Optimising the use of Materials for Construction MSMEs: Building a Comprehensive Framework for Decision-Making and Resource Allocation through an Analytic Hierarchy Process

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ABSTRACT

The efficiency, governance, and compliance with environmental ideals in construction is made possible thanks to a decision support system that ensures Materials, Models, and Methods (3Ms) are adaptable and integrated. Recent advances in Information Technology (IT), for instance, facilitate the visualisation of sequences and production stages in construction. Yet, this falls short in giving compatibility among the 3Ms, their suitability and workability, and their financial and legislative viability. To this end, this manuscript rethinks the concept of productivity, and lays the foundation for a new decision support system that is simple, affordable, and portable enough to attract large enterprises and MSMEs. Ideally, an efficient construction project has good flow of workstreams, is least complex, cost minimised but with added value, timely and in symbiosis with natural health provisions of the ecosystem. A mixed methodology based on gathering data from document reviews, semi-structured interviews, and observations of selected construction MSMEs, will allow to carry out longitudinal research and then code, group, link and analyse the collected raw data through the Analytic Hierarchy Process (AHP) Multi Criteria Decision Making technique. This technique is chosen to develop overall priorities for ranking the alternatives, measure, and monetise the impacting factors to draw out the main impediments to achieve good levels of efficiency. The outputs of the AHP analysis feeds into the novel decision support system, the concepts of which are introduced in this contribution.

KEYWORDS: Construction MSMEs; Productivity; Supply Chain Management; Analytic Hierarchy Process; Decision-Making; Resource Allocation.

1. INTRODUCTION

The construction industry, encompassing both large and small companies, is plagued by low levels of productivity attributed to on-site inefficiencies, inadequate planning, and lack of up-to-date information. These factors contribute to inefficient materials scheduling and delivery, resulting in delays, increased costs, and compromised productivity in construction projects. Several studies (Bell & Stukhart, 1986; Construction Industry Institute, 1987; Gould Frederick & Joyce, 2003; Makulsawatudom, Emsley, & Sinthawanarong, 2004) have reinforced the notion that the lack of timely and appropriate materials availability is a significant cause of such issues.

Monitoring the flow of materials and associated data, including quantities and inventory levels, has been highlighted by Chai and Yitzchakov (1995) as crucial for ensuring smooth operations on construction sites. Inadequate materials management can lead to time-sequencing problems, frustration among the labour force, and failure to meet productivity targets, particularly for self-employed workers.

This manuscript aims to address the complexities of the materials purchasing process for Micro, Small, and Medium-sized Enterprises (MSMEs) in the construction industry. It focuses on improving the effectiveness of materials management, from the ordering stage to delivery and on-site production. Special attention will be given to the unique characteristics of MSMEs and their use of data and information in purchasing and materials delivery processes. Furthermore, the study explores how the integration of new technologies can enhance materials flow management, reducing costs for MSMEs and ultimately benefiting clients through project cost reduction.

It will be highlighted the fact that Information Technology (IT) plays a pivotal role in efficiently managing the flow of materials and associated information, particularly regarding production capacity, customer demand, and low-cost inventories (Yu, Ting, & Chen, 2010). Effective and efficient materials management has the potential to reduce costs and increase productivity in construction projects. Green, Fernie, and Weller (2005) suggest that supply chain management is crucial for promoting improvements in the construction sector.

To delve into the challenges and priorities of the supply chain process, this study conducts a detailed analysis of three MSMEs through multiple approaches, including observation, semi-structured interviews, and document reviews. Additionally, nineteen projects undertaken by these MSMEs are extensively examined. The data analysis employs the Analytical Hierarchy Process (AHP) to comprehend the relative importance assigned by the companies to various challenges in the purchasing process.

Overall, this research aims to address the gaps in knowledge surrounding materials management for MSMEs in construction. By identifying the key challenges, exploring the potential of new technologies, and utilising the AHP framework, this study seeks to provide practical insights and recommendations for optimising materials, methods, and models in MSMEs, ultimately enhancing productivity and reducing costs in the construction industry.

2. LITERATURE REVIEW

2.1 Construction sector challenges and opportunities

The construction industry is a major employer in the UK economy, contributing to more than 8% of the national GDP and providing around 2.4 million jobs (Rhodes, 2019).

The execution of all the phases of a construction project consists of a series of decisions, which need to be clearly outlined in the work plan. The sector, though, is characterised by high levels of fragmentation (Ofori, 2000) and poor coordination among the stakeholders involved resulting in inefficiency, low productivity, excessive waste, and health and safety issues.

The integration of both information and material flows between supply chain partners has a direct significant effect on operational performance (Prajogo & Olhager, 2012). The impact of effective and efficient materials management on costs reduction and increase in productivity, in fact, has been strongly established (Construction Industry Institute, 1987; Formoso et al., 2002).

Current materials management and control procedures are insufficient, non-satisfactory, often inaccurate, time consuming, labour intensive and error prone (Navon & Berkovich, 2006), resulting in delays, lower productivity, and out-dated information (Navon & Berkovich, 2005).

Materials constitute a major portion of the total costs of a construction project, which makes the control of this resource important. On commercial buildings and housing projects the proportion is between 45%-70%; in refurbishment projects and house extensions, it is around 30% of the project value (Agapiou et al., 1998). For landscaping projects, materials represent around 50% of the cost of the work. Formoso and Revelo (1999) suggest that, despite their importance in construction projects, not enough attention is given to materials, their control and management.

Purchasing is then one of the important parts of materials management (Navon & Berkovich, 2006) and a complex process at the same time.

Flows of materials and their data, such as quantities and inventory levels, are important factors during materials purchase. A straightforward purchasing framework can help to identify sequence, interconnectivity, and relationships in the material procurement process, leading MSMEs, for instance, to gain a greater control over purchasing materials and subsequently to increase both productivity and efficiency of the project.

MSMEs play an important role in the construction industry. They are an important source of skills, employment and innovation, as highlighted in the next section. They represent an important section of the UK construction sector, as around 87% of businesses hire less than 10 staff members (Cressy & Olofsson, 1997; Mitchell, Wilson-Mah, & Van, 2022).

Green et al. (2005) suggest that supply chain management is central to the acceptance of an improvement agenda for the construction sector and several researches show that the main problems of materials management are in the purchasing process and control on-site and that MSMEs do not pay enough attention to these issues (Ala-Risku & Kärkkäinen, 2006; Fagbenle, Adeyemi, & Adesanya, 2004; Hewitt, 1995; Jenkins & Orth, 2004; Koontz, 2008; Motawa et al., 2007; Navon & Berkovich, 2006; Ofori, 2000; Saidi, Lytle, & Stone, 2003; Xiaohui et al., 2006).

While large companies have the capacity and capability to use sophisticated Information Technology and management to control labour and materials on projects more efficiently (Donyavi & Flanagan, 2009), the limited availability of resources of MSMEs may reduce access to new technologies or innovation (European Commission, 2010).

Thus, where large companies adopt structured control and Information Technology (IT) systems, MSMEs frequently have no systems in place and need support to implement them to improve performance and productivity on-site.

The efficiency, governance, and compliance with environmental ideals in construction, then, is made possible thanks to a decision support system that ensures Materials, Models, and Methods (3Ms) are adaptable and integrated. Recent advances in Building Information Modelling (BIM), for instance, facilitate the visualisation of sequences and production stages in construction. Yet, this falls short in giving compatibility among the 3Ms, their suitability and workability, and their financial and legislative viability.

2.2 MSMEs definition

MSMEs receive very little attention from the research community, yet they are recognised as the backbone of the entire economy as about 90% of the UK construction enterprises are of a Micro, Small or Medium size (Office for National Statistics, 2020), contributing to the regional dispersal of economic activities (Abdullah, 2000). The UK construction industry employs almost 3 million people (Keen, 2022) and MSMEs provide an important contribution to national development strategies, entrepreneurship, growth, innovation, but also to social capital being embedded into local societies (Cantafio & Parisi, 2021).

MSMEs provide complementary support and services to larger firms by acting as suppliers, contractors, and subcontractors in a range of projects from new builds to repair and maintenance (Bevilacqua et al., 2018; Bevilacqua et al., 2017; Bevilacqua, Parisi, & Biancuzzo, 2019; Parisi & Biancuzzo, 2021; Parisi & Eger, 2020). Many MSMEs, in fact, are highly specialised in providing labour and expertise to build projects, such as house extensions and renovations, or work as sub-contractors on major projects.

Cressy and Olofsson (1997) suggest that they have a lower fixed to total asset ratio, a higher proportion of trade debt as part of total assets and are heavily reliant on profits to fund investment flows. They suffer from a higher risk of bankruptcy, insolvency, and liquidation.

Table 1 shows the MSMEs classification for European Countries. When companies are below a maximum ceiling for staff members and specific levels of turnover, they qualify in one of those categories.

Table 1: MSMEs classification in Europe. Source: European Commission (2010)

Enterprise Category	Headcount	Turnover €m	Balance Sheet Total €m
Medium-Sized	<250	≤50	≤43
Small	<50	≤10	≤10
Micro	<10	≤2	≤2

2.3 Analytical Hierarchy Process (AHP), a decision-making process

The Analytical Hierarchy Process (AHP) is a decision-making method involving multiple criteria and applying both psychology and mathematics to process the selection, with minimal biases, if the final choice is not clear. The most valuable solution is recognised adopting this systematic approach based on a ranking system grounded on the importance criteria (Lee et al., 2020).

This multi criteria decision making process has first been developed by Thomas Saaty in the 1970s (Saaty, 1977). In this method the issues under investigation are put into a hierarchy to include all the attributes and then pair-wise comparisons are implemented on a nine-point ratio scale to develop overall priorities for ranking then the alternatives (Saaty, 1990).

The purpose is to assist people to organise thoughts and judgements to make more effective decisions. It is then a powerful decision-making tool to set priorities and make the best decision.

Rationality is set at the basis of this tool for concentrating and focusing on the goal to solve problems and be able to develop a thorough structure of relations and influences.

One advantage is its suitability to a wider range of decision-makers. Yet, the method involves a vast number of pair-wise comparisons (Jabri, 1990).

AHP focuses on three themes: "economics, social science and the linking of measurement with human values" (Saaty & G., 2012).

Under the economical point of view, AHP offers a diverse approach to deal with specific issues through ratio scales. It reviews the mathematical models which are interval scales and linear programming.

Under the point of view of social science, instead, "the AHP offers psychologists and political scientists the methodology to quantify and derive measurements for intangibles" (Saaty & G., 2012).

The third theme, instead, is concerned with providing people in the physical and engineering science with a quantitative method to link hard measurement to human values. In such a process one needs to interpret what the measurements mean. Numbers are useless until it is understood what they mean and even then, there may be different meanings to different problems (Saaty, 2008). Table 2 highlights advantages and disadvantages of this tool.

Table 2: AHP description, advantages and disadvantages. Source: Authors' elaboration (2022)

	AHP
Description	Basic approach to decision making. A pair wise comparison judgment to develop overall priorities for ranking the different available alternatives.
Advantages	Non-linear framework for inductive and deductive thinking without syllogism. Capability to structure a decision in hierarchy. Capability for improving consistency. Acceptable to multiple decision makers.
Disadvantages	Lack of complete high levels of accuracy. Vast pair-wise comparisons.

3. METHODOLOGY

This manuscript employs a mixed methodology, combining document reviews, semi-structured interviews, and observations to gather data. To ensure a representative sample, a thorough selection process was conducted.

Initially, twenty construction companies were reviewed, and three MSMEs were chosen based on their working areas, as outlined in Table 3. These companies are privately owned and located in the South-eastern area of England. Each of the selected MSMEs has short-term plans that encompass a diverse range of projects at various stages of development. For the purpose of this study, nineteen projects were observed throughout their lifecycle stages, with a particular focus on the procurement routes adopted, materials delivery, specifications, and handling.

This methodology enabled longitudinal research, allowing for the collection of data over an extended period. The collected raw data was subsequently coded, grouped, linked, and analysed using the Analytic Hierarchy Process (AHP) Multi-Criteria Decision Making technique.

AHP was chosen as the analytical tool for data analysis due to its ability to assist in selecting the best solution among multiple alternatives based on various criteria. In this process, the decision maker performs pair-wise comparisons, assigning values to different criteria, which are then used to determine overall priorities for ranking the alternatives.

By employing a mixed methodology and using AHP for data analysis, this study ensures a comprehensive and systematic approach to understand the challenges and dynamics of materials management in MSMEs within the construction industry. The selected sample of three MSMEs and nineteen projects provides valuable insights into the industry's practices and allows for meaningful analysis and interpretation of the collected data.

Table 3: Selected MSMEs characteristics. Source: Donyavi and Flanagan (2009)

MSME	Project Types	Headcount	Turnover (£ m)		
			2005	2008	2010
1	Established in 1992, the company focuses especially on hard and soft architectural landscape	≤ 65	4.9	0.7	5.8
2	Established in 1987, the company focuses especially on building and civil engineering	≤ 135	9.1	1.4	8.9
3	Established in 2001, the company focuses especially on construction – building extensions and refurbishment	≤ 8	2.2	0.09	1.5

4. DATA COLLECTION

The focus of the study is on the materials' purchasing process and its complexity; thus, cases had to be relevant representing all the significant attributes in the stage.

The aim was to observe and deduce the systems and processes on-site. Observation, semi-structured interviews, and document reviews were chosen for the research.

Three case studies (MSMEs) and their 19 projects (cases) were observed, then owners, managers, and site managers interviewed to understand priorities and methods of organising the procurement of materials and the management of their projects throughout the stages. The research also investigated materials' supply from the perspective of suppliers and logistic tracking companies responsible for supply and delivery.

The challenge was the diversity of projects and the different stages of the production process. The observations were undertaken from the beginning of the process at materials specification and was carried out for 1-3 hours each time; based on the project progresses and availability of materials on-site. Each observation began before work commenced on-site as materials specification was an important element of the research. The stages of purchasing process were also observed throughout the stages of the projects.

Accessibility of the chosen infrastructure was taken into consideration as well (i.e., access to the site, access to the documents and key personnel involved in the project).

The literature review revealed a substantive list of items, but there was no evidence of an attempt to weight them, nor were the issues related to the project sequence. These gaps have been addressed in this manuscript.

4.1 Identification of the problems

Observations allowed the researchers to understand the fundamental issues that the workforce faces daily. The identification of the problems began at the specification stage of materials. To achieve this, a list of problems from the purchasing process, based on the literature review, was developed (see Table 4). These problems occurred while observing the projects and then they were categorised under four categories (Planning and scheduling, Communication, Control and tracking, Skills and resource availability) and three criteria (Management and organisation (M), Technology and system (T), and Financial (F)).

Table 4: Issues experienced on construction projects. Source: Authors' elaboration (2022)

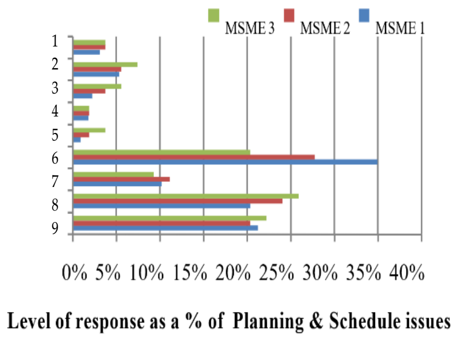
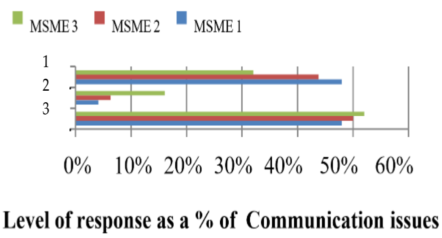
	Issues experienced on construction projects	No. of times the problems occurred		
		MSME1 15 projects	MAMES 2 2 projects	MSME 3 2 projects
1	Lack of expertise on site for receipt/placement of materials	43	9	5
2	Lack of proper schedule for ordering materials on site	40	9	0
3	Lack of up-to-date information on exact arrival of materials	33	5	2
4	Lack of purchasing order list on site	31	8	4
5	Improper categorisation of materials to be ordered	28	6	4
6	Wrong quantity of materials delivered	28	5	3
7	Wrong quality of materials delivered	24	4	3
8	Insufficient payment control	22	5	4
9	Improper checking of existing stock	21	3	1
10	Price of materials above estimated price	19	4	4
11	Responsible person for approving receipt is unavailable	19	4	3
12	Wrong materials delivered	15	3	2
13	Responsible person unavailable for directing materials to the correct position	14	4	3
14	Materials arrive on site at the wrong time	14	4	3
15	Ambiguity/confusion of responsibilities for materials management	14	3	3
16	Incorrect checking of materials received against receipt or bill of lading	12	4	3
17	Lack of cash flow for materials purchase	11	3	4
18	Loss of information during documents transfer	10	2	3
19	Inappropriate choice of shipping firm	10	2	1
20	Difficulty in obtaining samples	10	2	1
21	Omission of evaluation process	9	2	4
22	Poor tracking/monitoring materials on site	9	2	2
23	Unavailability of specific place for storing evaluation form	7	2	2
24	Inadequate material tracking	7	2	2
25	Late receipts of invoice	7	1	1
26	Wrong invoices received	7	1	1
27	Missing list of materials to be ordered	6	1	1
28	Poor information for monitoring materials lack of communication	6	2	0
29	Materials forgotten/not thought of in planning/ordering process (untargeted)	5	1	1
30	Incorrect classifications of materials for ordering	4	2	2
31	Lack of clarity of order e.g., type. quantity quality etc.	4	2	2
32	Responsible people unavailable for liaising with supplier/deliverer	4	1	2
33	Volume of waste materials on site	4	1	2
34	Burdensome paperwork	4	1	1
35	Delivered materials different from the sample tested	4	0	1
36	MSME forgot to order materials	3	1	2
37	Wrong quotations obtained from suppliers	3	1	1
38	Unpredictable changes in material price	3	1	1
39	Unclear criteria (price or service) when ordering materials	3	1	0
40	Improper evaluation formats (for supplier evaluation)	3	1	0
41	Unclear on materials availability-Incorrect technology use	3	1	0
42	Poor accessibility to client/supplier-lack of communication	2	2	1
43	Changing purchasing order by client	2	1	3
44	Incorrect information for supplier selection	2	1	2
45	Lack of petty cash for unpredictable small purchases	2	1	2
46	Late quotations obtained from supplier	2	1	2
47	Non-availability of materials because of shortage	2	1	1
48	Incorrect contract payments from clients for materials	2	1	3
49	Loss of receipt	2	1	1
50	Wrong materials received (not matching purchasing order)	2	1	1
51	Shortage of materials-errors in estimation	1	1	3
52	Lack of available storage space for materials	1	1	1
53	Unviability of accesses to the site	1	1	2
54	Loss of approval receipt	1	1	1
55	Lack of proper information for evaluation-document lost	1	1	1
56	Improper disciplines for stock	1	1	1
57	Difficulty with site waste materials that need to be removed	1	1	1
58	Lack of proper technology to track materials	1	2	0
59	Loss of evaluation forms	1	1	0

The identified 59 issues had to be further classified, as the number was too high to achieve an effective analysis. Table 4 shows the classification of each of the problems under their subordinate heading, i.e., the main categories. These headings constitute the criteria for the AHP calculation.

The table shows the number of times the issues occurred on-site for each project. As the number of projects observed for each MSME differed, the frequency was translated into percentage terms, and this is shown as a bar chart in Table 5.

The frequency that figures show in Table 6 give the relationship between the three criteria. By using percentages, the difference in the numbers of projects observed in each MSME is negated and comparisons can be made. The ratio between them is the basis of the AHP matrix for criteria comparison.

Table 5: Classified issues by categories, including frequency of observation per MSME. Source: Authors' elaboration (2022)

Categories	Classified issues	Issues by code	Criteria	Frequency of observation per MSME
Planning and Scheduling	Materials storage and space Availability (1)	49, 10, 45,50, 53,23	M	
	No supplier evaluation/feedback (2)	21, 39	M	
	Waste materials management (3)	33, 57	M	
	Burdensome paperwork (4)	34	M	
	Unplanned purchases (5)	43	F	
	Incorrect & incomplete materials (6)	12, 6, 7, 36,26,50	T	
	Poor time management (7)	44,25, 14	M	
	Inaccuracy/lack of clarity (8)	29, 30,10, 38,15,48	M	
	Inadequate planning (9)	2,29,36	M	
Communication	Disconnect between planning andsite activities (1)	4,5	T	
	Unexpected changes (2)	38,43	F	
	Loss of information/poor communication (3)	34,3,42,40,58,28, 18,55	M	

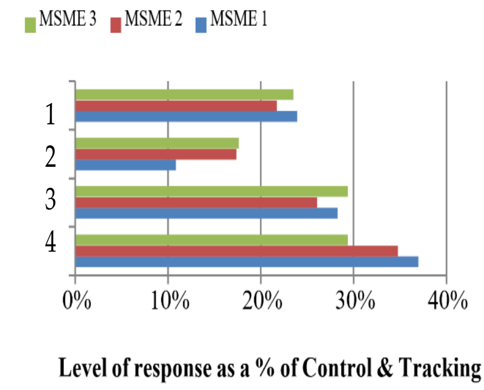
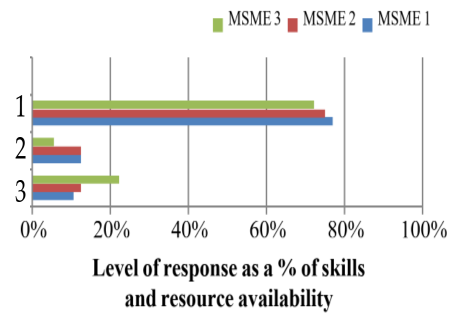
Control and Tracking	Inadequate payment control	8	M	
	Loss of paperwork	49,54,59,27	T	
	Inadequate tracking	19,22,24	T	
	Poor inventory/stock control	16,9,56	F	
Skills and resource availability	Lack of expertise people	1,32,13,11	F	
	Inadequate information of available resource	20,41	T	
	Lack of cash flow	17	M	

Table 6: the issues classified according to the criteria. Source: Authors' elaboration (2022)

Criteria	Coding according to the list	Times the problems occurred		
		MSME 1	MSME 2	MSME 3
Management and Organization	2, 29, 30, 49, 45, 50, 12, 6, 7, 44, 36, 38, 39, 4, 5, 15, 25, 26, 48, 1, 32, 13, 53, 16, 11, 21, 23, 9, 56, 29, 50, 36, 14, 33, 57	379	91	80
Technology and System	20, 34, 3, 42, 41, 40, 19, 58, 28, 18, 49, 54, 55, 59, 22, 27, 24, 34	112	30	19
Financial	43, 10, 38, 17, 8, 43	59	15	18

5. DATA ANALYSIS AND DISCUSSION

The aim of this step is to explore the levels in the analysis, understand how the process works, and determining the relative weights and rankings of criteria and categories. The process starts by identifying the objectives, then the criteria, and finally the categories. Then, the information is arranged in a hierarchical tree, and synthetised to determine relative rankings of each category. Both qualitative and quantitative criteria can be compared using informed judgements to derive weights and priorities.

Following this, pairwise comparisons are made, where the relative importance of one criterion over another is expressed in a matrix. This allows several factors to be looked at checking for simultaneously dependence and feedback and making numerical trade-offs to get a synthesis or a point of conclusion, delivering a decision-making process able to make the best choice. The eigenvector solution is the best approach and can be obtained by a short computational exercise to raise the pairwise matrix to powers, which are successively squared each time; the sum of the rows is then calculated and normalised. The computer is instructed to stop when the difference between these sums in two consecutive calculations is smaller than a prescribed value. For each of the processes the result produces a chart or a table to show the weight or comparison between different categories and ranks the categories. The analysis process was repeated for each of the three MSMEs, to find and compare the results.

An AHP decision-making software helped to automate and speed up the process and provide the relationships between the data. The raw data gathered during observations and interviews, have been coded, grouped, linked, and analysed. Unrelated categories have been removed if there was no link between them. AHP has the capability to structure a hierarchical decision which consists of three levels, the goal at the top, followed by a second level which is criteria, and alternatives located on the third level (Figure 1).

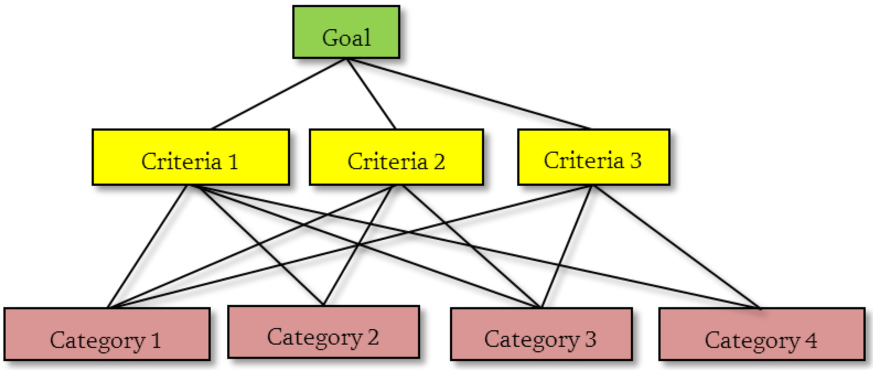


Figure 1: AHP hierarchy. Source: Authors' elaboration (2022)

The fundamental scale of values represents the intensities of judgement as shown in Table 7. A basic but reasonable assumption is that if attribute A is more important than attribute B and is rated at 9, then B must be absolutely less important than A and has a value of 1/9.

Table 7: Fundamental scale for pairwise comparisons. Source: Saaty (2008)

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	Two elements contribute equally to the objective.
3	Moderate Importance	Experience and judgment slightly favour one element over another
5	Strong Importance	Experience and judgment Strongly favour one element over another
7	Very Strong Importance	One element is favoured strongly over another, its dominance is demonstrated in practise.
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation.
Intensities of 2, 4, 6 and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3 etc. can be used for elements that are very close in importance		

The most important and creative part in making decisions through AHP is deciding what factors should be included in the hierarchical structure. Enough relevant level of detail to represent the issue as thoroughly as possible is important, but not so thoroughly as to lose the sensitivity to change the elements.

5.1 Criteria and categories in the pairwise comparison

This section discusses the findings from the qualitative analysis of the observations and semi-structured interviews undertaken with the selected MSMEs highlighted above. The environment of the issue and the participants associated with the issue were also under observation. The purpose of the analysis is to gain an understanding of the issues involved in the materials' purchasing process and to rank and weight their importance. The results will provide a better understanding of the purchasing process issues to help find ways of improving it for MSMEs. Data gathered through observations, interviews and document review were analysed and coded/categorised into the AHP framework. Thus, they were split between the three main criteria in the first instance and then the four categories highlighted above.

The elements of criteria and categories (purchasing issues) were analysed within their context/environment and sorted into a broad range of groups, which were further refined. This process led to the grouping shown above in Tables 5 and 6.

The study was divided into two levels, one with more general issues at the top level known as "criteria'' and the other one including more detailed issues at the lower level known as "categories" (Figure 2).

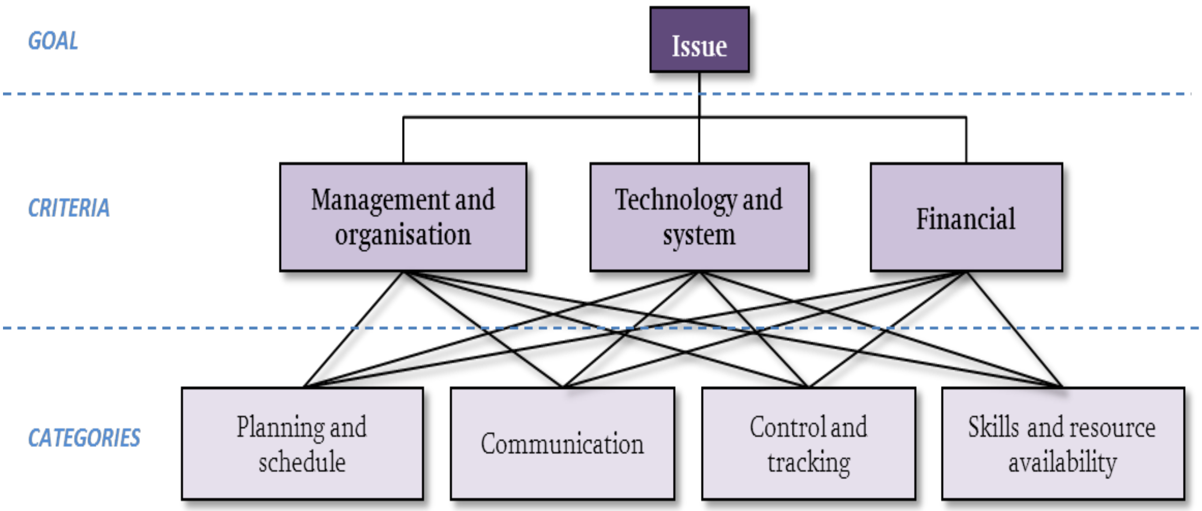


Figure 2: Criteria and categories in the pair-wise comparison. Source: Authors' elaboration (2022)

5.2 Correlation between criteria and categories

This section is about the correlation between criteria and categories. The number of comparisons is based on the formula: n (n-1)/2; where n is the number of elements for criteria or categories (Saaty, 2001). For example, for criteria there are 3 elements, so n=3. Thus, the number of comparisons is 3 (3-1)/2 = 3. For categories, instead, the number of elements is 4, so n=4. Thus, the number of comparisons is 4 (4-1)/2 = 6.

This will be used to make a reciprocal matrix for pairwise comparisons. It is a 3*3 reciprocal matrix comparison for criteria (data collected from table 6) and the three comparisons are:

- Management and Organisation vs. Technology and System,
- Management and Organisation vs. Financial,
- Technology and system vs. Financial.

A 4*4 reciprocal matrix comparison was made for categories (data collected from table 5) and the 6 comparisons are as follows:

- Planning and Schedule vs. Skills and Resource availability,
- Communication vs. Control and Tracking,
- Communication vs. planning and Schedule,
- Control and Tracking vs. Skills and Resource availability,
- Control and Tracking vs. Planning and Schedule,
- Communication vs. Skills and Resource availability.

There are 3 criteria to compare, which is the reason why a 3*3 matrix was created, according to Saaty's formula: n(n-1)/2 (Saaty, 2001). The diagonal elements of the matrix are always 1 for pairwise comparison. So, by comparing the 3 criteria according to the above data for MSME1, the completed comparison matrix is illustrated in the equation 5-1. The first column of the matrix is the ratio between the three criteria based on the data collection and analysis. Table 6 shows the ratio. All the equations relate to MSME1.

Equation 5-1

$$\begin{array}{ll} \text{Management and Organisation:} & M \\ \text{Technology and System:} & T \\ \text{Financial:} & F \end{array} \begin{pmatrix} 1/1 & 3/1 & 6/1 \\ 1/3 & 1/1 & 2/1 \\ 1/6 & 1/2 & 1/1 \end{pmatrix} \longrightarrow \begin{pmatrix} 1 & 3 & 6 \\ 0.33 & 1 & 2 \\ 0.16 & 0.5 & 1 \end{pmatrix}$$

After calculating the comparison matrix, the principal vector must be computed. This is the normalised eigenvector of the matrix and can be obtained by averaging across the rows. Squaring the matrix is necessary for normalising the eigenvector. Then the process must be repeated until it does not change from the previous iteration, or the difference is negligible. The normalised principal eigenvector is also called priority vector; since when it is normalised, the sum of all the elements of the priority vector is 1. The priority vector shows the relative weights among the items that are being compared. To normalise the eigenvector, the matrix (Equation 5.1) should be squared. To compute the first eigenvector, equation 5.2 is used:

Equation 5-2

$$\begin{array}{l} M \\ T \\ F \end{array} \begin{pmatrix} 1 & 3 & 6 \\ 0.33 & 1 & 2 \\ 0.16 & 0.5 & 1 \end{pmatrix} \begin{pmatrix} 1 & 3 & 6 \\ 0.33 & 1 & 2 \\ 0.16 & 0.5 & 1 \end{pmatrix} \longrightarrow \begin{pmatrix} 2.98 & 9 & 18 \\ 0.99 & 2.99 & 5.98 \\ 0.49 & 1.49 & 2.99 \end{pmatrix}$$

Equation 5-3

$$\begin{matrix} M \\ T \\ F \end{matrix} \quad \begin{pmatrix} 2.98 + 9 + 18 \\ 0.99 + 2.99 + 5.98 \\ 0.49 + 1.49 + 2.99 \end{pmatrix} = \begin{matrix} 29.98 \\ 9.96 \\ \underline{4.99} \\ 44.93 \end{matrix} \xrightarrow{\text{Normalise}} \begin{pmatrix} 0.67 \\ 0.22 \\ \underline{0.11} \\ 1 \end{pmatrix}$$

To verify consistency this process must be repeated until the eigenvector solution does not change from the previous iteration or difference is negligible. The normalised scores in equation 5.3 shows a marked difference and so the matrix should be squared again:

Equation 5-4

$$\begin{matrix} M \\ T \\ F \end{matrix} \quad \begin{pmatrix} 2.98 & 9 & 18 \\ 0.99 & 2.99 & 5.98 \\ 0.49 & 1.49 & 2.99 \end{pmatrix} * \begin{pmatrix} 2.98 & 9 & 18 \\ 0.99 & 2.99 & 5.98 \\ 0.49 & 1.49 & 2.99 \end{pmatrix} = \begin{pmatrix} 26.79 & 80.74 & 161.49 \\ 8.9 & 26.82 & 53.65 \\ 4.459 & 13.44 & 26.88 \end{pmatrix}$$

Computing the second eigenvector:

Equation 5-5

$$\begin{pmatrix} 26.79 + 80.74 + 161.49 \\ 8.9 + 26.82 + 53.65 \\ 4.45 + 13.44 + 26.88 \end{pmatrix} = \begin{matrix} 269.03 \\ 89.37 \\ \underline{44.77} \\ 403.19 \end{matrix} \xrightarrow{\text{Normalise}} \begin{pmatrix} 0.67 \\ 0.22 \\ \underline{0.11} \\ 1 \end{pmatrix}$$

The next stage is to calculate the difference between the previous two eigenvectors:

Equation 5-6

$$\begin{pmatrix} 0.67 \\ 0.22 \\ 0.11 \end{pmatrix} - \begin{pmatrix} 0.67 \\ 0.22 \\ 0.11 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

Since the computed eigenvector (Equation 5-6) is 0, the normalisation shows that management is at the top with 0.683, then technology with 0.177, and finally financial at 0.14. The same process was undertaken for categories comparison under each criterion.

To check consistency, it is also possible to test the consistency ratio (CR), that must be less than 0.1 (CR<0.1). CR can be calculated according to the following formula (Saaty, 2008):

CR = CI/RI, CI is the consistency Index that can be obtained through CI = λ max-n/n-1, where λ max is the largest Eigen value and for this equation is (see table 8):

λ max= (0.67) *(1.496) + (0.22) * (4.5) + (0.11) * (9) = 2.98232 and n is the number of criteria, which is 3.

Thus:

CI = 2.98232-3/2 = 0.00883

RI is the Random Consistency Index and can be obtain from table 9, then: CR=0.00883/0.52=0.0165<0.1 which means equation 5.3 is quite consistent.

Table 8: Pair comparison matrix level 1. Source: Authors' elaboration (2022)

Criteria	M	T	F	Priority Vector
M	1	3	6	67%
T	0.33	1	2	22%
F	0.16	0.5	1	11%
SUM	1.49	4.5	9	100%

Table 9: RI: Random Consistency Index. Source: Saaty (2008)

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Data from Tables 5 and 6 are processed for comparison through the AHP tool to study their correlation for the first preference (in this case, Management). The next sections, then, will focus on the relative weights of the comparison criteria, category comparison, category ranking, sensitivity analysis for management, technology and financial for the three chosen MSMEs.

5.3 Determination the relative weights of the comparison criteria

The categories were compared against the criteria to better understand the relationships between the two. Table 10 shows the values of the comparisons and figure 3 is a graphic representation of the hierarchical relationships.

Table 10: category comparison data. Source: Authors' elaboration (2022)

Category / Criteria	Communication	Control and Tracking	Planning and Schedule	Skills and Resources
Financial Management and	11.58	37.83	5.64	44.95
Organization Technology and	13.98	8.03	51.99	26.00
System	53.40	10.50	20.80	15.30

Red lines in figure 3 show the highest scores in each comparison. For what concern management and organisation, planning and schedule account the highest score with 51.99%, almost double the skills and resource score 26.00%, and over 3 times the communication score, with control and tracking having the lowest value at 8.03%.

Regarding the Technology and system criterion, then, communication scores the highest with 53.40%; this figure is over double the one of Planning and Schedule, which is in second place. Control and tracking is the least important with 10.50%. Under the Financial criterion, skills and resource availability is the highest rate with 44.95%, but, unlike the other criteria, this percentage is like the category occupying the second place, namely, control and tracking. Together, both account for about 83% of the score. The least important is planning and schedule with 5.64%.

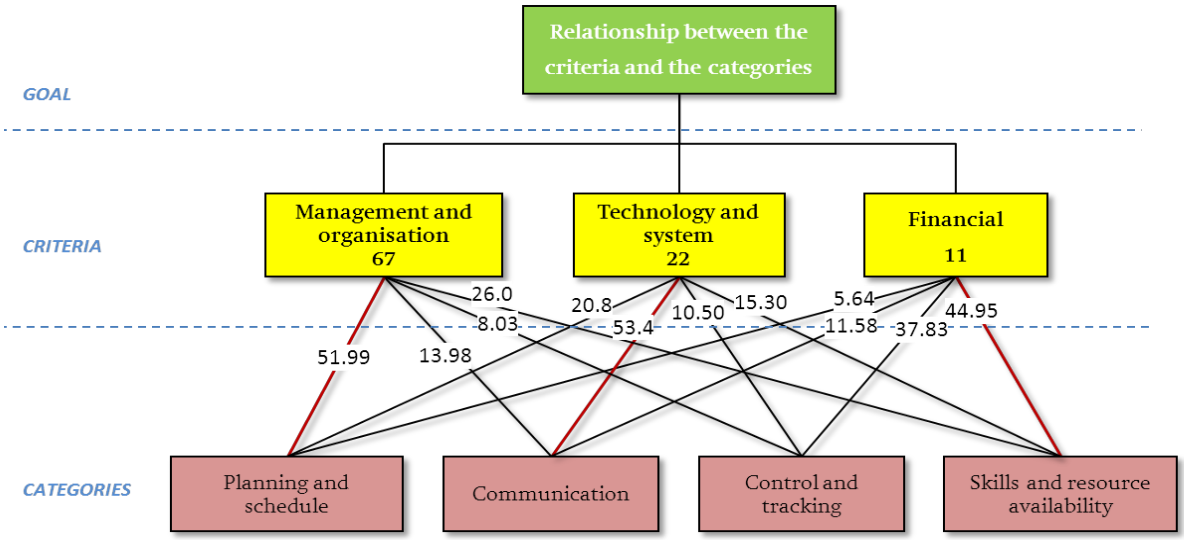


Figure 3: category ranking according to each criteria (%). Source: Authors' elaboration (2022)

The next step of data analysis will be category ranking and sensitivity analysis for each criterion.

5.4 Category ranking

Table 11 shows the ranking of the 4 categories: planning and schedule, skills and resource, communication, control and tracking against the three criteria. Planning and schedule score the highest with 40.03% and control and tracking the least important with 11.85%.

Table 11: data table category ranking. Source: Authors' elaboration (2022)

Category	Total	Financial	Management and Organization	Technology and System
Planning and Schedule	40.03	0.64	34.83	4.56
Skills and Resources	25.73	4.94	17.42	3.37
Communication	22.39	1.27	9.37	11.75
Control and Tracking	11.85	4.16	5.38	2.31

5.5 Sensitivity analysis

Sensitivity analysis shows to what extent the viability of a project is influenced by variations in major quantifiable variables and illustrates the effects of criteria change on the values of category's parameters. Steeper (rising or falling) lines show greater or less influence of the criteria on the categories. A relatively flat line, instead, indicates that a variable has little effect on the categories.

The idea of a sensitivity analysis is to test the change or removal of a variable and its effect on the other categories. Data derived from tables 5 and 6 developed the figures accordingly.

5.5.1 Sensitivity analysis (Management and organisation)

The line chart in figure 4 shows the percentage of the current weights of the management and organisation (66.67%) for different categories. Planning and schedule account for 40.03%, skills and resource scoring 25.73%, communication representing 22.39% and control and tracking the lowest with 11.85%. If the current weight (66.67%) of management and organisation is changed to a greater rate such as 76.89%, then the influences of Communication and Control and tracking decreases to 21.04% and 10.90% respectively. However, the performance of Planning and schedule and Skills and resource both increase to 43.45% and 26.42 % respectively.

If the current weight (66.67%) of management and organisation is changed to a smaller rate such as 65%, then the influence of Communication and Control and tracking increases to 23.45% and 12.14% respectively. However, the influence of Planning and Schedule and Skills and resource fall to 38.57% and to 24.93% respectively.

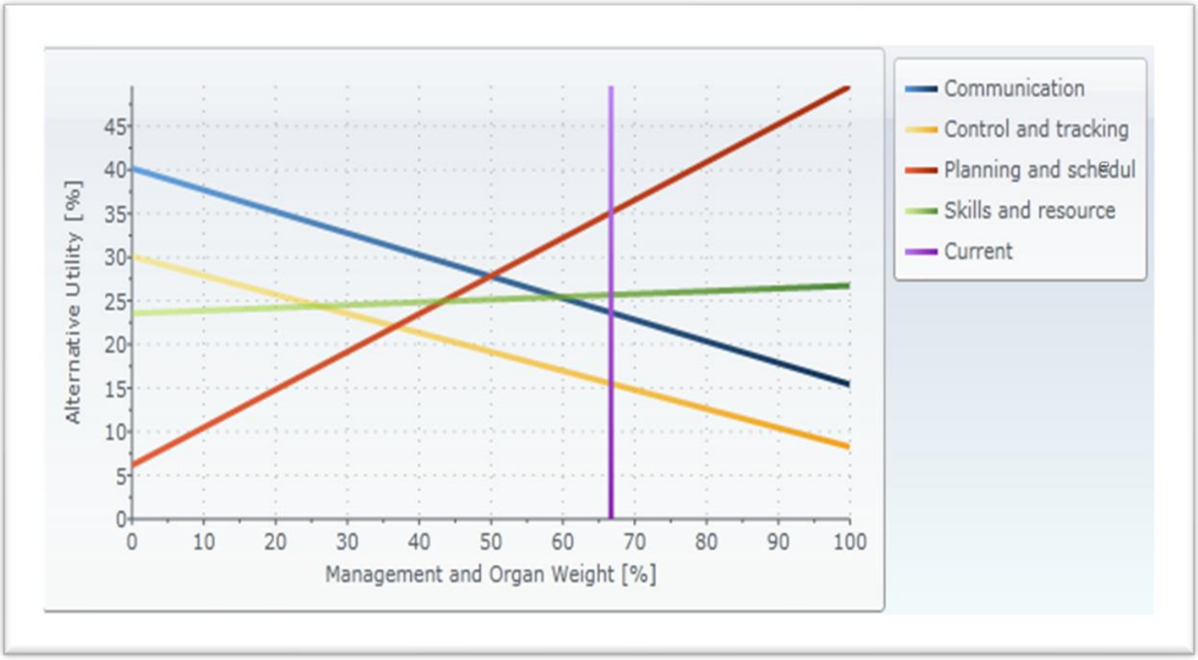


Figure 4: Sensitivity analysis (Management and Organisation) with current weight = 66.67%. Source: Authors' elaboration (2022)

5.5.2 Sensitivity analysis (Technology and System)

The line chart in figure 5 shows the percentage of the current weights of the technology and system (22.22%) for different categories. Planning and schedule account for 40.03%, skills and resource score 25.73%, communication represents 22.39% and control and tracking the lowest with 11.85%.

If the current weight of technology and system is changed to a greater rate such as 23%, then the influence of Communication and Control and tracking increase to 23.31%; and 12.14% respectively. However, the performance of Planning and schedule and Skills and resource decreases to 39.12% and 24.20% respectively.

If the current weight (22.22%) of technology and system is changed to a smaller rate: such as 12.22%, the influence of Communication and Control and tracking decreases to 18.80% and 10.32% respectively. The influence of Planning and schedule and Skills and resource increases to 42.70% and 27.42% respectively.

According to the literature review (Ala-Risku & Kärkkäinen, 2006; Fagbenle et al., 2004; Fiala, 2005; Hewitt, 1995; Navon & Berkovich, 2005) communication is crucial for improving purchasing materials. The sensitivity analysis showed that information and communication technologies can improve materials management for MSMEs.

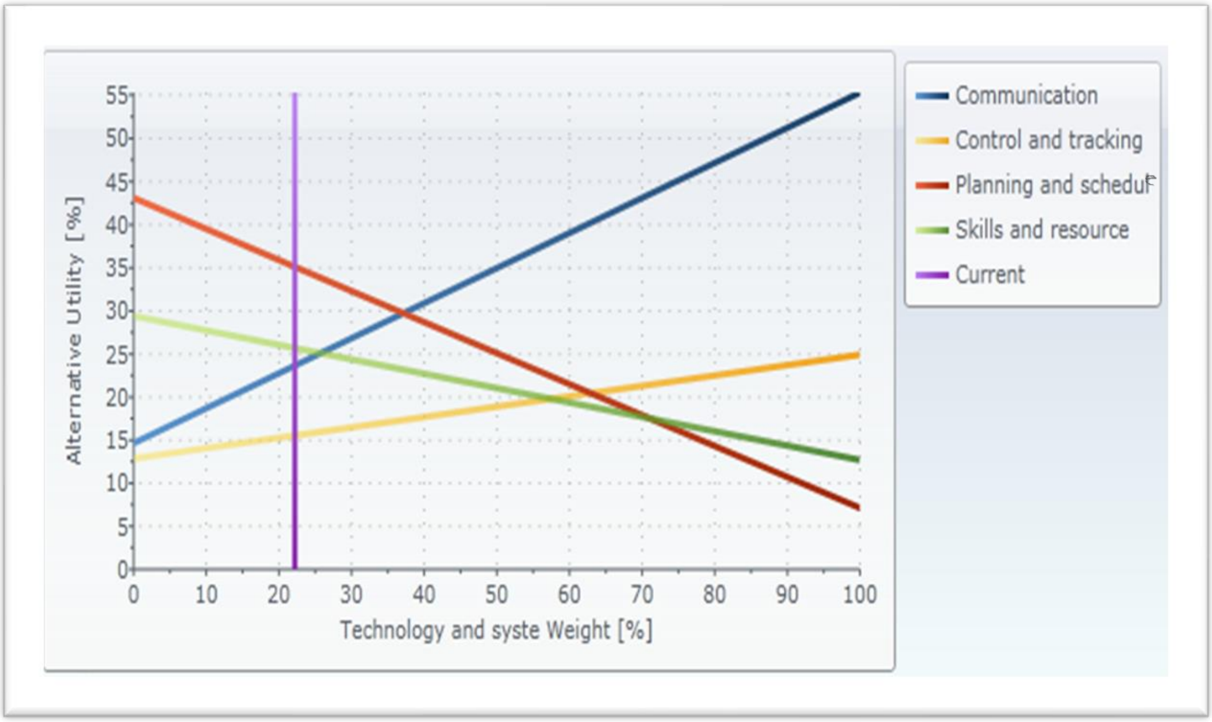


Figure 5: current rate sensitivity analysis (Technology and system) with current weight = 22.22%. Source: Authors' elaboration (2022)

5.5.3 Sensitivity analysis (Financial)

The line chart in Figure 6 shows the percentage of the current weights of the financial (11.11%) for different categories. Planning and schedule account for 40.03%, skills and resource score 25.73%, communication represents 22.39% and control and tracking the lowest with 11.85%.

If the current weight (11.11%) of financial is changed to a greater rate such as 21.11%, then the influence of Communication drops to 21.12% and the influence of Control and tracking rises to 12.95%. The influence of Planning and schedule decrease to 38.25% while the influence of Skills and resource moves up to 26.58%

If the current weight (11.11%) of financial is changed to a smaller rate such as 9.9 %, then the influence of Communication increases to 22.39%; the influence of Control and tracking decreases to 10.35%; Planning and schedule's influence increases to 41.85% and the influence of Skills and resource drops to 24.45%.

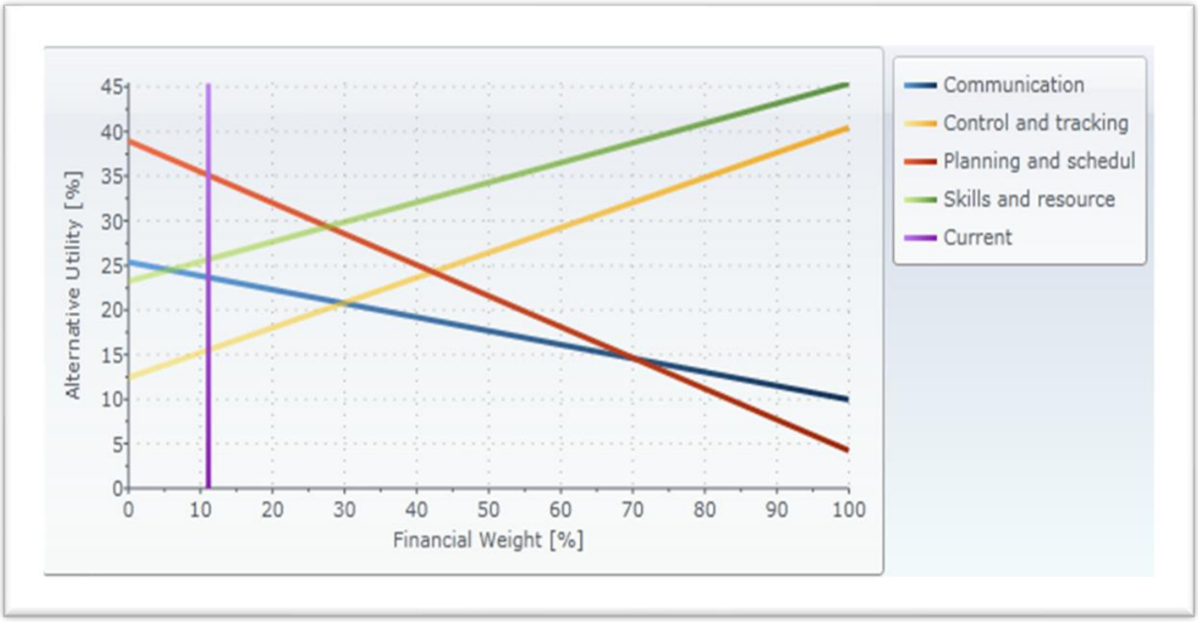


Figure 6: current rate sensitivity analysis (Financial) with current weight = 11.11%. Source: Authors' elaboration (2022)

5.6 The key points from the analysis

The findings of this study provide valuable insights into the priorities and dynamics of materials purchasing in MSMEs within the construction industry. These findings align with recent studies and shed light on the significance of various categories and criteria in optimising the purchasing process.

Figure 3 presents a comparison of the categories against the criteria for each chosen MSME. The results indicate that planning and schedule ranked as the most crucial category, followed by skills and resources, communication, and control and tracking. This finding is consistent with recent studies, highlighting the importance of effective planning and scheduling in optimising materials management (Nolz, 2021). Additionally, the prioritisation of skills and resources underscores the significance of a skilled workforce and appropriate resource allocation for successful materials procurement (He, Li, & Wang, 2021).

The category ranking analysis presented in Table 10 further reinforces these findings. Planning and schedule emerged as the primary issue, followed by skills and resources, communication, and control and tracking. This suggests that improving the efficiency of these key issues can have a significant positive impact on the overall purchasing process. Recent studies have also emphasised the importance of efficient planning and resource management in the construction industry (Nagaraju & Reddy, 2012).

The sensitivity analysis conducted in this study explored the impact of varying weights assigned to different criteria. The results revealed that changes in weight allocation influence the relative importance of each criterion. For instance, an increase in the weight of management and organisation reduces the need for communication and control and tracking but increases the importance of planning and skills and resources. On the other hand, an increase in the weight of technology and system highlights the greater need for communication and control and tracking, while decreasing the importance of planning and schedule and skills and resources. These findings align with recent research emphasising the role of technology in improving communication and tracking in the purchasing process (Ibem & Laryea, 2014).

It is worth noting that the literature review identified poor communication as a key issue during the purchasing process. However, the sensitivity analysis (Figure 5) revealed that a decrease in the weight assigned to technology reduces the need for communication. This suggests that technology can play a significant role in improving communication during the purchasing process, as supported by recent studies (Rejeb, Sűle, & Keogh, 2018).

Furthermore, Figure 7 presents the relative weights of the comparison criteria, highlighting their importance and relationships. According to the pie chart, the organisation and management criterion emerges as the most important issue during the purchasing process. This finding aligns with recent studies emphasising the significance of effective organisational and managerial practices in optimising materials procurement (Said & El-Rayes, 2011). Technology and system rank as the second most important criterion, further emphasising the potential of technology in enhancing the purchasing process. The financial criterion represents the third most important aspect, underscoring the need for effective financial management during materials procurement.

Overall, these findings contribute to the existing body of knowledge and provide practical insights into the priorities and dynamics of materials purchasing in MSMEs within the construction industry. The alignment with recent studies underscores the reliability and validity of the findings, highlighting the importance of planning, skills and resources, communication, and control and tracking in optimising the purchasing process. The sensitivity analysis further demonstrates the impact of weight allocation on the relative importance of each criterion, while the literature review and the pie chart support the role of technology, organisation and management, and financial considerations in materials procurement.

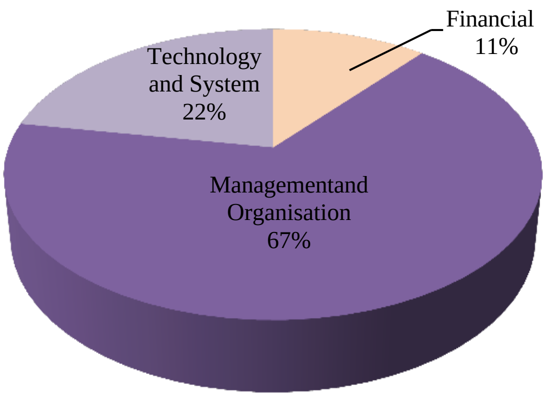


Figure 7: Weight of the comparison criteria. Source: Authors' elaboration (2022)

6. CONCLUSIONS

The research highlights the main areas where construction companies of a Micro, Small and Medium size can improve their materials management, particularly during the purchasing process phase. It demonstrates the complexity of this process, the issues that can arise and the main areas within the purchasing process where most of the issues occur.

The observed MSMEs worked on a project-to-project short-term basis, where materials arrive on-site on a Just-In-Time basis, often procured from the lowest cost provider.

By their nature, MSMEs do not have full design details and often lack up-to-date and detailed information. Frequently, the design team is not retained after the bid stage, leading to the contractor dealing directly with the client and jointly solving both design and production issues.

MSMEs need to make assumptions when estimating materials, which is often based on experience with inadequate information and insufficient time spent at the bid stage.

Fifty-nine main issues were identified based on literature review, interviews, and site observations.

Delays during the production process were identified among the main issues when purchasing materials. These are often caused by insufficient lead-time for ordering materials and unrealistic time plans, which affect the project timeline.

Other elements affect the materials' purchasing process during projects, such as: inadequate estimate for the cost of transportation (e.g., fuel cost), little understanding and tracking of materials' price increases, lack of correct plant and equipment being available at the project for the materials, little thought for handling materials once they are off-loaded to the site because of packaging, unpredictable events, and inadequate schedule delivery time.

Interviews and observations confirmed the lack of planning and management systems for the procurement of materials.

Issues and times were identified during the observations and then categorised into different subordinates, which were further classified into four different categories and three criteria.

The AHP technique was used to analyse the data to find out the degree of importance of the problems. This tool allowed to understand the relationship between the issues and then rank them.

According to the relative weights of the comparison criteria for the three analysed MSMEs, it was discovered that Management and Organisation can be considered as the main issue in the process of purchasing materials. This is then followed by Technology and System, and lastly, Financial.

If the current rate of technology decreases, for instance, there is less need for communication; thus, technology is identified as one way for improving the purchasing materials for what concern communication.

Yet, whilst advances in IT help to provide better integration of design and production information, this has to deal with the fragmentation issue affecting many small sub-contractors working on construction projects with little planning and control.

Limitations of the Study

The exploratory character of this contribution implies several limitations, reflected mainly in the methodological aspect.

The AHP pairwise comparisons of the issues, for instance, can only be subjectively performed and thus their accuracy depends on the knowledge and experience of the respondents.

It is important to also highlight the limitedness in the number of observations, which made the results modestly significant under a statistical point of view.

Recommendations for Future Work

Further Validation and Application: Future research should focus on validating and applying the developed Analytic Hierarchy Process (AHP) framework in real-world scenarios involving MSMEs in the construction industry. This can help establish the effectiveness and practicality of the proposed approach in optimising material, method, and model selection.

- Case Studies: Conducting a more comprehensive study based on more case studies. Broadening the sample of the selected MSMEs will strengthen the findings of the research and provide valuable insights into the implementation of the AHP framework across different MSMEs and construction projects. These case studies can evaluate the framework's performance, identify potential challenges, and gather feedback from practitioners to refine and improve its application.
- Integration of Sustainability Considerations: It is essential to incorporate sustainability considerations within the AHP framework. Future work can explore the integration of environmental, social, and economic factors to support MSMEs in making sustainable choices regarding materials, methods, and models. This can contribute to more environmentally friendly and socially responsible construction practices.
- Enhanced Decision Support Tools: Developing user-friendly decision support tools and software based on the AHP framework would facilitate its adoption among MSMEs in the construction industry. These tools can provide a structured and intuitive interface for users, making the decision-making process more accessible and efficient.
- Long-Term Performance Evaluation: To assess the long-term benefits of the AHP framework, future studies could focus on evaluating the performance and outcomes of projects where the framework has been implemented. This analysis would help measure the effectiveness of the AHP approach and identify areas for improvement.
- Collaboration and Knowledge Sharing: Encouraging collaboration between researchers, practitioners, and industry stakeholders is crucial for the advancement and wider adoption of the AHP framework. Establishing platforms for knowledge sharing, such as conferences, workshops, and industry forums, can facilitate the exchange of ideas, experiences, and best practices.
- Comparative Studies: Conducting comparative studies between the AHP framework and other decision-making approaches or optimisation methods can provide valuable insights into the strengths and weaknesses of different methodologies. This comparative analysis can help researchers and practitioners make informed decisions when selecting the most suitable approach for specific construction scenarios.
- Continuous Improvement and Adaptation: The AHP framework should be viewed as a dynamic tool that evolves with changing industry needs and advancements. Future work should focus on continuously refining and adapting the framework to address emerging challenges and incorporate new developments in materials, methods, and models within the construction industry.

By addressing these recommendations, future research can build upon the existing work, further enhancing the effectiveness and applicability of the proposed AHP framework targeting MSMEs in construction.

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