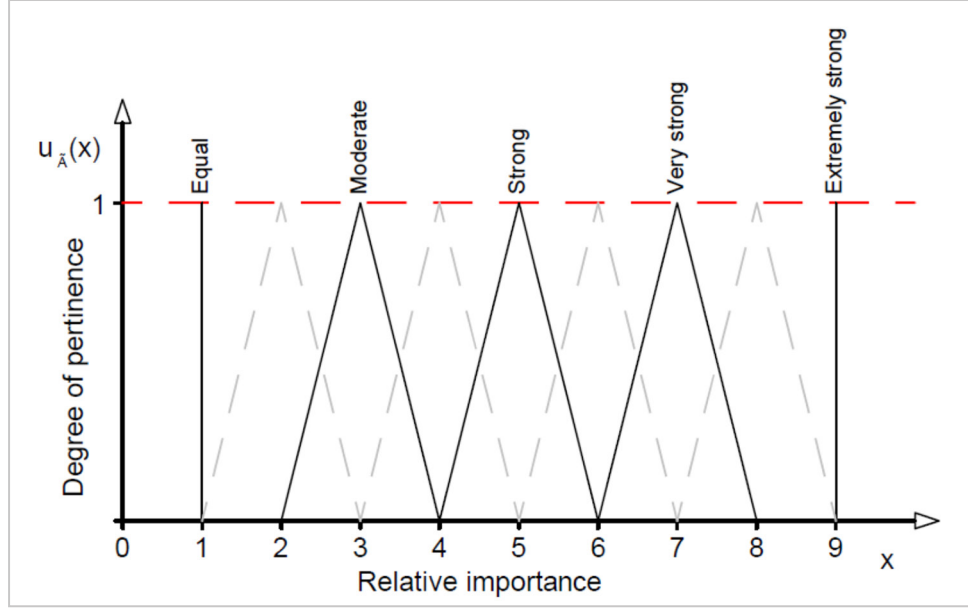


Figure 4 – Fuzzy scale of relative importance (Source: Elaboration from Kannan *et al.* (2013)).

The reciprocal fuzzy numbers of relative intensity are given according to Equation 2.

$$\tilde{A}^{-1} = (l, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l} \right) \quad (2)$$

Step 4 – Transform the paired comparison matrix for judging criteria into linguistic variables and calculate the importance weight vectors for each criterion, using

the basic concept of FAHP in triangular fuzzy numbers.

The fuzzy geometric mean value ($\tilde{r}_i$), given by Equation 3, it is necessary for the

calculation of the weight vectors of importance of the criteria.

$$\tilde{r}_i = ((l_1, l_2, \dots, l_n)^{1/n}, (m_1, m_2, \dots, m_n)^{1/n}, (u_1, u_2, \dots, u_n)^{1/n}) \quad (3)$$

The fuzzy weight vector ($\tilde{w}_i$) for each criterion is obtained through Equation 4.

$$\tilde{w}_i = \tilde{r}_i * (\tilde{r}_1 + \tilde{r}_2 + \dots + \tilde{r}_n)^{-1} \quad (4)$$

The defuzzification (expression that refers to the action of transforming a fuzzy

number in to a numeric value) is carried out through the center of the area, to

obtain the weight vectors of importance of the criteria (w_i), as given by Equation 5.

$$w_i = \left(\frac{l + m + u}{3} \right) \quad (5)$$

The normalized importance weight vectors (Nw_i) are obtained through Equation 6.

$$Nw_i = \left(\frac{w_i}{\sum w_i} \right) \quad (6)$$

3. Results

3.1 Identified criteria

Through the application of the Delphi method, with the participation of specialists from the technical and sales areas, the following criteria were identified as relevant for the selection of wet mortar pumping systems: price, quality, market reference, after-sales, performance and

ease of use. After the selection, the specialists defined in a few words the identified criteria: the *price* comprises the amount actually paid by the customer; *quality* refers to the durability, constructive finish and visual appearance of the equipment; the market reference is an

indication of the influences of other customers, competing companies, among others, on the acquisition; after-sales is represented by the availability of spare parts, *after-sales* service and the delivery of equipment to the customer with the presence of a technician and training;

performance is directly linked to two characteristics valued by customers: the

flow, given in m³/h, and the maximum pumping distance; and ease of use refers

to the operating conditions and cleanliness of the equipment.

3.2 Judgment matrix

Based on the information obtained in the interviews with the

decision-makers, the FAHP method was applied were resulting in an

FAHP judgment matrix, presented in Table 2.

Table 2 – Fuzzy AHP judgment matrix for decision-making group.

	Price	Quality	Market reference	After sales	Performance	Ease of use
Price	(1,1,1)	$(5\frac{1}{6}, 6, 6\frac{7}{9})$	$(3\frac{1}{5}, 4, 4\frac{5}{8})$	$(2\frac{6}{7}, 3\frac{5}{9}, 4\frac{1}{4})$	$(3, 3\frac{1}{2}, 4)$	$(3\frac{3}{7}, 4\frac{1}{7}, 4\frac{8}{9})$
Quality	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{5})$	(1,1,1)	$(5\frac{3}{4}, 6\frac{2}{3}, 7\frac{1}{2})$	(5,6,7)	$(3\frac{6}{7}, 4\frac{1}{2}, 5)$	$(3\frac{1}{5}, 3\frac{7}{8}, 4\frac{4}{7})$
Market reference	$(\frac{2}{9}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{8}, \frac{1}{7}, \frac{1}{6})$	(1,1,1)	$(5\frac{1}{3}, 6\frac{2}{9}, 7)$	$(3\frac{4}{7}, 4\frac{1}{4}, 5)$	$(2\frac{8}{9}, 3\frac{1}{2}, 4)$
After sales	$(\frac{1}{4}, \frac{2}{7}, \frac{1}{3})$	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{5})$	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{5})$	(1,1,1)	$(2\frac{3}{7}, 3, 3\frac{1}{2})$	$(3\frac{2}{5}, 4, 4\frac{4}{5})$
Performance	$(\frac{1}{4}, \frac{2}{7}, \frac{1}{3})$	$(\frac{1}{5}, \frac{2}{9}, \frac{1}{4})$	$(\frac{1}{5}, \frac{1}{4}, \frac{2}{7})$	$(\frac{2}{7}, \frac{1}{3}, \frac{2}{5})$	(1,1,1)	$(5\frac{2}{9}, 5\frac{4}{5}, 6\frac{1}{3})$
Ease of use	$(\frac{1}{5}, \frac{1}{4}, \frac{2}{7})$	$(\frac{2}{9}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{4}, \frac{2}{7}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{4}, \frac{2}{7})$	$(\frac{1}{6}, \frac{1}{6}, \frac{1}{5})$	(1,1,1)

3.3 Criteria weight vector

From the judgment matrix, the next stage of the model was applied by calculating the weight importance vectors of the analyzed criteria.

It was identified that the price criterion was, in isolation, the most important, with 39.5% representation. In second position, the quality criterion was identified, presenting 26.7% of importance and, in third, the market reference was presented with 15.0%. The other criteria, called after-sales, performance and ease of use, were of little importance, with 8.2%, 6.8% and 3.7%, respectively, as plotted in Figure 5.

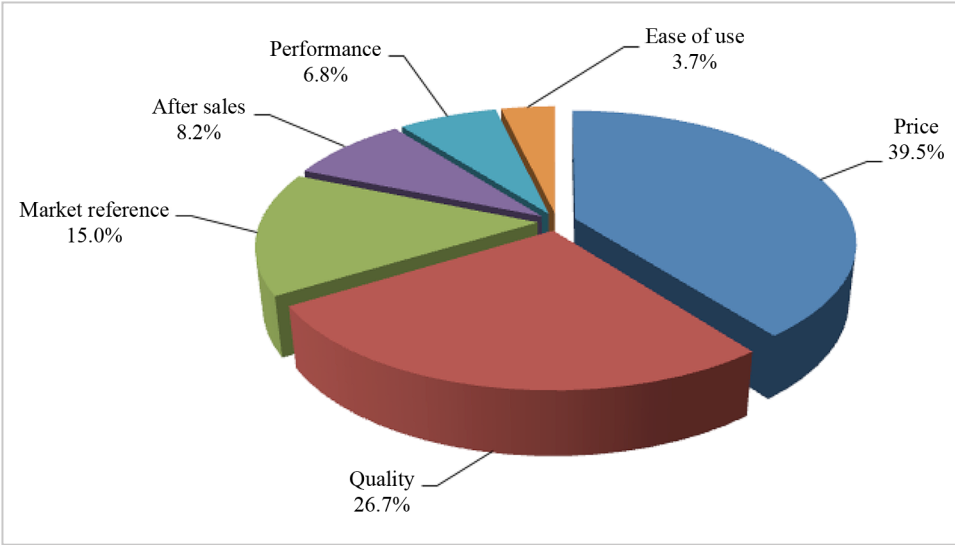


Figure 5 – Weight vectors of importance of the criteria for the group of purchasing decision makers.

4. Discussion

The most important criteria in the decision-making of the analyzed group were price and quality. The appreciation

of these two criteria is already expected in acquisition processes. At an intermediate level, the market reference criterion

was maintained. Some criteria, such as after-sales, performance and ease of use individually represented less than 10% of

the weight of the decision.

Criteria such as ease of operation which can be decisive for the acceptance of a new work methodology by operational professionals, and performance, which allows for a more in-depth assessment of the cost/benefit relationship was not valued.

The market reference criterion, which can boost a greater sense of security in the decision-making process through experiences lived by other organizations,

and the after-sales, which provides better results in the use and security of system availability, remained in positions central in the ranking, presenting low importance for decision makers.

It is suggested that this result may result from professionals, decision makers, showing themselves to be more immersed in objectives that are divided into numerous issues related to their own business, not paying greater attention to criteria of technical predominance of the equipment.

The most significant part of importance given by the concentrated group, remains among the first three classified criteria. Price is an important criterion in the analysis of an acquisition process, as is the durability of the acquired good, verified by quality criteria. However, it was expected that aspects such as pumping capacity, conferred by the performance criterion, would be among the top positions in the ranking, a proposition that did not prove to be true.

5. Conclusions

The following criteria were identified by experts as relevant for the selection of wet mortar pumping systems: price, quality, market reference, after-sales, equipment performance and ease of use.

It was found that the two most important criteria in decision-making are price (39.5%) and quality (26.7%). It is noteworthy that the two major criteria in the ranking together are responsible for almost 2/3 (66.2%) of the decision weight

in mortar pump system selection.

The *market* reference (15%), a benchmark from other organizations experiences and *after-sales* (8.2%), which provides better results in use and security in maintaining the availability of the product system, are criteria that presented medium to low importance to decision makers.

The technical and operational aspects of the equipment, such as pump-

ing performance (6.8%) and ease of use (3.7%) were not so relevant regarding mortar pump selection, accounting only around 1/10 of the total decision.

In addition to the quantitative results obtained, the study presented the academic contribution of proposing a framework that made it possible to identify the relevant criteria and quantify their importance in the selection of wet mortar pumps by stakeholders.

References

- AMARAL, D. R. B.; OLIVEIRA, A. J. P. O.; LIMA, M. R. V. M. Comparativo entre os sistemas de projeção de argamassa: método convencional x método de projeção. *TEC-USU*, Rio de Janeiro, v. 6, n. 1, p. 26-34, 2023.
- ASSOCIAÇÃO BRASILEIRA DE CIMENTO PORTLAND. *Manual de revestimentos de argamassa*. São Paulo: ABCP, 2002.
- AUSTIN, S. A. Production and installation. In: AUSTIN, S. A.; ROBINS, P. J. *Sprayed concrete*: properties, design and application. Caithness, Inglaterra: Whittles Publishing, 1995. Cap. 4, p. 31-51.
- BORGES, P. H. R.; RAMOS, F. C. R.; CAETANO, T. R.; PANZERRA, T. H.; SANTOS, H. Reuse of iron ore tailings in the production of geopolymer mortars. *REM – International Engineering Journal*, v. 72, n. 4, p. 581-587, oct./dec. 2019.
- BOUBAAYA, R.; DJENDEL, M.; BENANIBA, S.; KESSAL, O.; DRISS, Z. Impact of the loading of date palm fibers on the performances of mortars. *REM - International Engineering Journal*, v. 76, n. 2, p. 159-168, apr./jun. 2023.
- CALABRESE, A.; COSTA, R.; LEVIALDI, N.; MENICHINI, T. A fuzzy analytic hierarchy process method to support materiality assessment in sustainability reporting. *Journal of Cleaner Production*, v. 121, p. 248-264, 2016.
- CHANG, D. Applications of the extend analysis method on fuzzy AHP. *European Journal of Operational Research*, v. 95, n. 3, p. 649-655, 1996.
- CHOLET, H. *Progressing cavity pumps*. Institute Français du Pétrole Publications. Paris, França: Éditions Technip, 1997. 112 p.
- CICHINELLI, G. C. Revestimento rápido: escassez de mão de obra abre espaço para projeção mecanizada de argamassas. *Revista Construção Mercado*, 2010.
- COOK, T. H. *Concrete pumping and spraying*: a practical guide. Londres: Thomas Telford House, 1990. 234 p.
- CRESCÊNCIO, R. M.; PARSEKIAN, G. A.; BARROS, M. M. S. B.; SABBATINI, F. H. Execução de revestimentos com argamassa projetada. In: ENCONTRO NACIONAL DE TECNOLOGIA DO AMBIENTE CONSTRUÍDO, v. 8, p. 1067-1074, 2000.
- EMROUZNEJAD, A.; HO, W. Fuzzy analytic hierarchy process. Boca Raton: CRC Press, 2017.
- EMROUZNEJAD, A.; MARRAB, M. The state of the art development of AHP (1979-2017): a literature review with a social network analysis. *International Journal of Production Research*, v. 55, n. 22, p. 6653-6675, 2017.
- FRENCH, S. Reflections on 50 years of MCDM: issues and future research needs. *EURO Journal on Decision Processes*, v. 11, p. 100030, 2023.
- GOMES, L. F. A. M.; ARAYA, M. C. G.; CARIGNANO, C. *Tomada de decisões em cenários complexos*: introdução aos métodos discretos do apoio multicritério à decisão. São Paulo: Cengage Learning, 2011. 168 p.
- HA, S. J.; YUN, T. S.; KIM, K. Y.; JUNG, S. G. Experimental study of pumping rate effect on hydraulic fracturing of cement paste and mortar. *Rock Mechanics and Rock Engineering*, v. 50, p. 3115-3119, Jul. 2017.

- HASSON, F.; KEENEY, S.; MCKENNA, H. Research guidelines for the Delphi survey technique. *Journal of Advanced Nursing*, v. 32, n. 4, p. 1008-1015, 2000.
- HELMER, O. *The use of Delphi technique in problems of educational innovations*. Santa Mônica: Rand Corporation, 1966.
- HO, W. Integrated analytic hierarchy process and its applications - a literature review. *European Journal of Operational Research*, v. 186, n. 1, p. 211-228, 2008.
- JACOBSEN, S.; MORK, J. H.; LEE, S. F.; HAUGAN, L. Pumping of concrete and mortar - state of the art. *SINTEF*, 2008.
- JAISWAL, R. K.; GHOSH, N. C.; LOHANI, A. K.; THOMAS, T. Fuzzy AHP based criteria decision support for watershed prioritization. *Water Resources Management*, v. 29, p. 4205-4227, 2015.
- KANNAN, D.; KHODAVERDI, R.; OLFAT, L.; JAFARIAN, A.; DIABAT, A. Integrated fuzzy multi criteria decision making method and multi-objective programming approach for supplier selection and order allocation in a green supply chain. *Journal of Cleaner Production*, v. 47, p. 355-367, 2013.
- MAIDL, B. R. *Equipment for the production of sprayed concrete*. Sprayed concrete - properties, design and application. McGraw-Hill, 1995.
- MORGAN, D. M. *Special sprayed concretes*. Sprayed concrete technology. Londres, Inglaterra: E&FN, 1996.
- M-TEC Soluções em equipamentos para obras e fábricas de argamassas. *Bomba de argamassa*. Available at: <https://www.m-tec.ind.br/informacoes/bomba-de-argamassa/> Accessed at: 17 fev. 2023a.
- M-TEC Mathis Technik gmbh. *M-tec about ourselves*. Available at: <https://m-tec.com/> Accessed at: 21 fev. 2023b.
- NETZSCH Bombas & Sistemas. *Bombas helicoidais NEMO*. Available at: https://pumps-systems.netzsch.com/pt-BR/produtos-and-acessorios/bomba-helicoidais-nemo?gclid=Cj0KCQiAorKfBhC0ARIsAHDzslt9Cimi1aEzqdoMwp50gMx8GTRr1_r7fiqbtRQQPyWJyw1Gv42XDXYaAgOYEALw_wcB Accessed at: 15 fev. 2023.
- OLIVEIRA, J. D. O.; COSTA, M. M.; WILLE, M. F.; MARCHIORI, P. Z. *Introdução ao método Delphi*. Curitiba: Mundo Material, 2008. 16 p.
- ONAR, S. Ç.; BÜYÜKÖZKAN, G.; ÖZTAYSI, B.; KAHRAMAN, C. Anew hesitant fuzzy QFD approach: an application to computer workstation selection. *Applied Soft Computing*, v. 46, p. 1-16, 2016.
- PAUL, S. K. Supplier selection for managing supply risks in supply chain: a fuzzy approach. *The International Journal of Advanced Manufacturing Technology*, v. 79, p. 657-664, 2015.
- PÉREZ, C. T.; COSTA, D. B.; GONÇALVES, J. P. Avaliação do processo de revestimento com argamassa projetada: aspectos econômicos e ambientais. *Tecnologias para Canteiro de Obras Sustentável*, p. 383-406, 2017.
- SAATY, R. W. The analytic hierarchy process - what is and how it is used. *Mathematical Modeling*, v. 9, n. 3-5, p. 161-176, 1987.
- SAATY, T. L. *The analytic network process*. MacGraw Hill: New York, 1980.
- SANTOS, D. R.; MORAIS, G. A. T.; LORDSLEEM JR, A. C. Parâmetros de referência para perdas e consumo da tecnologia de revestimento com aplicação projetada de argamassa: estudos de casos. *Revista de Engenharia Civil*, n. 54, p. 46-53, mar. 2018.
- VALGE progressing cavity pumps. *Helical pumps*. Available at: <https://valge.com.br/en/helical-pumps/> Accessed at: 17 fev. 2023.
- ZADEH, L. A. Fuzzy sets. *Information and Control*, v. 8, n. 3, p. 338-353, 1965.

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