



Revista Legado de Arquitectura y Diseño
ISSN: 2007-3615
ISSN: 2448-749X
legado@uaemex.mx
Universidad Autónoma del Estado de México
México

Weighted sums method applied for decision making in improvement towards complete street: a case study in Popayan, Colombia

albán-Pérez, Carlos andrés
Serrano-Guzmán, María Fernanda
Pérez-ruiz, Diego Darío

Weighted sums method applied for decision making in improvement towards complete street: a case study in Popayan, Colombia

Revista Legado de Arquitectura y Diseño, vol. 18, núm. 34, 2023

Universidad Autónoma del Estado de México

Disponible en: <https://www.redalyc.org/articulo.oa?id=477975707013>



Esta obra está bajo una Licencia Creative Commons Atribución-NoComercial-SinDerivar 4.0 Internacional.

Weighted sums method applied for decision making in improvement towards complete street: a case study in Popayan, Colombia

Método de sumas ponderadas aplicado para la toma de decisiones en la mejora hacia la calle completa: un estudio de caso en Popayan, Colombia

Carlos Andrés albán-Pérez
Constructora Solanillas, Cali, Colombia
alban77@gmail.com

María Fernanda Serrano-Guzmán
María Fernanda Serrano-Guzmán *Pontificia Universidad*
Javeriana Cali, Colombia
maria.serrano@javerianacali.edu.co

Diego Darío Pérez-ruiz
Pontificia Universidad Javeriana Cali, Colombia
ddperez@javerianacali.edu.co

Revista Legado de Arquitectura y
Diseño, vol. 18, núm. 34, 2023

Universidad Autónoma del Estado de
México

Recepción: 13 Febrero 2023
Aprobación: 12 Junio 2023

Resumen: El diseño de una calle debe mantener unos requisitos de funcionalidad que garanticen la seguridad y el confort de los usuarios. Desde esta perspectiva, si una calle cumple atributos de seguridad, inclusión, sostenibilidad y resiliencia, puede denominarse calle completa. Este estudio presenta la aplicación del método de sumas ponderadas para la evaluación de las condiciones de una calle completa para la modernización de la malla vial en Popayan, considerando el impacto que ofrecen diferentes alternativas para mejorar la calidad vial. Previo a la implementación de este método, un grupo de expertos definió el peso de cada uno de los atributos de calle completa y haciendo uso de una hoja de verificación del cumplimiento de estos, se realizó la valoración visual en cuatro tramos de vía en la ciudad.

El estudio muestra un ejemplo de la calificación de una margen en un tramo de estudio y la repercusión económica frente al beneficio de las mejoras implementadas para alcanzar la funcionalidad de calle completa. Este procedimiento permite que un gerente de proyecto o gerente de gasto público evalúe cómo mejorar el éxito o la integridad de la calle antes de ejecutar una obra pública. El objetivo final del método de sumas ponderadas empleado en este estudio es proporcionar un instrumento para evaluar el cumplimiento de las condiciones de la calle completa antes de ejecutar las obras.

Palabras clave: infraestructura verde, proyecto urbano, calle completa.

Abstract: The design of a street must adhere to functionality requirements that ensure the safety and comfort of users. From this perspective, if a street encompasses attributes of safety, inclusivity, sustainability, and resilience, it can be referred to as a complete street. This study presents the application of the weighted sum method for evaluating the conditions of a complete street in the modernization of the road network in Popayan, considering the impact that different alternatives offer to enhance road quality. Prior to implementing this method, a group of experts defined the weight of each attribute of a complete street, and using a compliance checklist, a visual assessment was conducted across four sections in the city.

The study provides an example of rating a segment within a study section and the economic impact in relation to the benefits of the implemented improvements to

achieve complete street functionality. This procedure enables a project manager or public expenditure manager to assess how to enhance the success or integrity of the street before carrying out a public project. The goal of the weighted sum method applied in this scenario is to provide a tool for evaluating the fulfillment of complete street conditions before commencing construction.

Keywords: green infrastructure, urban project, complete streets.

INTRODUCTION

A street in the city is more than a physical place because in it life takes place allowing social activities and the development of the economy (Acuti, Bellucci & Manetti, 2020). That fact explains why is so essential to enable the continuity of its service and passability despite inclement weather conditions. Which could be exposed (Secretaría de Desarrollo Agrario, Territorial y Urbano (SEDATU) – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2020). Due to the above, the conjunction of compliance in the conditions of safety, inclusion, sustainability, and resilience leads to the materialization of a complete street (figure 1) from which users of all ages benefit (González Saboyá, 2009).

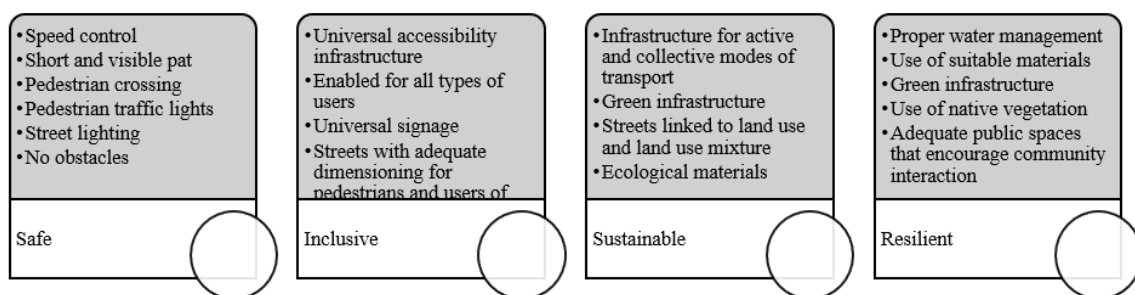


Figure 1. Characteristics for the complete street attributes.

Source: Prepared with information from (Albán Pérez, 2022).

A safe street is characterized by numerous, wide, and adequate quality pedestrian areas that interact with green zones and well-maintained parks (Yang, Thomas Ng., Zhou, Xu & Li, 2020) as far as possible with good areas for enjoyment. In that way, the street always remains in operation captivating the use of people by de comfort provided. As for the inclusive street, that allows all types of users moving from origin to destination without interruptions with varied modal transport (Choi, Naderpajouh, Yu & Hastak, 2019).

On the other hand, a sustainable street, also considered healthy (McDaniels, Chang, Peterson, Mikawoz & Reed, 2007), creates spaces that promote alternative transport modes to the private vehicle in harmony with the green infrastructure, allowing it to attract businesses, mobilize commerce and the educational, recreational and health sectors, among others.

Finally, a resilient street offers symbiosis with its surroundings, assuming characteristics of adaptation to different spatial conditions (Seppanen, Luokkala, Zhang, Torkki & Virrantaus, 2018), taking elements from the vegetation and materials incorporated responding to the environmental climatic variations.

Without a doubt, it can be affirmed that most of the streets in the cities lack the concept of a complete street due to flaws in the design aspects or construction errors that are evident during the operation and functioning of the street. To made intervention or improvements

to this physical space for the benefit of users is sometimes more complex due to the variety of infrastructure works that may be required to reach the recommended characteristics for a complete street.

The main objective of this work is to show how apply the method of weighted sums as a help tool regarding decision making towards interventions or improvements to do in the infrastructure of a street so that it achieves the qualification of a complete street. For doing that, participated a focus group composed of experts in the field of urban infrastructure, who contributed their knowledge to assign weight to each of the following attributes: safe street, inclusive street, sustainable street and resilient street and to the corresponding sub-attributes. The tool developed in Excel allows the entity responsible for forecasting the road infrastructure evaluate the required budget according with the relevance of a certain physical work, thus being able to justify the budget proposal for this purpose.

TECHNICAL ASPECTS OF GREEN INFRASTRUCTURE

The green streets are constituted in circulation spaces where blocks containing buildings, spaces or sites of cultural interest are interconnected for their enhancement. Under this concept, the existing urban voids and community spaces are used to interconnect areas (C40 Cities Climate Leadership Group, 2016), converting the existing green space into an urban street with facades on both sides (Pérez Silva, Olvera Rodríguez, García Cerrud, Soler Anguiano & Flores de la Mota, 2020), thus integrating the new periphery with the so-called green tissue (Rey Domínguez, 2010).

Green infrastructure is an urban infrastructure system that contributes to strengthening the ecosystem from a social perspective in a way that allows the operation of the street facing climate change (Hernández-Rojas & Sanabria-Marín, 2019). This implies that the stages of the life cycle of a project are applied to finally offer ecosystem services and multiple benefits, taking advantage of the best conditions that nature offers (Acuti, Bellucci & Manetti, 2020).

When it is planned to analyze the fulfillment of the attributes of green streets, a spatial analysis is carried out on the coverage and land uses of the study area, zoning four thematic dimensions: ecological connectivity, multifunctionality, ecological status and accessibility to the population (Hernández-Rojas & Sanabria-Marín, 2019) and, where are possible, other topics could be included such as population density (Martín Robles & Pancorbo, 2015), places of cultural interest, means of transportation, among others.

TECHNICAL ASPECTS OF SUSTAINABLE URBAN INFRASTRUCTURE

Part of the sustainable development objectives contemplate that the construction of sustainable and sustainable infrastructure in

developing countries must be ensured (López-Goyburu, 2012) with actions such as the construction of green spaces, pedestrian paths, and adequate management of solid waste disposal, among other aspects (McDaniels, Chang, Peterson, Mikawoz & Reed, 2007).

The materialization of a sustainable street allows the cultural use as an endogenous resource and the valuation of the entrepreneurial ideas that are leveraged in each territory and that usually tend to improve the quality of life (C40 Cities Climate Leadership Group, 2016) and allow the income generation. That is, local resources and knowledge are incorporated, seeking to maintain the cultural heritage whenever possible. To the extent that spaces of this type are conferred, economic, social, and environmental benefits are achieved because actions are implicitly being generated that reduce CO₂ emissions and therefore improve the quality of the air and the landscape conditions (McDaniels, Chang, Peterson, Mikawoz & Reed, 2007).

TECHNICAL ASPECTS OF RESILIENT URBAN INFRASTRUCTURE

The media is continually communicating about natural disasters that paralyze anthropogenic activities. This reality evidences the need to anticipate climatic actions (Secretaría de Desarrollo Agrario, Territorial y Urbano (SEDATU) – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2020) to counteract the negative impact on the quality of life of people (ONU, 2017) that affects them economic and social functionality due to the reducing of the level of service of the existing road infrastructure (López-Goyburu, 2012). Without a doubt, it can be stated that it is important to always maintain the functionality of a road, despite the inclement weather and adverse conditions to which is subjected, and that emphasizes why is relevant to update data regarding its use conditions which allowing opportune decision (Seppanen, Luokkala, Zhang, Torkki & Virrantaus, 2018).

The concept of resilience is widely contemplated in the sustainable development goals that seek to promote actions based on the recovery of humanity and the planet using different techniques (López-Goyburu, 2012). Systems, that mean cities or regions, are resilient when faced sudden and can adapt to it or re-emerge in better conditions. In the case of cities, they manage to increase the resilience capacity through biodiversity, the construction of ecological urban networks, the multifunctionality of spaces and the adaptation of designs (López-Goyburu, 2012).

Ecological work and inclusive climate actions contribute to benefits health and prosperity in communities (Secretaría de Desarrollo Agrario, Territorial y Urbano (SEDATU) – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2020). The system resilience conditions allow to a street recovering from adverse effects and continuing its functionality, with adaptation and restoration (Moreno, 2017) (Albán Pérez, 2022). That allows

operation despite the impact, maintaining an updated record of the damage or negative effects on the street (Choi, Naderpajouh, Yu & Hastak, 2019). The fulfillment of this condition prepares the street to be resilient.

Most urban resilience studies consider only the conditions of connectivity and convergence, that is, the topological conditions, concentrating solely on the results of modeling that is sometimes carried out in a disjointed way from reality (Seppanen, Luukkala, Zhang, Torkki & Virrantaus, 2018).

The ideal in any road infrastructure work is to achieve the installation of equipment with sensors that provide information in real time (Serrano Guzmán, Solarte Vanegas & Pérez Ruíz, 2013) and monitor the operation of a road, thus achieving the identification of factors or agents that may affect its operation and the called “critical structures”, those that must be intervened in a timely manner to avoid the total collapse of a system (Seppanen, Luukkala, Zhang, Torkki & Virrantaus, 2018).

This reality justifies the existence of water level measurement systems in urban infrastructure, mainly in advanced countries, to guarantee the timely making of technical decisions that provide the stability of the works (Seppanen, Luukkala, Zhang, Torkki & Virrantaus, 2018), thus preparing the regions for sudden changes in the behavior of water sources anticipating the effects derived from climatic actions (McDaniels, Chang, Peterson, Mikawoz & Reed, 2007).

It should be noted that, although it is true that the maintenance of assets, in this case of infrastructure works, plays a key role in the continuity of the service of any system (Seppanen, Luukkala, Zhang, Torkki & Virrantaus, 2018), in the case of road infrastructure projects it does not. It is enough with the preventive maintenance that is carried out, but it must be complemented with corrective maintenance when necessary.

TECHNICAL ASPECTS OF INCLUSIVE URBAN INFRASTRUCTURE

After the Second World War, disability conditions began to be identified in the communities (Sverdlik, Mitlin & Dodman, 2019), emerging proposals to support this population segment and integrate it into global society (Serrano Guzmán, Pérez Ruíz, Galvis Martínez & Rodríguez Sierra, 2017) (Environmental Protection Agency, 1992).

In the case of Colombia, the Political Constitution, the country's Magna Carta, in its articles 13, 14, 54 and 68 defines the inclusion policies that must be contemplated at a national level. Part of this regulation is considered in accessibility adjustments (Serrano Guzmán, Pérez Ruíz, Jaimes Jiménez, Estupiñán Monroy & Torres Riascos, 2019) made explicit in laws, decrees and government documents (figure 2).

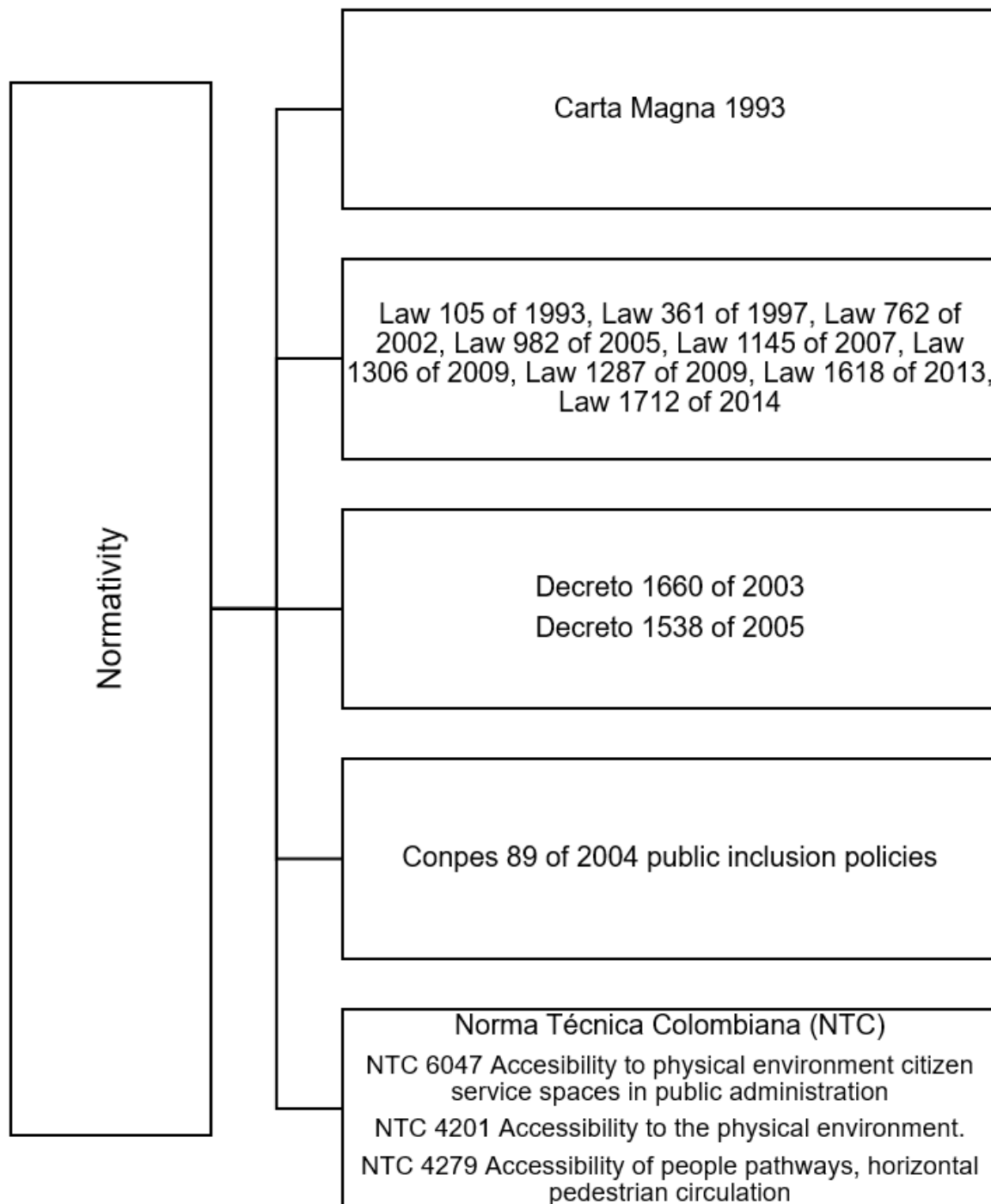


Figure 2. Summary of main normativity regarding inclusion policies.

Source: own elaboration.

In essence, a complete street is one that does not have physical barriers, which are those that generate social inequality among people with some type of disability, preventing their incorporation into everyday life (Environmental Protection Agency, 1992).

APPLICATION OF WEIGHTED SUMS IN PREVIOUS STUDIES

Multi-objective optimization problems have aroused the interest of academics since 1960 (Day et al., 2018). This method starts with the assignment of weights, considering the Pareto frontier (22) (Chagas & Wagner, 2022) to solve situations in natural sciences, social sciences and in the field of engineering (Bonyadi, Michalewicz & Barone, 2013) (Marler & Arora, 2009), among other areas.

In particular, the weighted sums method is a recognized strategy to solve optimization problems, providing a solution based on the weight preference assigned to the attributes and sub-attributes involved (Silva, Valente & Schaller, 2022). Therefore, there can be as many solutions as weights are assigned in the evaluation (Dougier, Garambois, Gomand, & Roucoules, 2021) without losing sight of the fact that an optimal solution is sought for the multi-objective problem.

This method has been used in different applications, for example to solve the optimization problem of the traveling thief in which he plans to collect articles from the passengers of a train during his trip in a certain time and place said objects in his suitcase without exceeding the weight of this Yisong, Ye, Lin & Gen, 2021. On the other hand, weighted sums have been used to analyze production performance in a workshop where it is key to take into account the functionality of each machine, the delivery date and even the customer that requires the service (Yang, Hu & Li, 2021) or to decide the type and number of equipment to be installed in a decentralized power grid (microgrid) (Yang, Karamanoglu & He, 2013) where the interaction of economic and environmental variables as well as the type of equipment results in the benefit of the end user of the power line.

Also, to estimate the benefits of the use of non-conventional energy systems considering variables such as cost, consumption and carbon footprint generated by the energy (Chagas & Wagner, 2022) or to compare different energy sources and select the one with less negative environmental impacts (Madathil, Pandi V, Nair & Jamasb, 2021). Another possible application in the selection of the amount of demolition waste that can be incorporated for the production of concrete (Sojobi, Xuan, Long, Liu & Poon, 2021). In our research, the weighted sum method has been used to assess the concept of a complete street in a city and identify the improvements to be implemented to offer better quality streets.

APPLICATION OF THE WEIGHTED SUM METHOD IN POPAYAN, COLOMBIA

The growth of Popayan, the capital city of the Cauca department, combined with the touristic importance of this municipality in western Colombia, led to the modernization of roads and the enhancement of public spaces on 1n Street between 8th and 11th Avenues (Sections 9, 9A, 3A, and 5, as shown in figure 3). The weighted sum method was employed to support decision-making

related to the projects aimed at enhancing the overall conditions of the street in the areas that required intervention.

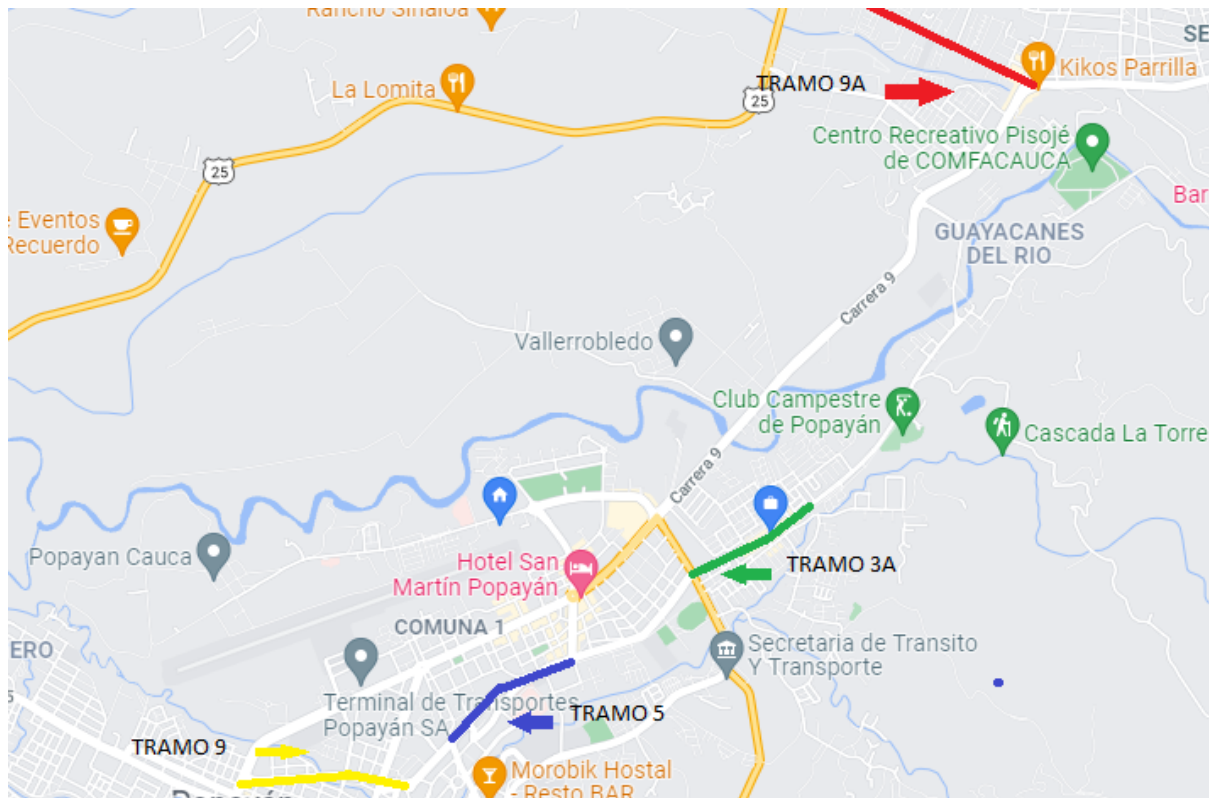


Figure 3. Location of Areas where the Weighted Sum Method was Applied.

Source: adapted from (Albán Pérez, 2022).

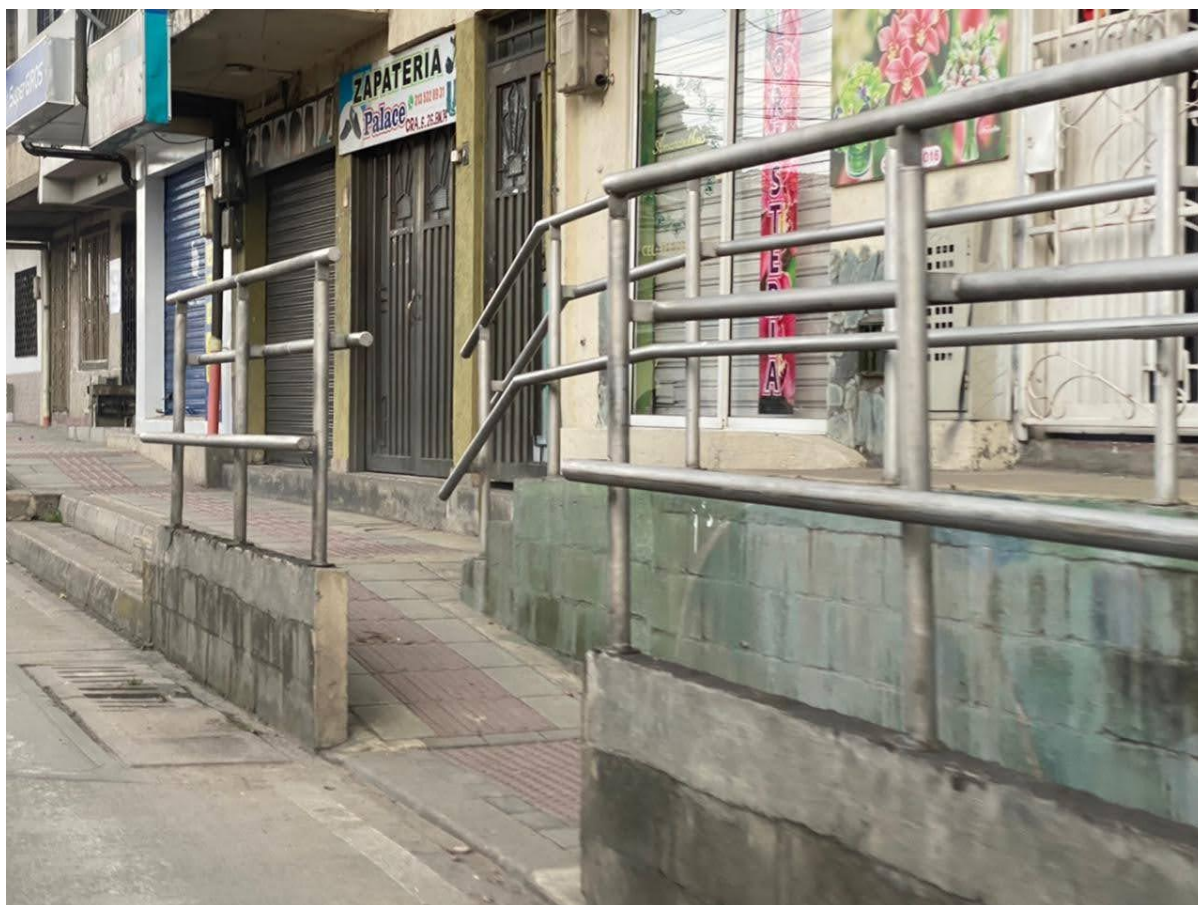
Issues such as pedestrian paths with obstacles (figure 4a), unclear pedestrian circulation (figure 4b), and non-inclusive sidewalks (figure 4c) are some examples of the weaknesses identified in the environment.



a)



b)



c)

Figure 4. Example of Identified Issues.

Source: adapted from (Albán Pérez, 2022).

The utilization of this method facilitated the execution of projects with the goal of attaining the designation of a complete street within each of the intervened zones. These areas were intricately connected, either directly or indirectly, to the enrichment of public spaces in the vicinity. This alignment corresponds to the connections that citizens encounter as they interact with zones designated for communal use. According with that, different kind of solutions such as the construction of vehicular accesses (figure 5a), pedestrian pathways (figure 5b), and broad sidewalks (figure 5c) with integrated green barriers are among the enhancements implemented in this area.



a)



b)



c)

Figure 5. Example of solutions implemented.
Source: adapted from (Albán Pérez, 2022).

METHODOLOGY

This study began with the review of complete street concepts and included in an Excel sheet considering the weighted sum method described in (Madathil, Pandi V, Nair & Jamasb, 2021) and (Dehghanmongabadi & Hoşkara, 2022). For doing this, a focus group made up of 33 experts 21 professionals belonging to RAM, the Academic Network for Mobility in Colombia for its acronym in spanish, composed of professors and researchers from disciplines related to mobility and transportation, along with five employees linked to the private sector and seven consultants who established the weights that should be assigned to the factors or attributes and the corresponding sub-attributes around safe, resilient, inclusive and sustainable street conditions. The collection of information was carried out through a tool developed in a digital form (Google Forms), which was available for a period of seven days. In this form, each participant could choose the order of importance that, in their opinion, the fulfillment of the complete street attributes on a road should have.

The weights were assigned based on the relative importance that the considered attribute and sub-attribute represented for these experts. As a result of the focus group analysis, it was agreed to assign a weight of 27, 25, 23 and 24 to the attributes safety, inclusion, sustainability, and resilience, respectively, and to the sub-attributes contemplated in each of these descriptors (table 1).

Table 1. Definition of the weight of attributes and sub-attributes according to the relative importance considered by the focus group

Safety Street Sub-Attribute Weight		
Road usability	There are speed controls.	15
	Short and visible pathways	15
Accesibility	Adequated pedestrian crossings	
	Ford/level crossings	5
	Pompeian	5
	Cross lines (zebras)	6
	Refuge area	6
Pedestrian comfort	Pedestrian traffic lights	15
	Description infrastructure-platforms	
	Texture of the platforms	5
	Platform dimensions	8
	Cross slope	5
	Street lighting	15
	Obstacles/visibility	15
Including Streets Sub-Attribute Weight		
Particular requirements	Universal accessibility infrastructure	18
	Universal signage	17
	bike paths	16
Mobility for user	Streets that give you adequate space	17
	Platforms	16
	green barrier	16
Sustainable Streets Sub-Attribute Weight		
Public and private sector access	Private transport infrastructure	19
	Public transport infrastructure	19
landscape comfort	green infrastructure	21
	Binding streets land use	21
	bioclimatic materials	20

Resilient Streets Sub-Attribute Weight		
Urban drainage system	Adequated water management	10
	Sinks	10
	Sump	10
	Ditch	10
Landscape adjusments	Green infrastructure	25
	Native vegetation	25
	Community spaces	
	Park	5
	Square	5

Source: adapted from (Albán Pérez, 2022).

The value given in the evaluation is multiplied by the weight of each attribute and the sum is made for the entire street, determining the value achieved in each main attribute as a safe, inclusive, sustainable, and resilient street. To analyze the results, an assessment scale such as the one indicated in table 2 is proposed.

RESULTS AND DISCUSSION

The weighted sums method was implemented in Excel and has a Menu for the user to identify the project and to adjust the values of the attributes as indicated (figure 6).

Project	Tramo_3A_Antes	Safety	Inclusion	Sustainable	Resilient	TOTAL
Secundaria		0	0	0	0	0,0
Longitud del tramo:	100 m	27	25	23	24	

Figure 6. Detail of input data.

Source: own elaboration.

The scale used to assess the qualifiers existence, location, condition, quantity and cost was:

- **Existence:** It is graded as 1 or 2 if the evaluation of the evaluated sub-attribute is does not exist or if it exists, respectively.
- **Location:** It is graded as 1 or 2 if the evaluation of the evaluated sub-attribute is inadequate or adequate, respectively.
- **Status:** It is graded as 1, 2 or 3 if the evaluation of the evaluated sub-attribute is bad, fair or good, respectively.
- **Slope:** It is graded as 1 or 2 depending on whether the slope is greater than 2% or less than or equal to 2%, respectively.
- **Quantity:** is considered in the speed controls sub-attribute.
- **Cost:** The user can include the associated cost of the constructive intervention required to improve the sub-attribute or the global attribute.

The qualitative assessment in the study area revealed the behavior depicted in table 3, which shows non-compliance with sustainability and resilience attributes in Sections 3A, 5, and 9A.

Table 3. Qualitative Assessment of Study Sections

Attribute	Safe	Inclusive	Sustainable	Resilient
Tramo 3A	<i>Does not satisfy</i>	<i>Does not satisfy</i>	<i>Does not satisfy</i>	<i>Does not satisfy</i>
Tramo 5	<i>Does not satisfy</i>	<i>Acceptably compliant</i>	<i>Does not satisfy</i>	<i>Does not satisfy</i>
Tramo 9A	<i>Fully complies on the left bank and acceptably on the right bank</i>	<i>Does not satisfy</i>	<i>Does not satisfy</i>	<i>Does not satisfy</i>
Tramo 9	<i>Highly compliant</i>	<i>Acceptably compliant</i>	<i>Highly compliant</i>	<i>Fully complies</i>

Source: own elaboration.

The implementation of the weighted sum method allowed for the technical evaluation of the work area prior to project execution. This was achieved by applying a Verification Sheet of Technical Specifications. Some of the issues identified in the evaluated sections were as follows:

Issue 1: Popayán undergoes fluctuations in monthly precipitation, exemplified by an average of 22 mm in August surging to 124 mm in November. Consequently, residences positioned beneath road levels face the risk of rainwater infiltration, especially in the absence of an effective surface drainage infrastructure. Notably, subpar drain designs, compounded by the necessity to cater to inclusive driveway features, have led to a situation where runoff water is channeled toward these homes (figure 7).



Figure 7. Issue identified regarding surface drainage.

Source: adapted from (Albán Pérez, 2022).

Solution: In addressing this issue, a runoff control infrastructure comprising culverts and catch basins was meticulously constructed and strategically placed, guided by well-crafted surface drainage designs. This intervention effectively redirects runoff waters into the pre-existing drain surface system.

Issue 2. The presence of houses positioned at an elevated level compared to the road poses challenges for both pedestrian and vehicular access, as depicted in figure 8.





Figure 8. Creation of a public space enhancing housing accessibility in relation to road level.

Source: Adapted from (Albán Pérez, 2022).

Solution: The proposed interventions must prioritize seamless access for both vehicles and pedestrians to residential properties, adhering to inclusivity principles and universal design criteria for all users. By utilizing a Field Verification Sheet to Verify Street

Conformance, homes and businesses facing this challenge can be pinpointed, facilitating the allocation of necessary funds for these enhancements within the project scope.

Issue 3. Urban designs characterized by wide sidewalks where no green barriers are incorporated to mitigate heat islands or provide protection for pedestrians (figure 9).

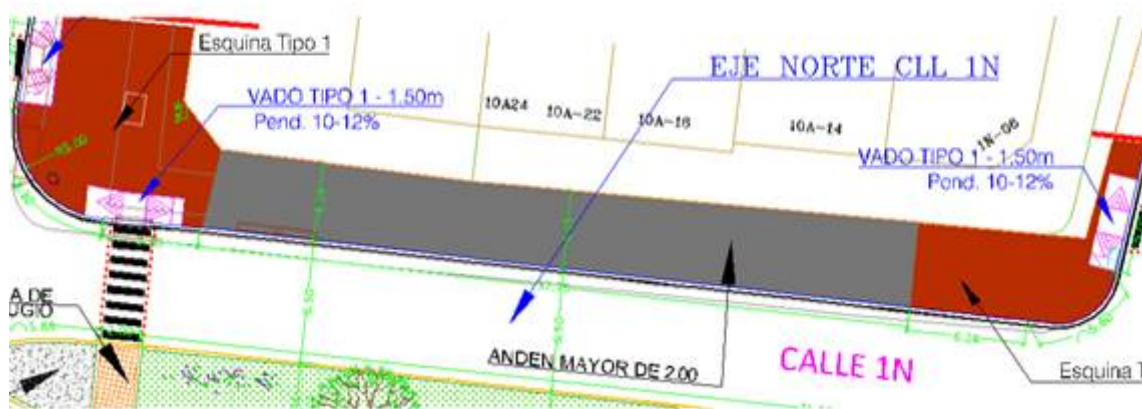


Figure 9. Initial Site Plan.

Source: own elaboration.

Solution: The plan includes the establishment of green areas intended for the planting of medium-sized trees, strategically positioned to offer shading. These spaces also function as verdant shields, enhancing pedestrian safety and augmenting user comfort along the roadway (figure 10).

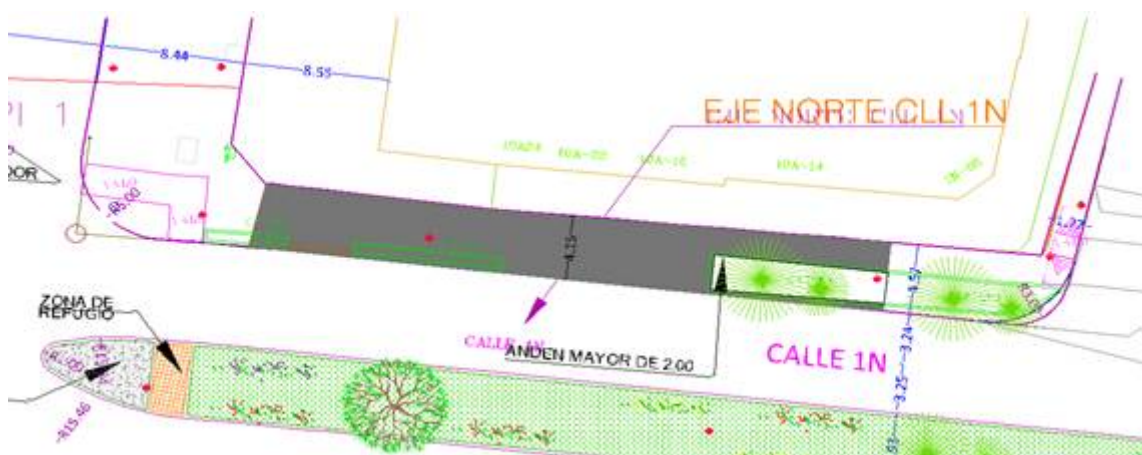


Figure 10. Plan of the final outcome of this intervention.

Source: own elaboration.

Issue 4: Absence of an inventory of properties with vehicular access.

Solution: By utilizing the Field Verification Sheet for Successful Street Compliance, it's possible to identify properties with vehicular access. Consequently, it's essential to ensure that the construction or improvements of these accesses adhere to current regulations, as specified in the Public Space Manual.

By way of example, the outcome of the assessment pertaining to the adherence of the complete street criteria on the left side of a road segment within sector 3A is showcased.

Safe street: It does not have speed controls, on the other hand has reduced visibility without level crossings or refuge areas for pedestrians. It has pedestrian crossing that delimit the way for pedestrians at signalized intersections. It does not count or need traffic ramps. On the other hand, the dimensions of the platforms are not adequate, do not comply with the regulations for universal accessibility, and the cross slope of the platforms sometimes exceeds the 2% allowed for pedestrian traffic (figure 11).

		LEFT					
	PESO	Existence	Location	Status	Quantity	Cost	Score
1. Safe Street							
There are speed controls	15	Not Exist	Inadequate	Bad	5		0
Short and visible road	15	Not Exist	Inadequate	Bad			0
Adequate pedestrian crossings							
Ford/level crossings	5	Not Exist	Inadequate	Bad			0
Pompeian	5	Not Exist	Inadequate	Bad			0
Crossing lines (zebras)	6	Exist	Inadequate	Bad			0
refuge area	6	Not Exist	Inadequate	Bad			0
Pedestrian traffic lights	15	Not Exist	Inadequate	Bad			0
Description Infrastructure-Platforms							
Texture of the platforms	5	Not Exist	Appropriate	Well			0
Platform dimensions	8	Inadequate					0
Cross slope	5	Higher tha					0
Street lighting	15	Exist	Inadequate	Regular			0
Obstacles/Visibility	15	Not Exist					0
	10					\$ -	0

Figure 11. Safety Street assessment.

Source: own elaboration.

Inclusive street: It does not have infrastructure for universal accessibility or universal signage. It does not have delimitations for bicycle paths. On the other hand, it does not have green barriers that isolate the vehicle circulation area from the pedestrian circulation zones (figure 12).

		LEFT					
	PESO	Existence	Location	Status	Quantity	Cost	Score
2. Inclusive Street							
Universal accessibility infrastructure	18	Not Exist	Appropriate	Well			0
Universal signage	17	Not Exist	Appropriate	Well			0
Bike paths	16	Not Exist	Appropriate	Well			0
Streets that give you adequate space	17	Not Exist	Appropriate	Well			0
Platforms	16	Exist	Inadequate	Regular			0
Green barrier	16	Not Exist	Appropriate	Well			0
	10					\$ -	0

Figure 12. Inclusive Street assessment.

Source: own elaboration.

Sustainable street. It does not have infrastructure that allows adequate parking for transport for private use. Likewise, it does not have infrastructure for public transport. On the other hand, it does not binder with the use of land. Some areas of the street are occupied by commerce without authorization. Sometimes the users take over half a section of the public space and the road for the parking of customer vehicles. These actions generate obstacles in both pedestrian and vehicular circulation (figure 13).

Project	Figuras	Safety	Inclusion	Sustainable	Resilient	TOTAL
Tramo_3A_Antes		0	0	0	0	0,0
Secundaria		27	25	23	24	

LEFT						
PESO	Existence	Location	Status	Quantity	Cost	Score
3. Sustainable street						
Private transport infrastructure	19	Not Exist	Appropriate	Well		0
Public transport infrastructure	19	Not Exist	Appropriate	Well		0
Green infrastructure	21	Not Exist	Appropriate	Well		0
Binding streets land use	21	Not Exist	Appropriate	Well		0
Bioclimatic materials	20	Not Exist	Appropriate	Well		0
10					\$ -	0

Figure 13. Sustainable Street assessment.

Source: own elaboration.

Resilient street: It has a surface drainage system but the drains are not well located. It has no gutters or sumps. It does not have green infrastructure nor is use of native vegetation. The interconnection from the street to the park is not working properly (figure 14).

Project	Figuras	Safety	Inclusion	Sustainable	Resilient	TOTAL
Tramo_3A_Antes		0	0	0	0	0,0
Secundaria		27	25	23	24	

LEFT						
PESO	Existence	Location	Status	Quantity	Cost	Score
4. Resilient Street						
Adequate water management	10	Exist	Inadequate	Well		0
Sinks	10	Exist	Inadequate	Bad		0
Sump	10	Not Exist	Appropriate	Well		0
Ditch	10	Not Exist	Appropriate	Well		0
Green infrastructure	25	Not Exist	Appropriate	Well		0
Native vegetation	25	Not Exist	Appropriate	Well		0
Community spaces		Exist	Inadequate	Bad		0
Park	5	Exist	Inadequate	Bad		0
Square	5	Not Exist	Appropriate	Well		0
10					\$ -	0

Figure 14. Resilient Street Assessment.

Source: own elaboration.

The competent authority can execute improvements on the left bank of 100 m length in a street for a value of US\$42,700, achieving a rating of 72.6%, thus getting acceptable compliance (table 4). The reported value of the activities is obtained from the budget prepared using the price list from the Valle del Cauca Government for the year 2020.

Tabla 4. Approximate costs of interventions in the physical infrastructure of the street

Activity	Global Budget approximate (dollar)
Construction of three speed controls	400
Adjustment to the public lighting system	8.000
Protection zone construction	1.250
Improvements of platforms, adjustment in slope and dimensions	10.000
Installation of universal design	1.000
Landscaping adaptation with green barriers with grasses	800
Adaptation of fords.	500
Demarcation of cycle paths.	5.000
Adaptation of green infrastructure by planting native species	1.000
Adaptation of bays and parking areas.	10.000
Improvement of sinkholes and construction of gutters	5.000

Source: own elaboration.

If the municipality does not have all the resources, it can evaluate the option, for example, of adapting only the area for maneuvering public transport, reducing this item from US\$10,000 to US\$5,000, reaching a rating of 69.1%, remaining in the range of acceptable compliance. In this way, the administrative teller can use this tool to assess the solutions that are economically adjusted to the budget available to the city (Albán Pérez, 2022).

It should be highlighted that the limitation encountered during this research was the absence of an updated study on the recognized public spaces in the city of Popayan. This absence made it challenging to easily identify and weigh the sub-attributes. On the other hand, the development of this study provides technical solutions that, when implemented, can enhance the municipal administration's efforts towards effective public space management at the municipal level. In this case, the findings are specific to the street sector 1N between 8th and 11th Avenues in the city of Popayan.

In summary, the planning of construction activities for the improvement of a street is a requirement to satisfy the needs of all users through the implementation of technical and economically viable solutions (González Saboyá, 2009) and with this method is feasible checking before building if the solution is adequate.

CONCLUSION

This study delves into the intricacies of a complete street and its essential attributes: safety, inclusivity, sustainability, and resilience. It accentuates the significance of preserving street functionality across a spectrum of scenarios, including adverse weather conditions. Notable interventions, such as the installation of pedestrian crosswalks, fords, and speed-reducing traffic ramps, not only enhance user comfort but also contribute profoundly to the overall safety of the street. Similarly, augmenting platform quality and dimensions, integrating

bike lanes, and establishing pedestrian refuge areas imbue the street with inclusivity. Equally important are adaptations to facilitate maneuverability, accessibility, as well as the ascent and descent of both public and private vehicle users, effectively embedding sustainability within the road's framework. Concurrently, the creation of hydraulic structures as dictated by surface drainage designs bolsters the street's resilience.

The utilization of the weighted sums method to evaluate and enhance street infrastructure is meticulously elucidated in this study case. Furthermore, the outcomes derived from employing this methodology during the revitalization of streets in Popayan, Colombia, are thoughtfully presented. In this endeavor, specific segments of the city's streets were subjected to thorough analysis, unearthing concerns like drainage issues, accessibility hurdles, and the absence of green barriers. Innovative solutions were proffered, encompassing the implementation of runoff control infrastructure, heightened accessibility, and the integration of green spaces. The methodological underpinnings, the assessment process, and the estimation of costs associated with these interventions are comprehensively expounded.

In essence, the realization of safety, inclusivity, sustainability, and resilience prerequisites harmoniously coalesce to furnish streets with genuine functionality. The onus lies on governmental bodies and urban developers to implement pragmatic solutions that align with the technical requisites of these attributes. Previously, it is imperative for each city to possess updated insights into public spaces, particularly commercial and residential activities occurring within the targeted areas. By doing so, and recognizing the budgetary limitations faced by many nations, governing bodies can judiciously employ the weighted sums method, integrated within platforms like Excel, to strategically plan the execution of interventions. This strategic case study exemplifies the method's application in the context of a street renovation project along the left bank in Popayan, illuminating a pathway toward enhancement and progress.

Acknowledgment

The collaboration of the Academic Mobility Network (ram) is appreciated for their participation in the focus group.

REFERENCES

- Acuti, D., Bellucci, M. & Manetti, G. (2020), "Company disclosures concerning the resilience of cities from the Sustainable Development Goals (SDGs) perspective", *Cities*, 99, 1-14. doi: <https://doi.org/10.1016/j.cities.2020.102608>, consultado el 11 de febrero de 2023.
- Albán Pérez, C. (2022), Evaluación de las características de en el proyecto urbanístico del sector Calle 1N entre carreras 8 y 11 de la ciudad de Popayan. Santiago de Cali: Trabajo de Maestría para optar el título de Magister en Ingeniería Civil, Pontificia Universidad Javeriana Cali, dirigido por Ph.D. María Fernanda Serrano Guzmán y Diego Darío Pérez Ruíz.
- Bonyadi, M., Michalewicz, Z. & Barone, L. (2013), The travelling thief problem: the first step in the transition from theoretical problems to realistic problems. Proceedings of the IEEE Congress on Evolutionary Computation, CEC 2013, 1037-1044.
- C40 Cities Climate Leadership Group (2016), *Beneficios de la acción climática: Experimentando un acercamiento global para mediciones*, México.
- Chagas, J. & Wagner, M. (2022), "A weighted-sum method for solving the bi-objective traveling thief problem", *Computers and Operations Research*, 138, 105560. pp. 1-15. doi: <https://doi.org/10.1016/j.cor.2021.105560>, consultado el 3 de enero de 2023.
- Choi, J., Naderpajouh, N., Yu, D. & Hastak, M. (2019), "Capacity building for an infrastructure system in case of disaster using the system's associated social and technical components", *ASCE Journal of Management in Engineering*, 35(4), pp. 1-15.
- Day, T., Gonzales-Zuñiga, S., Hohne, N., Fekete, H., Sterl, S., Hans, F., Breevoort, P. (2018), Opportunity 2030: Benefits of climate action in cities. New Climate Institute. Disponible en <http://www.c40.org/research>, consultado el 8 de enero de 2023.
- Dehghanmongabadi, A. & Hoşkara, Ş. (2022), An integrated framework for planning successful complete streets: Determinative variables and main steps. *International Journal of Sustainable Transportation*, 16(2), pp.181-194.
- Dougier, N., Garambois, P., Gomand, J. & Roucoules, L. (2021), "Multi-objective non-weighted optimization to explore new efficient design of electrical microgrids", *Applied Energy*, 304, 117758. pp. 1-15. doi: <https://doi.org/10.1016/j.apenergy.2021.117758>, consultado el 9 de febrero de 2023.
- Environmental Protection Agency (1992), *Prevention Guide*, Office of Research and Development Environmental Protection Agency, Washington.

- González Saboyá, S. (2009), El uso social del espacio público y sus vínculo con el sistema integrado de transporte masivo. Caso: Cartagena. Cartagena: Trabajo de Grado para optar el título de Magister (TRA) en Planeación Urbana y Regional de la Pontificia Univesidad Javeriana Bogotá.
- Hernández-Rojas, C. & Sanabria-Marín, R. (2019), “Characterization of Green Infrastructure at the Local Level with Geographical Information System”, *Revista Facultad de Ingeniería*, 29(54), e10294. doi: <https://doi.org/10.19053/01211129.v29.n54.2020.10294>, consultado el 18 de enero de 2023.
- López-Goyburu, P. (August 2012), “Herramientas urbanísticas utilizadas para contener la dispersión urbana: Estrategias de planificación territorial boloñesa”, *Arquitectura y Urbanismo*, XXXIII(2), pp. 57-67.
- Madathil, D., Pandi V, R., Nair, M. & Jamasb, T. (2021), “Consumer-focused solar-grid net zero energy buildings: A multi-objective weighted sum optimization and application for India”, *Sustainable Production and Consumption*, 27, 2101-2111. doi: <https://doi.org/10.1016/j.spc.2021.05.012>, consultado el 18 de enero de 2023.
- Marler, R. & Arora, J. (12 de diciembre de 2009), “The weighted sum method for multi-objective optimization: new insights”, *Structural and Multidisciplinary Optimization*, 41(6), pp. 853-862. doi: DOI 10.1007/s00158-009-0460-7.
- Martín Robles, I. & Pancorbo, L. (2015), “Retorno a la densidad: la hibridación topológica como herramienta urbana. Julio Cano Lasso y Hilberseimer”, *Urbano*, 18(31), pp. 8-23. Disponible en <http://www.redalyc.org/articulo.oa?id=19841107002>, consultado el 18 de enero de 2023.
- McDaniels, T., Chang, S., Peterson, K., Mikawoz, J., & Reed, D. (2007), “Empirical framework for characterizing infrastructure failure interdependencies”, *ASCE Journal of Infrastructure Systems*, 13(3), pp. 175-184.
- Moreno, L. (2017), “Abordar lo complejo desde el diseño: una mirada hacia la transdisciplinariedad”, *Educación y Humanismo*, 19(33), pp. 369-385. doi: <https://doi.org/10.17081/eduhum.19.33.2650>, consultado el 18 de enero de 2023.
- Organización de las Naciones Unidas (ONU) (2017), División de Política Social y Desarrollo Discapacidad: Algunos datos sobre las personas con discapacidad. ONU. Disponible en <https://www.un.org/development/desa/disabilities-es/algunos-datos-sobre-las-personas-con-discapacidad.html>, consultado el 8 de enero de 2023.
- Pérez Silva, A., Olvera Rodríguez, V., García Cerrud, C., Soler Anguiano, F. & Flores de la Mota, I. (2020), “Internet of things and industry 4.0 applied in the delivery system for the bicipuma bike-sharing system in UNAM-Mexico”, *Procedia Manufacturing*, 42, pp. 434-441. <https://>

doi.org/10.1016/j.promfg.2020.02.052, consultado el 4 de enero de 2023.

Rey Domínguez, G. (2010), "Centro Habana búsqueda del desarrollo urbano sustentable", *Arquitectura y Urbanismo*, XXXI(3), pp. 7-15. Disponible en <http://www.redalyc.org/articulo.oa?id=376839860002>, consultado el 4 de enero de 2023.

Secretaría de Desarrollo Agrario, Territorial y Urbano (SEDATU) – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. (2020), *Manual del Participante del Curso Calle e Infraestructura Verde*, SEDATU, México.

Seppanen, H., Luukkala, P., Zhang, Z., Torkki, P. & Virrantaus, K. (2018), "A method for identifying the infrastructure service failure interdependencies", *International Journal of Critical Infrastructure Protection*, 22, pp. 25-38.

Serrano Guzmán, M., Pérez Ruíz, D., Galvis Martínez, J. & Rodríguez Sierra, M. (julio-diciembre de 2017), "Weighted sums evaluation applied for selection of nonconventional energy sources", *Prospectiva*, 15(2), pp. 7-12. doi: <http://dx.doi.org/10.15665/rp.v15i2.913>, consultado el 4 de enero de 2023.

Serrano Guzmán, M., Pérez Ruíz, D., Jaimes Jiménez, Á., Estupiñán Monroy, J. & Torres Riascos, J. (2019), "Condiciones de cumplimiento de accesibilidad incluyente: realidad encontrada en Santiago de Cali", *Educación y Humanismo*, 21(37), pp. 86-103. doi: <https://doi.org/10.17081/eduhum.21.37.3444>, consultado el 14 de enero de 2023.

Serrano Guzmán, M., Solarte Vanegas, N. & Pérez Ruíz, D. (2013), "Viviendas incluyentes: un compromiso del diseñador y del constructor", *Logos Ciencia & Tecnología*, 42(2), pp. 81-89.

Silva, A., Valente, J. & Schaller, J. (2022), "Metaheuristics for the permutation flowshop problem with a weighted quadratic tardiness objective", *Computers and Operations Research*, 140, 105691. pp. 1-17. doi: <https://doi.org/10.1016/j.cor.2021.105691>, consultado el 22 de enero de 2023.

Sojobi, A., Xuan, D., Long, L., Liu, S. & Poon, C. (2021), "Optimization of gas-solid carbonation conditions of recycled aggregates using a linear weighted sum method", *Developments in the Built Environment*, 7, 100053. pp.1-14. doi: <https://doi.org/10.1016/j.dibe.2021.100053>, consultado el 12 de diciembre de 2022.

Sverdlik, A., Mitlin, D. & Dodman, D. (2019), *Realizing the multiple benefits of climate resilience and inclusive development in informal settlements*, International Institute for Environment and Development (iied), Estados Unidos.

Yang, L., Hu, X. & Li, K. (2021), "A vector angles-based many-objective particle swarm optimization algorithm using archive", *Applied Soft Computing*, 106, 107299. pp.1-16. doi: <https://doi.org/10.1016/j.asoc.2021.107299>, consultado el 12 de diciembre de 2022.

- Yang, X.-S., Karamanoglu, M. & He, X. (2013), Multi-objective Flower Algorithm for Optimization. *Procedia Computer Science*, International Conference on Computational Science, ICCS 2013, 18, 861-868. doi:doi: 10.1016/j.procs.2013.05.251.
- Yang, Y., Thomas Ng, S., Zhou, S., Xu, F. & Li, H. (2020), “Physics-based resilience assessment of interdependent civil infrastructure systems with condition-varying components: A case with drainage system and road transport system”, *Sustainable Cities and Society*, 54, pp. 1-15. doi: <https://doi.org/10.1016/j.scs.2019.101886>, consultado el 17 de diciembre de 2022.
- Yisong, Y., Ye, S., Lin, L. & Gen, M. (2021), “Multi-objective multi-mode resource-constrained project scheduling with fuzzy activity durations in prefabricated building construction”, *Computers & Industrial Engineering*, 158, 107316. pp. 1-16. doi: <https://doi.org/10.1016/j.cie.2021.107316>, consultado el 1 de febrero de 2023.