Multicriteria Decision Analysis in Urban Planning: Case study in the choice of urban pavements, in São Carlos / SP

Aplicação do Apoio Multicritério à Decisão no Planejamento Urbano: Estudo de caso na escolha de pavimentos urbanos, em São Carlos/SP

Aplicación del apoyo multicriterio a la decisión en la planificación urbana:caso de estudio en la elección de pavimentos urbanos, en São Carlos / SP

LOSS, Camila Fávero[1]
FERREIRA, Marcos Antonio Garcia[2]

[1] [2] Federal University of São Carlos - UFSCar, São Carlos, Brazil.

camilafaveroloss@gmail.com
ORCID ID: 0000-0002-1042-7708
dmag@ufscar.br
ORCID ID: 0000-0003-0144-5645

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Abstract

The contexts related to transport and planning are complex in decision making because there are several participants and conflicting objectives involved. In this sense, the application of Multicriteria Decision Analysis (MDA) was proposed in urban planning, specifically in a study for the choice of pavements in a medium-sized Brazilian city. This application consisted in three main steps: structuring the problem, evaluating alternatives, and making recommendations. Alternatives in Warm Mixed Asphalt (WMA), Precast Concrete Blocks for Paving (PCBP) and PCBP equipped with a structure for infiltration and rainwater storage were evaluated. As a result, the alternative in WMA was recommended. The application of the MDA provided a comprehensive view for the choice of urban pavements, based on the value judgment of the participants involved; made it possible to identify the potentialities and limitations of each pavement; identified values that determined the best global performance of WMA, which were relevant for public administration. The developed model can be applied in other areas of transportation and urban planning.

Keywords: Urban Planning; Choice of Urban Pavements; Decision Making; Multicriteria Decision Analysis.

Resumo

Os contextos relacionados a planejamentos e transportes apresentam complexidade para a tomada de decisão, por envolver vários atores e objetivos conflitantes. Neste sentido, foi proposta uma aplicação do Apoio Multicritério à Decisão, na área de planejamento urbano, especificamente, em um estudo para a escolha de pavimentos em uma cidade brasileira de porte médio. Foi desenvolvido em três etapas principais: estruturação do problema, avaliação das alternativas e recomendações. Avaliou-se alternativas em Concreto Asfáltico Usinado à Quente (CAUQ), em Peças Pré-moldadas de Concreto (PPC) e uma terceira em PPC dotada de estrutura para infiltração e armazenamento de águas pluviais. Como resultado, recomendou-se a alternativa em CAUQ. A aplicação do AMD proporcionou uma visão abrangente para a escolha de pavimentos urbanos, embasada no juízo de valores dos atores envolvidos; possibilitou a identificação das potencialidades e as limitações de cada pavimento; identificou valores que determinaram o melhor desempenho global do CAUQ e que se revelaram relevantes para a gestão pública. O modelo desenvolvido pode ser aplicado em outras áreas de transporte e planejamento urbano.

Palavras-Chave: Planejamento Urbano; Escolha de pavimentos urbanos; Tomada de decisão; Apoio Multicritério à Decisão.

Abstract

The contexts related to transport and planning have complexity for the decision making, because there are several actors involved and conflicting objectives. In this sense, it was proposed an application of Multicriteria Decision Analysis, in the area of urban planning, specifically in a study for the choice of pavements in a medium Brazilian city. It was developed in three main stages: structuring the problem, evaluating alternatives and recommendations. Alternatives in Warm Mixed Asphalt (WMA), Precast Concrete Blocks for Paving (PCBP) and a third in PCBP equipped with a structure for infiltration and rainwater storage were evaluated. As a result, the alternative in WMA was recommended. The application of the AMD provided a comprehensive view for the choice of urban pavements, based on the value judgment of the involved actors; made it possible to identify the potentialities and limitations of each pavement; identified values that determined the best overall performance of the CAUQ and which were relevant for public management. The developed model can be applied in other areas of transportation and urban planning.

Key-Words: Urban Planning; Choice of urban pavements; Decision making; Multicriteria Decision Analyses.

1. Introduction

Due to the complexity of scenarios related to transport and planning, there is an increase in the application of Multicriteria Decision Analysis (MDA) in decision-making processes. This is because this method facilitates the association of a series of impacts of projects, policies or programs in a single framework, enabling the understanding of the decision-making process by the members of the public administration and other decision makers, supporting them in the actions that must be taken (GALVES, 2005; DODGSON, 2009).

In urban planning, notably in the area of urban paving, defining and dimensioning a pavement that considers several factors in a comprehensive perspective, such as costs, durability, comfort, safety, environmental criteria, among others, can become a complex and conflicting task.

Belton and Sterwart (2002) mention that in decision-making problems at the level of public administration, with conflicting characteristics and different opinions, the application of the MDA approach can help decision-makers in the organization of all factors that involve the problem, providing greater security for decision making.

In the municipality of São Carlos, a medium-sized Brazilian city where this study was developed, there was a lack of guidelines for the planning and implementation of urban paving, according to data obtained through consultation to the current legislation and the Municipal Department of Public Works. This fact, associated with the notorious relevance of exploring the choice of urban pavements through the application of the MDA approach, motivated the proposal of a case study from this perspective.

Furthermore, in the consolidated urban space of the municipality, most of the urban roads are paved and an urban expansion macrozone is foreseen in the Master Plan. Thus, this case study is intended to support decisions regarding urban planning, especially in future road openings in the urban expansion area of the municipality.

2. Bibliography

The MDA set of methods aims to clarify the decision-making process, incorporating the value judgments of the participants involved in the process, modeling how their preferences are expressed and recommending the alternative that presents the best performance. In general, multicriteria methods have three main phases: structuring, evaluation, and recommendations (GALVES, 2005; GOMES et al., 2002).

In the structuring phase, the decision context is characterized, and the participants involved are defined. They are consulted and, from the data provided, the objectives that are intended to be reached with the decision are identified, hierarchically organized, and measured through attributes (ENSSLIN et al., 2013).

In evaluating the alternatives of a structured problem, the multi-attribute value function method can be used. Such method makes it possible to build a tool that combines several attributes and associates a real number to each alternative, generating an order of preference among them, instituted by the value judgment expressed by the decision maker (BELTON and STERWART, 2002; KEENEY, 1992).

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In order to ascertain whether the order of preference obtained has presented a consistent result or whether it is sensible to changes in terms of model, a sensibility analysis is carried out. This consists of making changes to the model's parameters to assess its robustness. With the result of this verification, it is possible to corroborate the recommendation of the alternative that presented the best performance, or investigate what information needs to be added or improved for the success of the model (BELTON and STERWART, 2002).

3. Materials and Methods

The present work is classified as applied research with a mixed approach (qualitative and quantitative), presents an exploratory character, and utilizes the technical procedures of a case study (SILVA; MENEZES, 2005; GIL, 2008; COSTA; COSTA, 2009).

This study started with a literature survey on sets of MDA methods and alternatives of urban pavements. From this review, the study method was developed and organized in the phases of structuring the problem, evaluating alternatives, and making recommendations.

3.1. Structuring the Problem

The structuring of the problem was performed using the Value Focused Thinking (VFT) method. This phase consisted of the following steps: characterization of the decision context; identification and structuring of objectives; means and fundamental objectives; fundamental objectives hierarchy; definition of attributes; proposition of alternatives and definition of levels of attributes (KENEEY, 1992).

In characterizing the decision context, the decision level, the geographical and temporal limits of the object of study were defined and the participants involved were identified (DELOSPITAL, 2016).

To identify and structure the objectives, semi-structured interviews were conducted, and the participants were asked what they would like to achieve in the decision situation. The inquiries encouraged respondents to explore alternatives; cite problems, deficiencies, and restrictions; as well as to think from different perspectives, with the aim of obtaining a comprehensive list of objectives (KENEEY, 1992).

After analyzing the collected data, the objectives were identified and hierarchically formalized, having the main objective positioned at the highest level, and the others at lower levels (KEENEY and MCDANIELS, 1992).

After the hierarchy was conceived, attributes were determined through a literature review to measure each objective. Each of them presented a name, a measurement scale (quantitative or qualitative) and levels of impact contained in a range between the best viable level and the worst acceptable level (DELOSPITAL, 2016).

In sequence, alternatives in Warm Mixed Asphalt (WMA), in Precast Concrete Blocks for Paving (PCBP) and PCBP equipped with a structure for infiltration and rainwater storage were proposed. Then, through literature consultation, the levels of the attributes in each alternative were defined and these data were tabulated and organized for their evaluation phase.

3.2. Evaluating Alternatives

In this phase, the multi-attribute value function was used, in the additive form, according to Equation 1. For its construction, it was necessary to determine the value functions and the scale constants, obtained by interviewing the decision maker. Having determined these values, local evaluations and a global evaluation of alternatives were carried out (BELTON and STERWART, 2002).

$$V_a = \sum_{i=1}^{n} w_i v_i(a) \quad (1)$$

Where:
$V_{(a)}$ = Global Value of Alternative a;
w_i = Scale Constants of Attributes 1, 2,...,;
v_{i_a} = Local Value of Alternative a in Attributes 1, 2,...,;
n = Number of Attributes of the Model.

To define the value functions, direct and bisection scoring methods were used (ENSSLIN et al., 2001). The bisection method was applied for the attributes that varied in a numerical interval and, for the others, the direct scoring method was utilized. The scale constants were defined by the Swing Weighting method.

The local evaluation of the alternatives consisted of transforming the level of every attribute conferred to each alternative into a value of preference through the value function (DELOSPITAL, 2016).

With the local evaluations carried out and the scale constants defined, Equation 1 was applied to each alternative, to obtain its global performance. The results provided the alternative that achieved the best value, and ranked all alternatives (BELTON and STERWART, 2002).

3.3. Making Recommendations

The sensibility analysis was performed with variations in the scale constants, as these parameters had a greater influence on the global evaluation and the model was recalculated (BELTON and STERWART, 2002). It corroborated the results of the global evaluation and reinforced the recommended alternative.

4. Case Study: The Municipality of São Carlos/SP

4.1. Structuring the Problem

The municipality of São Carlos is in the geographic center of the State of São Paulo and is known as the Capital of Technology, as it has universities, research centers, high-tech companies and industries (A CIDADE, 2017). It has an estimated population of 246,088 inhabitants and a demographic density of 195.15 inhabitants / km² (BRASIL, 2017).

In 2010, São Carlos presented a Municipal Human Development Index (MHDI) of 0.805, and in 2015, a GDP (Gross Domestic Product) per capita of R$ 40,435.49 (BRASIL, 2017). Its territorial unit is 1,136,907 km² and the urban area is 67,25 km². This area is equivalent to 6% of its total territory, of which 33 km² are occupied (DADOS, 2017).

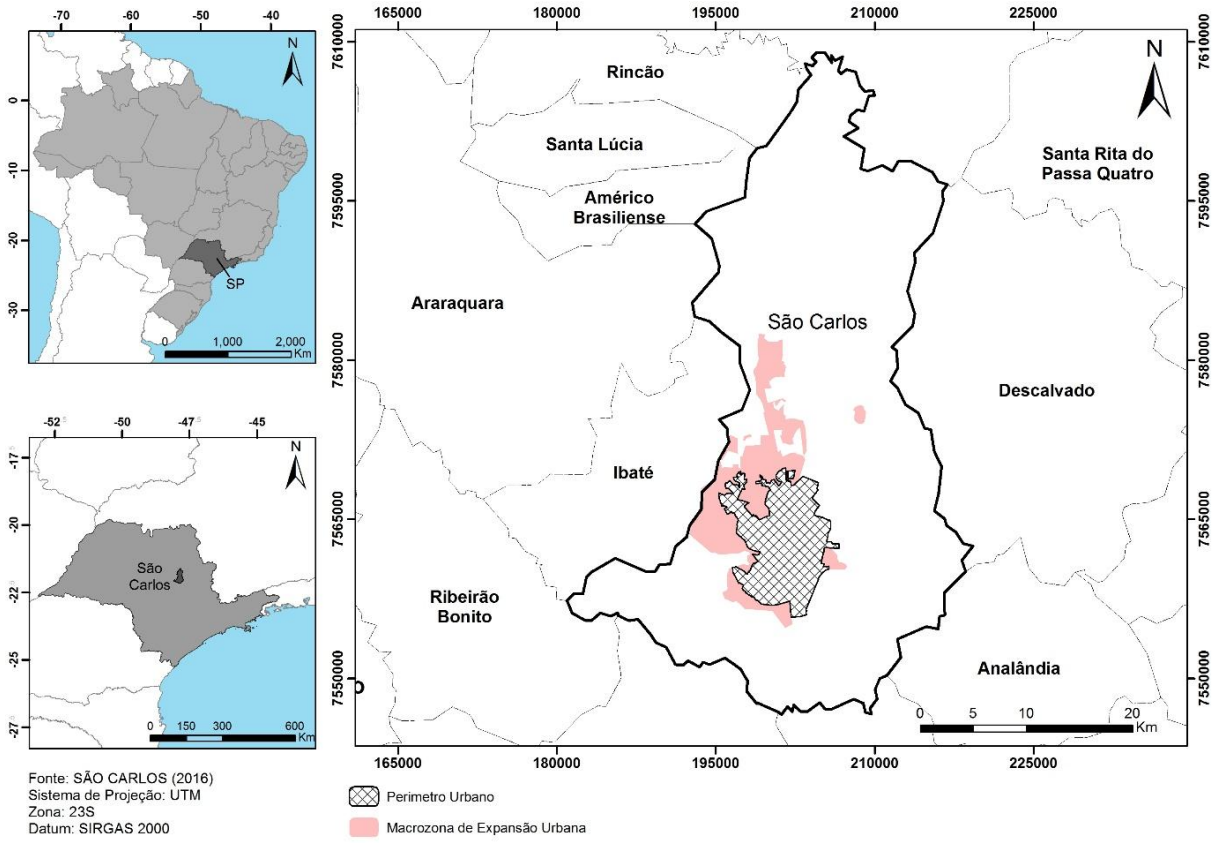
Most of the urban roads are paved, for this reason the geographical limits of the decision context contemplated the two-way collecting roads to be implemented in the urban expansion area. Figure 1 shows the location of the municipality at the national and state levels, as well as the urban expansion macrozone (SÃO CARLOS, 2016).

The decision level consisted of providing subsidies to the municipality for the elaboration of projects and dimensioning of urban pavements in future roads. As for the time limits, the research was developed to assist in medium-term urban planning, from the next review of its Master Plan.

The participants considered in the decision context formed three distinct groups: the public decision maker, the road users, and the researchers of the municipality, as follows:

- **a.** Decision Maker: Municipal Department of Public Works – a civil engineer appointed by the administration. The Department was selected due to its duties related to essential services for opening and paving public roads (SECRETARIA, 2017).
- **b.** Road users: drivers of all types of vehicles, pedestrians, and users of public transport.
- **c.** Researchers: Post-graduate students from the Urban Engineering Program in UFSCar and from the Transportation Program in USP/São Carlos; as well as professors from the Department of Civil Engineering in UFSCar and from the Department of Transport Engineering in USP/São Carlos.

Figure 1: Urban perimeter and urban expansion macrozone.



Users were interviewed in the central area of the city. This is due to the fact that citizens who circulate in this region travel through various routes in the city, thus are able to provide information related to the

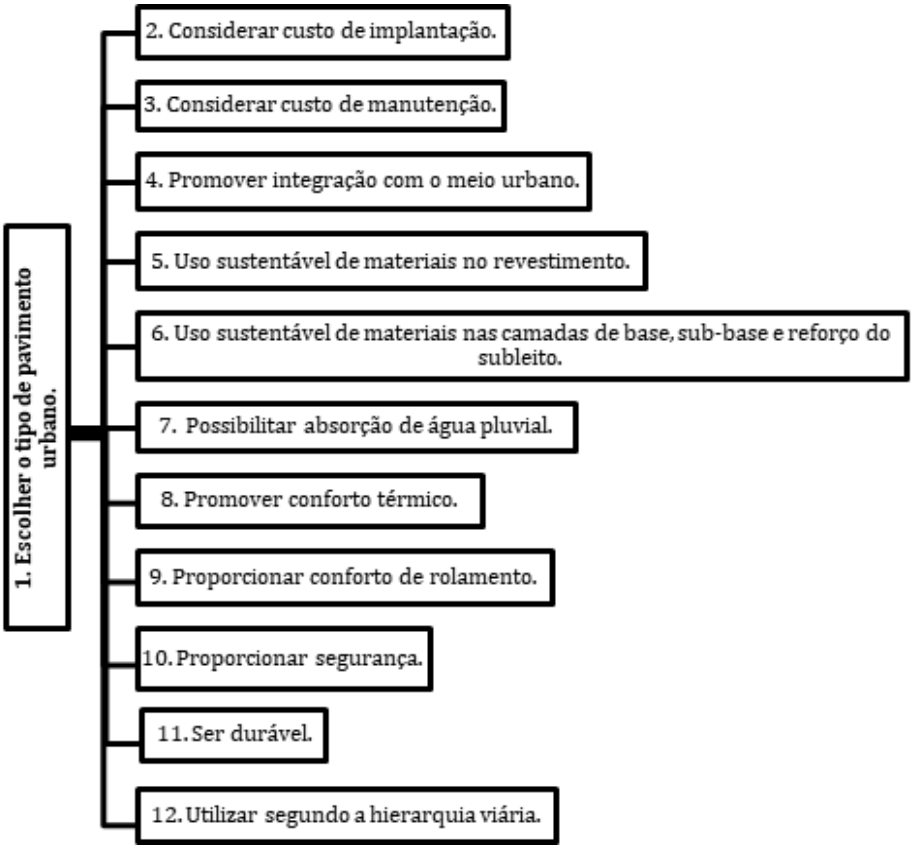
entire municipality. UFSCar and USP researchers, in turn, were from various areas related to paving and urban planning.

Both the decision maker and the researchers were interviewed on the premises of the institutions to which they were linked. The interviews took place between 19th of August 2017 and 12th of September 2017. 53 people were interviewed, which generated 23 general objectives. Researchers and users were interviewed until the collected objectives began to repeat themselves. This condition limited the number of participants consulted (DELOSPITAL, 2016).

4.1.1 Identification of fundamental objectives and hierarchical organization

The objectives mentioned by users were more related to trafficability, use according to road hierarchy, costs, stability and maintenance of the pavement. The researchers, in turn, pointed out objectives according to their research views. The decision maker, in addition to technical issues, also indicated objectives aimed at the administrative view. The fundamental objectives were determined and structured in the hierarchy represented by Figure 2.

Figure 2: Hierarchy of Fundamental Objectives.



4.1.2 Defining Attributes

Using the information in Figure 2, a new bibliographic review was carried out and attributes were defined for each objective. Most of them were designed and structured in three impact levels (level 1 to level 3), except for the attributes implementation cost, maintenance cost and lifespan, which were considered in a numerical interval.

Table 1 presents the attributes defined for each fundamental objective, their scales, the intervals of variation and the authors used in their elaboration.

Table 1: Attributes, Scales, Intervals and Authors.

Fundamental Objective	Attribute	Scale	Variation	Authors
Consider Implementation Cost	Implementation Cost	R$/ m²	70.00 – 168.25	São Paulo (2004 a, 2004b, 2004c, 2004d; 2017).; Virgiliis (2009).
Consider Maintenance Cost	Annual Maintenance Cost	%	9,24 – 31,62	Moura (2004).
Promote Integration with the Urban Environment	Aesthetic Potentialities	Built	N1 to N3	Ferreira (2007).
Sustainable Use of Materials in the Coating	Recycled Materials Applied to the Coating	Built	N1 to N3	ABNT (2004a, 2004b,2005,2013); Carvalho (2010); Gennessaux (2015); Shu e Huang, (2014); Vieira, (2014).
Sustainable Use of Materials in the Base, Sub-base, and Reinforcement of the Subgrade	Recycled Materials Applied to the Base, Sub-base, and Reinforcement of the Subgrade	Built	N1 to N3	
Enable Rainwater Absorption.	Permeability	Built	N1 to N3	Autora (2017).
Promote Thermal Comfort.	Surface Temperature	Built	N1 to N3	Macedo Neto (2016).
Provide Bearing Comfort.	Functionality	Built	N1 to N3	Ferreira (2007).
Provide Security.	Braking Distance	Built	N1 to N3	ABCP (2008); Moschetti (2015).
Be Durable.	Lifespan	Years	10 - 20.	Senço (2007); Balbo (2009).
Use According to the Road Hierarchy.	Traffic Type	Built	N1 to N3	São Paulo (2004a, 2004b, 2004c, 2004d); São Carlos (2016).

4.1.3 Alternatives of Pavements

The proposed alternatives were pavements covered with Warm Mixed Asphalt (WMA) and Precast Concrete Blocks for Paving (PCBP). WMA was adopted because it has the best quality among asphalt pavements, provides greater bearing comfort and is one of the most used pavements on urban roads (CARVALHO, 2010).

Precast Concrete Blocks for Paving have been proposed because they offer the possibility of being reused in maintenance, it is possible to allow traffic immediately after their execution, they are easy to perform and they are aesthetic due to the variations in shape and color of the blocks (OAK, 1998).

Due to environmental aspects, a type of permeable pavement was also adopted. This is because in the urbanization process, a considerable part of the lack of permeability in cities is due to paving. The pavement adopted in this work, in turn, has sufficient permeability to capture part of rainwater and delay its rapid passage to downstream, contributing to flow control (BAPTISTA et al., 2015).

All alternatives were dimensioned according to the method established by Project Instructions for the Dimensioning of Pavements of the Municipality of São Paulo (São Paulo, 2004a; 2004b; 2004c; 2004d) and the criteria were presented by São Carlos Master Plan (SÃO CARLOS; 2016). Figures 3, 4 and 5 show the cross sections of the alternative in WMA, PCBP and permeable PCBP.

Figure 3: Pavement in WMA.

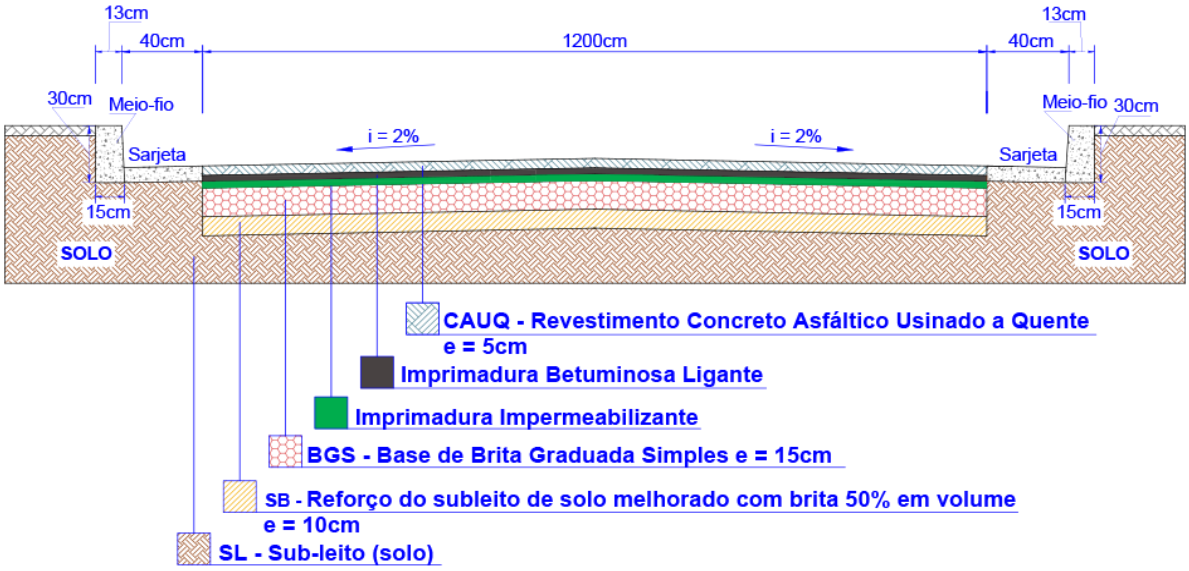


Figure 4: Pavement in PCBP.

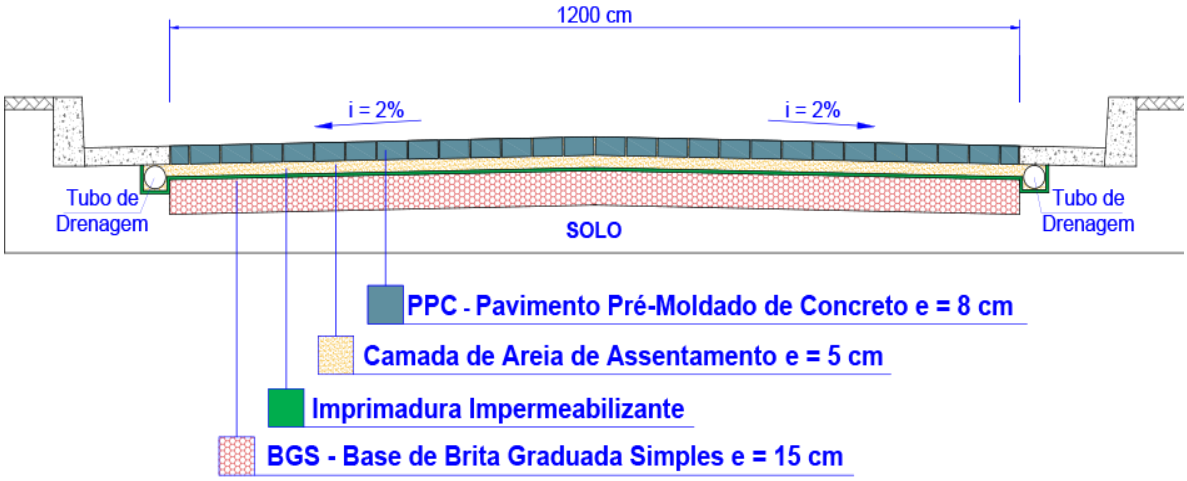


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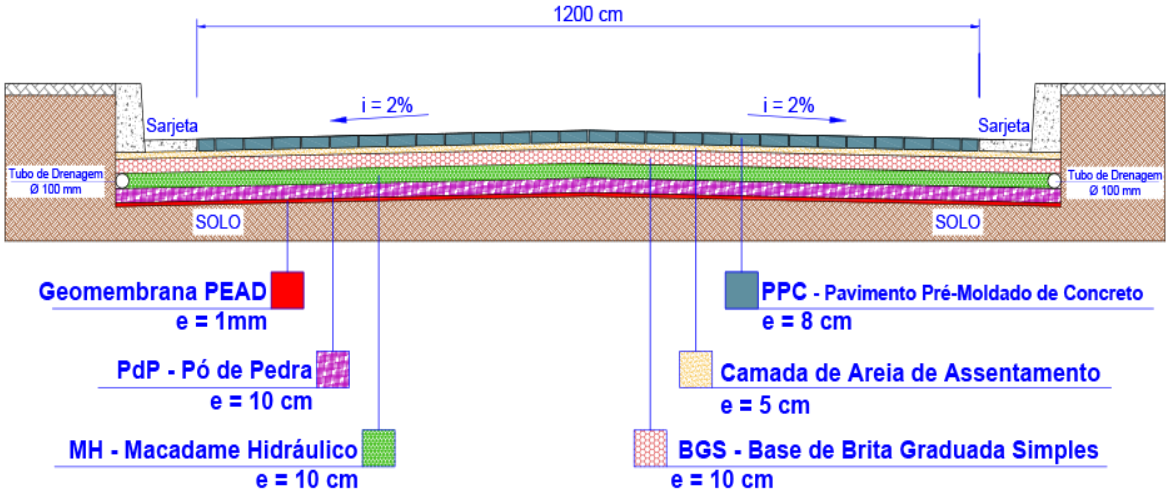
Figure 5: Pavement in Permeable PCBP.



After conceiving the proposed alternatives, the impact levels of the attributes were defined for each one. That is, the pavements were analyzed according to each attribute and the level of impact of the attributes of each pavement was defined. Subsequently, the research moved on to the evaluation stage.

4.2 Evaluating Alternatives

In this phase, a second interview was conducted with the decision maker to determine two fundamental parameters: the value functions and the scale constants. With these data, a local evaluation of the alternatives was made, and it is shown in Table 2, which displays the local performance of each alternative.

Table 2: Value Function.

Attributes	Alternatives					
	WMA		PCBP		Permeable PCBP	
	Level	Value Function	Level	Value Function	Level	Value Function
Implementation Cost	77.87	60.65	100.10	24.95	140.30	6.68
Annual Maintenance Cost	9.24	98.88	26.17	20.82	31.62	1.36
Aesthetic Potentialities (Visual Attractiveness)	N1	0	N3	100	N3	100
Recycled Materials Applied to the Coating	N3	100	N1	0	N1	0
Recycled Materials Applied to the Base, Sub-base, and Reinforcement of the Subgrade	N3	100	N3	100	N1	0
Permeability	N1	0	N2	25	N3	100
Surface Temperature	N1	0	N3	100	N3	100
Comfort Aspects	N3	100	N1	0	N1	0
Braking Distance	N1	0	N3	100	N3	100
Lifespan	10	0	15	25	10	0
Traffic Type	N2	75	N1	0	N1	0

Considering the local evaluation, it appears that in terms of cost of implementation the WMA had an attractiveness of around 60 points, the PCBP of 25 and the permeable PCBP of nearly 7 points, revealing a significant discrepancy between them. In the attribute of annual maintenance cost, the alternatives in PCBP had an even greater difference in relation to WMA.

As for the permeability, it was assumed in advance that the WMA would be at the worst level and the permeable PCBP at the best. However, the PCBP alternative had a performance of 25 points, demonstrating that this pavement contributes little to the environmental aspect in the view of the decision maker.

When analyzing the lifespan, the alternative in PCBP was evaluated at 25 points. This showed that, despite being more durable, this factor did not obtain considerable relevance. Finally, in relation to the type of traffic, WMA remained at an advantage over the alternatives in PCBP, with an attractiveness of 75 points.

In order to proceed with the global evaluation, the scale constants established by the decision maker were used and are expressed in Table 3.

Table 3: Scores given by the decision maker and scale constants.

Attributes	**Score**	**w (Scale Constants)**
Implementation Cost	100	0,155
Annual Maintenance Cost	95	0,147
Lifespan	90	0,140
Permeability	85	0,132
Traffic Type	75	0,116
Comfort Aspects	50	0,078
Aesthetic Potentialities (Visual Attractiveness)	40	0,062
Braking Distance	35	0,054
Surface Temperature	30	0,047
Recycled Materials Applied to the Coating	25	0,039

The attributes related to costs and lifespan were assigned high values, and the permeability attribute was scored in the fourth position. Meanwhile, the attributes of surface temperature and recyclable materials applied to the pavement layers were given the lowest scores.

With the local evaluations and the scale constants determined, the global evaluation was carried out by applying Equation 1, which generated the result shown in Table 4.

Table 1: Global Evaluation.

Alternatives	**Global Evaluation**
WMA	47
PCBP	34
Permeable PCBP	31

The WMA pavement presented the best result. However, when analyzing the plots that made up the multi-attribute value function for each alternative, that is, the values obtained by multiplying the value functions by the respective scale constants, the attributes that most influenced the result of the global assessment were identified (Table 5).

Table 2: Influence of Attributes on the Global Evaluation

WMA	PCBP	Permeable PCBP
Annual Maintenance Cost: 31%	Permeability: 18%	Permeability: 43%
Implementation Cost: 20%	Aesthetic Potentialities: 16%	Aesthetic Potentialities: 20%
Traffic Type: 18%	Braking Distance: 14%	Braking Distance: 18%
Bearing Comfort Aspects: 16%	Surface Temperature: 11%	Surface Temperature: 15%

When checking Table 5, it is noted that the alternatives in PCBP displayed the same attributes as most influential due to the similarity of the coatings. Nevertheless, they present different percentages, mainly in relation to permeability, which is the most relevant property of the permeable PCBP.

As for the WMA pavement, it was found that the attributes related to costs, the ability to resist different types of traffic and the bearing comfort, had a greater influence on the result, being desirable technical aspects from the point of view of public administration.

4.3 Sensibility Analysis and Recommendations

The sensibility analysis was performed by varying the scale constants. The constants of permeability and implementation cost attributes were selected. This choice was due to the permeability being a critical parameter in environmental terms, and to the cost of implantation having obtained the highest score among the attributes. The result of the analysis is shown in Table 6.

Table 3: Sensibility Analysis

Alternatives	Permeability		Implementation Cost	
	+10%	-10%	+10%	-10%
WMA	47	48	48	47
PCBP	34	34	34	34
Permeable PCBP	32	30	30	31

Through the sensibility analysis, it is observed that there was no change in the order of the alternatives, verifying that the model is consistent and that the alternative in WMA is the most recommended for the case study.

5. Conclusion

The application of MDA provided a more comprehensive view for the choice of urban pavements, addressing a considerable variation of attributes and enabling the construction of a model based on the judgment of values of the participants involved. Furthermore, the model can be replicated in other areas of transport and urban planning.

In the structuring stage, users raised objectives more related to trafficability and use of the road, while researchers brought a technical look at the criteria to be adopted and the decision maker contributed with a more administrative view. In defining the attributes and levels of impact in which the alternatives fit, the potentialities and limitations of each pavement were identified.

In evaluating the alternatives, the local evaluation showed that the alternative in PCBP was favored in the attributes of aesthetic potentialities, permeability, surface temperature, braking distance, lifespan and use of recycled materials. The permeable PCBP obtained good local performance in aesthetic potentialities, surface temperature, braking distance and its greatest contribution was in permeability. However, it is in great disadvantage in relation to costs. WMA showed good results in terms of comfort, use of recycled materials, type of traffic and costs.

In the global evaluation, the WMA pavement was the alternative with the best result. The most influential attributes in this result were the cost of annual maintenance, cost of implementation, type of traffic and comfort, which in addition to good local performance, received great importance in defining the scale constants. Thus, the WMA was indicated for a two-way collecting road to be implemented in the municipality of São Carlos, and this recommendation was corroborated by the sensibility analysis. It can be inferred that these attributes, added to the lifespan attribute, can point out relevant values for the public administration and urban planning of the municipality.

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