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Innovation in Cleaning Tools: User-Centered Design for Waste Separation Using Design Thinking, the Kano Model, and AHP

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Abstract*– Street vending is a key economic activity and an ideal setting for implementing sustainable solutions. This study evaluates the satisfaction of street vendors in Metropolitan Lima who use cleaning tools for waste management in food vending areas. Issues related to transportation, storage, and waste separation were identified, impacting hygiene, efficiency, and recycling. To address these challenges, Design Thinking, the Kano model, and the Analytic Hierarchy Process (AHP) were applied in the development of an innovative broom and dustpan set, tailored to users' needs. A survey revealed that 70% of respondents were dissatisfied, highlighting compactibility, easy assembly, and improved storage as valued attributes. The Kano model classified storage, portability, and practicality as attractive attributes, while separation, hygiene, and usability were considered mandatory. The AHP method confirmed that separation, recycling, and hygiene are key priorities in the product design. Prototype testing and refinement demonstrated that combining these methodologies enabled a comprehensive evaluation, resulting in a functional, adaptable, and sustainable product. This design enhances waste management and hygiene in vending stalls and can be applied to other informal trade contexts, fostering more sustainable practices in urban environments.

Keywords*-- Design thinking, Kano model, Analytic Hierarchy Process (AHP), Street vending, waste separation.

I. Introduction

Street vending dates to the earliest forms of informal commerce, serving as a fundamental element in the economic and social life of communities. This type of trade, which has evolved significantly over time, has deep roots in cultural traditions, migrations, and economic opportunities [1] [2]. In Peru, this activity traces back to pre-Hispanic times when commercial transactions were conducted through bartering during seasonal festivities. With the arrival of the Spanish in the 16th century and the introduction of currency, central markets such as Lima's Plaza Mayor became vital hubs for trade, solidifying the importance of street vendors in both urban economies and daily life [3] [4]. During the colonial period, figures such as the *mercachifle*, *regatón*, and *recaudera* were common in streets and plazas. The *mercachifle* traveled through cities selling diverse products, while the *regatón* resold goods outside regular market hours, sometimes selling adulterated products, which led to its prohibition and legal persecution [5]. Meanwhile, the *recaudera* managed small food stalls, contributing to the development of commercial networks and fulfilling urban populations' needs [6]. This type of commerce, whether formal or informal, remains crucial for economies like Peru's, where 72.7% of the working population is engaged in the informal sector [7].

In the modern context, street food vending has become a practical and accessible solution for individuals. These vendors not only offer affordable and convenient food but also play a significant role in tourism by providing authentic local gastronomic experiences [8]. However, managing the waste generated in these spaces presents significant challenges. Solid waste such as plastics, disposable utensils, and organic residues often mix with soil and other materials, making recycling difficult and contributing to environmental pollution. This issue affects not only urban environments but also public health, as waste accumulation fosters pest proliferation and generates toxic leachates [9].

The lack of proper waste separation and recycling practices in food vending areas is a growing concern. More than 45% of solid waste ends up in uncontrolled dumps, while a significant portion reaches beaches, harming marine life and ecosystems [10]. Additionally, inadequate waste management represents a missed opportunity to foster the circular economy, which seeks to maximize material reuse by transforming discarded materials into new products [11].

In this context, research and innovation in the design of cleaning tools and accessories that promote solid waste separation are highly relevant [12]. Furthermore, design solutions can play a key role in fostering environmental awareness within communities. The implementation of accessories that enable efficient waste separation benefits not only street vendors but also cities in general [13]. A clean and well-managed urban environment enhances citizens' quality of life, improves tourists' perceptions, and fosters a shared culture of environmental responsibility [14].

Despite the availability of differentiated waste bins and other recycling devices, many do not effectively address cross-contamination between waste types [15]. Among street vendors, this problem is exacerbated because existing cleaning tools lack adequate design for daily transport. Current compact models have designs that allow cleaning elements to become dirty easily [16]. During continuous cleaning in vending areas, for instance, brooms frequently fall due to a lack of support to

remain upright, leading to issues such as hand contamination, which affects both hygiene during food service and product handling. This problem is particularly evident in street vending spaces, where the mixture of soil, plastics, and organic waste complicates the proper handling of recyclable materials [17].

Local regulations, such as Article 44 of the food vending ordinance from the Metropolitan Municipality of Lima, require vendors to keep their surroundings clean [18]. However, these regulations are rarely effectively enforced due to a lack of appropriate tools and insufficient environmental awareness. In this regard, developing innovative solutions that facilitate cleaning and waste separation could significantly transform waste management in these spaces.

An important aspect of developing these tools is involving end-users in the design process. Street vendors, as the primary beneficiaries, possess unique knowledge about the conditions and challenges they face daily. Their active participation in the design process ensures that the final product meets their real needs, fostering a sense of ownership and commitment to its use.

Accordingly, this study focuses on designing a new broom and dustpan set aimed at solid waste separation as a response to this issue. Unlike traditional models, which do not consider waste classification during cleaning, this proposal seeks to integrate functionality with sustainability. Through the application of methodologies such as Design Thinking, this study aims to identify and address the specific needs of street vendors, developing an efficient and functional tool. The design process also considers the product's technical and economic feasibility. The approach focuses on improving the broom and dustpan set design to make it more functional, hygienic, and suitable for daily use by street vendors. Additionally, implementing simple and effective waste separation mechanisms can maximize its impact without increasing design complexity.

Finally, this study examines the implementation and evaluation of the broom and dustpan set using the Kano model, which identifies the features that generate the highest satisfaction and value for users. This approach ensures that the product is not only functional but also perceived as an innovative and valuable solution. Furthermore, the possibility of expanding this model to other contexts and users is proposed, promoting a culture of sustainability within informal trade and beyond. In the final stage, the Analytic Hierarchy Process (AHP) method was employed to establish a hierarchy of the attributes identified during the Design Thinking process, allowing for the prioritization of critical factors to improve the design of cleaning accessories.

Thus, this study aims to obtain representative results that allow for the identification and evaluation of cleaning tool features that influence user satisfaction and daily performance.

II. Methods and Materials

A. Methodology

For the development of the new product design, the Design Thinking methodology and the Kano-AHP Method were implemented.

1) Design Thinking Methodology: This research followed the Stanford model, which consists of five stages: Empathize, Define, Ideate, Prototype, and Test [19]. This user-centered methodology facilitates a deep understanding of the problem from the perspective of stakeholders, enabling the visualization and materialization of conceptualized ideas. It also allows for the identification of their impact and the implementation of necessary adjustments or improvements that adhere to principles of originality, execution, and feasibility.

2) Kano Model: The Kano model, developed by Noriaki Kano, a professor at the Tokyo University of Technology, focuses on identifying product attributes based on their impact on user satisfaction [20]. It analyzes the relationship between product characteristics and the level of satisfaction they provide, as well as which attributes may cause dissatisfaction or have minimal influence on customer satisfaction.

The Kano model classifies the relationship between satisfaction and functionality for each attribute into five categories: Must-be Quality (M), Attractive Quality (A), One-dimensional Quality (O), Indifferent Quality (I), Reverse Quality (R). To assess satisfaction, the Kano model allows for the formulation of functional and dysfunctional questions, helping to evaluate users' attitudes toward their requirements. Additionally, it enables the creation of a Kano questionnaire for each identified requirement, classifying and relating the attributes of street food vendors' needs with their level of satisfaction, as shown in Table I [21].

TABLE I
EVALUATION MODEL OF RESPONSES ACCORDING TO THE KANO MODEL

		DYSFUNCTIONAL				
		Likes	Expects	Neutral	Accepts	Dislikes
FUNCTIONAL	Likes	Q	A	A	A	O
	Expects	R	I	I	I	M
	Neutral	R	I	I	I	M
	Accepts	R	I	I	I	M
	Dislikes	R	R	R	R	R

To determine the classification of each attribute according to the Kano model, the responses from each surveyed individual are first recorded in an attributes and responses table, as shown in Table II. Once the table is completed with

all the respondents' answers, the frequency of each category is counted for each row corresponding to an attribute.
Finally, in this table, the letter with the highest occurrence in each row is identified, allowing the classification of each attribute into its predominant category.

TABLE II
TABLE OF RECORDED RESULTS OF SURVEYED INDIVIDUALS BASED ON PRODUCT ATTRIBUTES

	Persons Surveyed						
ATTRIBUTE	1	2	3	4	….	30	CATEGORY
Attribute 1	A	I	A	I	….	O	I
Attribute 2	O	A	A	M	….	A	A
Attribute 3	I	O	O	O	….	I	O
Attribute …	A	O	O	O	….	O	O
Attribute n	O	O	I	O	….	O	O

3) Analytic Hierarchy Process (AHP): The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty, is a multi-criteria decision-making technique that structures a complex problem into a hierarchical framework. This method allows for the evaluation of alternatives based on criteria through pairwise comparisons. Each criterion and alternative is compared in terms of relative importance, using a scale from 1 to 9, generating judgment matrices that are then normalized to obtain a priority vector. Subsequently, the consistency of the comparisons is verified using the Relative Consistency Index (RCI), which must be below 0.10 to ensure reliability. Finally, the priorities are synthesized to determine the optimal alternative [22]. Following this methodology, a broom and dustpan cleaning tool set was designed and evaluated based on the satisfaction levels of street food vendors in the Comas district of Lima, as presented in Fig. 1.

B. Participants

A total of 35 street food vendors participated in this study, from which 30 valid responses were obtained. The surveyed participants in this research were adult street food vendors who regularly use cleaning accessories for sweeping and collecting solid waste during their work at vending stalls.

C. Data Collections

Data collection for the empathy stage of the Design Thinking methodology was conducted through a semi-structured face-to-face survey, which included closed and open-ended questions directed at vendors as direct users. Additionally, to measure user satisfaction, a survey following the Kano model was conducted using face-to-face data collection methods. Initially, an alternative was proposed to conduct this survey virtually via QR Code.
However, this option was discarded due to the high distrust among the population regarding the downloading of such codes, mainly due to the risk of cyber fraud, such as Quishing or QR phishing [23] [24].

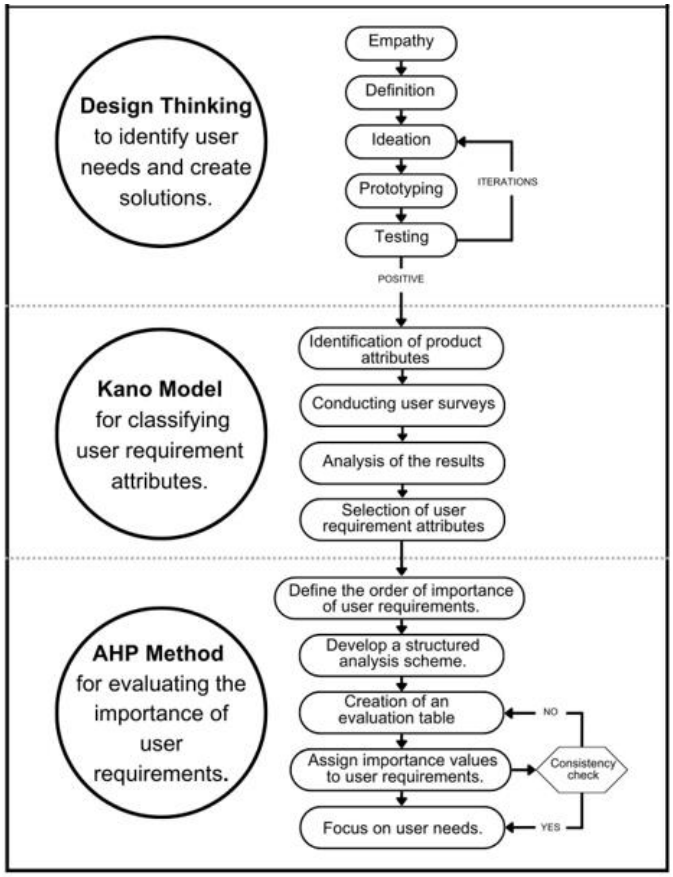

Fig. 1 Construction model for the design of cleaning accessories for sweeping and solid waste collection.

D. Ethical Considerations

All participant data were collected anonymously. Additionally, street vendors were informed that they had the freedom to withdraw from the study at any time, for any reason, and that their participation was entirely voluntary.

II. RESULTS

A. Design Thinking Methodology

1) Empathize: To initiate this stage, semi-structured face-to-face interviews were conducted using both closed and open-ended questions, focusing on street food vendors and their experiences and perceptions regarding the cleaning accessories they use for sweeping and collecting solid waste in their vending stalls. The survey questions covered aspects such as storage, size, satisfaction, frequency of use, and surface conditions where they operate. Regarding satisfaction with current cleaning tools (broom and dustpan), the results indicated that: 33.3% of respondents were dissatisfied with sweeping and waste collection accessories, 36.7% were completely dissatisfied, 26.7% remained neutral, Only 3.3% reported being satisfied with these tools. In total, 70% of the vendors expressed dissatisfaction with the tools used for waste collection.

Additionally, respondents were asked about the features they would like in cleaning accessories. The most highlighted features were: Compactibility (83.3%), Ease of assembly (70%), Ease of storage (46.7%). Furthermore, 86.7% of users stated that they were dissatisfied with the size of sweeping and waste collection accessories, as they consider them difficult to transport.

2) Define: Street food vendors have become essential in meeting the daily needs of mobile populations. However, they continue to face challenges in keeping their workspaces clean, due to the lack of appropriate and practical cleaning accessories, making this task time-consuming and inefficient. These categories represent the most relevant attributes identified based on user feedback regarding the challenges faced with current cleaning accessories. Based on the needs and considerations of the surveyed users, a cleaning set was developed with specific features aligned with the identified issues. As shown in Table III, these characteristics aim to enhance efficiency and hygiene in street food vending areas. These accessories provide practical solutions that enable vendors to perform cleaning tasks more quickly, effectively, and effortlessly.

TABLE III
CATEGORIES IDENTIFIED

Category	Description
Hygiene	Frequent hand contamination during the cleaning process.
Storage	Caused by the size and lack of compactibility of cleaning accessories.
Portability	Transportation difficulties due to the size and weight of cleaning accessories.
Solid Accumulation	Accumulation of soil mixed with solid waste collected during the sweeping and collection process.
Usability	Current cleaning accessories lack an easy-to-use design, reducing efficiency and complicating daily tasks.
Practicality	Inconvenience caused by having to frequently pick up cleaning accessories when interrupted during work activities.

3) Ideate, Prototype, and Test: In this stage, a joint brainstorming session was conducted, combined with the mood board technique, as illustrated in Fig. 2. This approach allowed for a visual representation of the project's style and conceptual direction.

Fig. 2 Moodboard for the Conceptualization of the Cleaning Tool Set.

From the information gathered during the empathy phase, where the main needs related to the use of brooms and dustpans were identified, initial sketches of the first design were developed, as shown in Fig. 3.This initial proposal aims to address these issues through key design criteria, such as the compactibility of the broom and dustpan body, along with other important features.

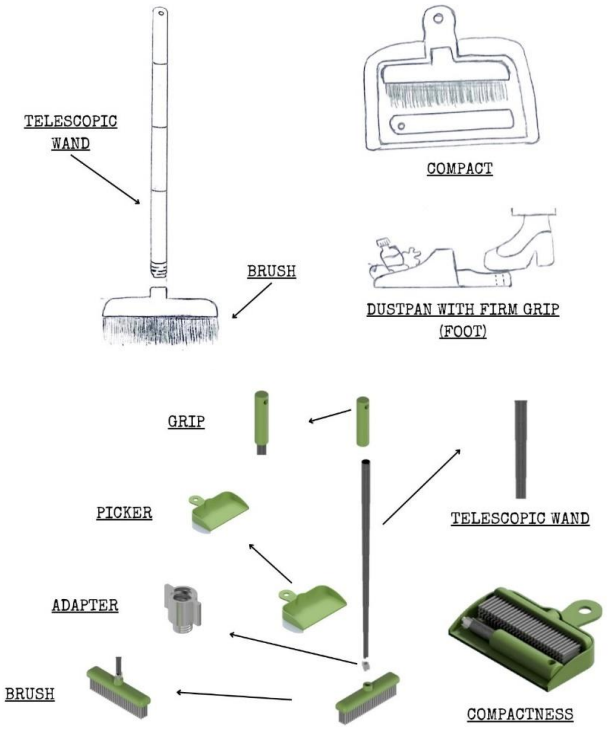

Fig. 3 Initial Sketches and 3D modeling of the Cleaning Tool Set Based on User Needs.

As shown in Fig.4, a low-fidelity prototype made of cardboard was developed to evaluate the design proportions and basic functionality before progressing to more detailed versions. However, improvement opportunities were identified, leading to the evolution of the design toward the final proposal.

Fig. 4 Low-Fidelity Cardboard Prototype for Initial Design Evaluation.

After testing the initial prototype with users, several observations and insights were gathered, leading to the development of a second version. In this iteration, the cleaning accessories were integrated into a broom and a dustpan, as shown in Fig. 5. Both components are separate but designed to fit together using a conical joint, enhancing their compactibility, facilitating storage, and making transportation lighter and more convenient. Additionally, the dustpan incorporates a grid system that acts as an automatic separator, allowing soil to detach from solid waste when lifted. This feature promotes the recycling of materials, such as plastic, which is frequently found in food vending areas.

Furthermore, an integrated alcohol dispenser was added to the top section of the dustpan, ensuring easy access and allowing the user to sanitize their hands if cleaning activities are interrupted by a sale. Moreover, magnets were incorporated into both components, enabling them to attach securely to each other, making handling more practical and preventing the broom from falling repeatedly, thus enhancing user convenience.

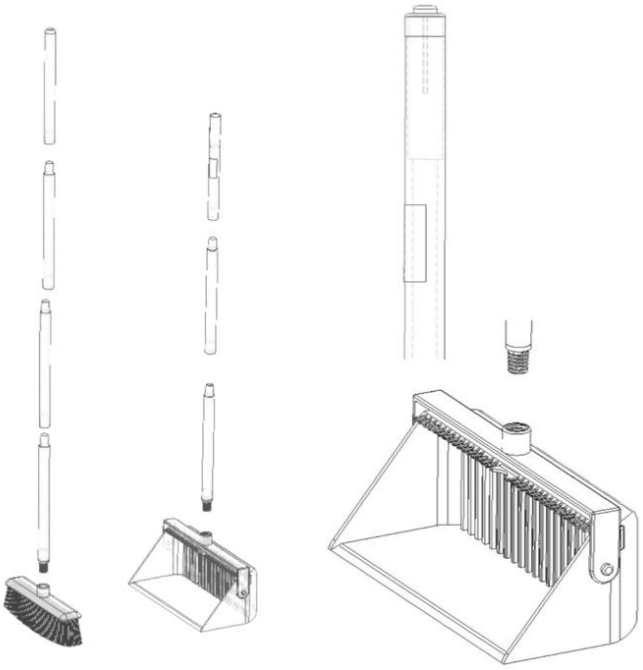

Fig. 5 Improved Design of the Cleaning Tool Set with Enhanced Functional Features.

In Fig. 6 presents the renders of the final proposal, showcasing the design evolution through 3D modeling and Fig. 7 includes a comparative image between the 3D model and the physical prototype in its real-world context, allowing for the analysis of similarities and differences between both versions.

This innovative design is currently patent-pending, as it has been submitted as a utility model patent to the National Institute for the Defense of Competition and Protection of Intellectual Property of Peru (Indecopi)

Fig. 6 Final 3D Renders Illustrating the Design Evolution of the Cleaning Tool Set.

Fig. 7 Comparative Image Between the 3D Model and the Physical Prototype in a Real-World Context.

B. Kano model

For data collection using the Kano method, the survey was conducted in six areas with a high concentration of street vendors, selected within industrial and commercial zones of the Comas district in Lima. In these areas, shown in Fig 8, efforts were made to standardize participant conditions,

ensuring that users faced similar situations regarding consumer needs and the characteristics of the streets where vending takes place.

This approach aims to obtain representative results that allow for the identification and evaluation of cleaning accessory features that influence user satisfaction and daily performance.

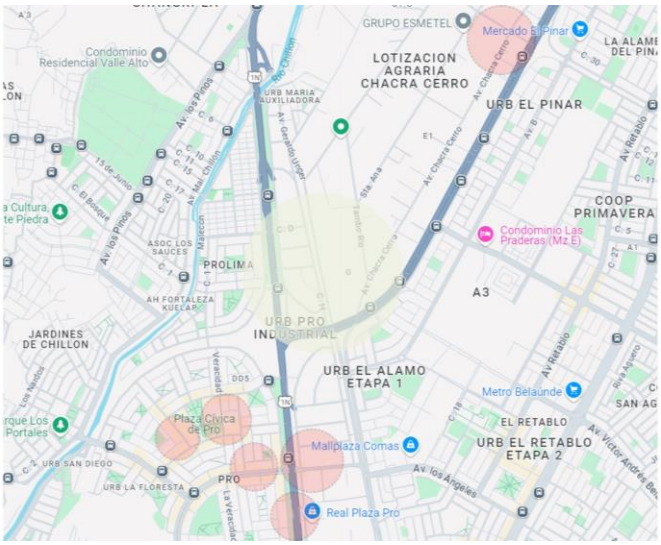

Fig. 8 Map Highlighting the Survey Locations for Data Collection Using the Kano Method.

For these questionnaires, the six attributes identified during the "Empathize" stage of the Design Thinking methodology were used. The results were analyzed to determine the predominant category for each attribute, with the frequency of each category being recorded, as shown in Table IV.

TABLE IV
CLASSIFICATION OF ATTRIBUTES BASED ON THE KANO MODEL ANALYSIS

ATTRIBUTE	A	M	O	R	Q	I	TOTAL	CATEGORY
Storage	15	2	7	0	0	6	30	A
Portability	12	2	7	0	0	9	30	A
Practicality	14	0	11	0	0	5	30	A
Solid Accumulation	3	0	27	0	0	0	30	O
Hygiene	11	3	15	0	0	1	30	O
Usability	4	1	24	0	0	1	30	O

C. Analytic Hierarchy Process (AHP)

The AHP method allows for the prioritization of identified attributes through pairwise comparisons. To achieve this, a pairwise comparison table was developed in collaboration with a product design specialist and a user, where each attribute was compared against the others using the importance scale (see Table V) and resulting in a normalized priority vector (see Table VI).:

TABLE V
Priority Assignment of Identified Attributes Using the AHP Method.

Attribute	Storage	Portability	Practicality	Solid Accumulation	Hygiene	Usability
Storage	1.00	1/5	1/7	1/9	1/9	2.00
Portability	5.00	1.00	1/2	1/2	1/9	4.00
Practicality	7.00	2.00	1.00	1/2	1/2	6.00
Solid Accumulation	9.00	2.00	2.00	1.00	1/3	9.00
Hygiene	9.00	9.00	2.00	3.00	1.00	9.00
Usability	1/2	1/4	1/6	1/9	1/9	1.00

TABLE VI
Normalized priority vector

Attribute	Normalized priority vector
Storage	0.0345
Portability	0.0983
Practicality	0.1455
Solid Accumulation	0.2340
Hygiene	0.4299
Usability	0.0278

A way to verify the results in the normalized priority vector table is to ensure that the sum of all attribute values equals 1.0. To analyze the matrix consistency, the maximum eigenvalue (λmax) was calculated, obtaining a value of 6.37. Additionally, the Consistency Index (CI) and the Random Consistency Index (RCI) were determined.

$$CI = (\lambda max - n)/(n - 1) \quad (1)$$

Where n is the number of attributes (n = 6), the Consistency Index (CI) was calculated as 0.074. According to the AHP theory, for a 6 × 6 matrix, the Random Consistency Index (RCI) is 1.25. Therefore, the Consistency Ratio (CR) is obtained by:

$$RC = CI/RCI \quad (2)$$

Obtaining a result of CR = 0.059

IV. CONCLUSIONS

Users had the opportunity to test the product prototype during the data collection phase, which provided more accurate insights into their experiences and perceptions. This direct interaction confirmed the relevance of the prioritized

attributes and generated suggestions for design improvements, particularly in terms of hygiene and portability.

The combination of Design Thinking, the Kano model, and AHP proved to be a robust approach for user-centered product design. Each methodology compensated for the weaknesses of the others, allowing for a holistic evaluation of users' needs, expectations, and priorities.

The results from the Kano model indicate that storage, portability, and practicality are classified as attractive attributes. While their presence can significantly enhance product perception, their absence does not generate dissatisfaction. In contrast, separation and recycling, hygiene, and usability were classified as must-have attributes, meaning users expect them by default. Failing to meet these attributes would cause dissatisfaction but fulfilling them does not necessarily enhance the product's perception. Therefore, the product design should prioritize mandatory attributes, while attractive features can offer competitive differentiation.

Regarding attribute prioritization using the AHP method, the pairwise comparison matrix was found to be consistent, with a Consistency Ratio (CR) of 0.059, which is below the threshold of 0.10. This validates the reliability of the attribute rankings.

According to the normalized priority vector, separation and recycling, along with hygiene, are critical attributes for users, as they hold a high relative weight. The product should therefore focus on effective waste management and maintaining high hygiene standards. Practicality and portability are also relevant, albeit to a lesser extent, suggesting that the design should be adaptable and easy to handle. Users expect the product to be versatile in different scenarios and ensure hassle-free transport.

Lower-priority attributes, such as storage and usability, have a limited impact on overall product perception. While improving these aspects is not essential, they should not be completely overlooked to prevent usability issues. Usability should ensure a simple and effortless user experience, while storage should be optimized as long as it does not compromise other functional aspects. Overall, these attributes complement the key attributes, enhancing the product's overall acceptance without being decisive for its adoption.

For future research, it would be valuable to explore the specific needs of street vendors based on the type of products they sell. For instance, vendors selling only breakfast items, fast food, seafood, or grilled foods operate in different street vending contexts and use different utensils and equipment. Additionally, it would be useful to compare the cleaning tool requirements of vendors operating in commercial and industrial areas, as studied in this research, versus those in beach settings or popular events such as concerts, sports events, and festivals.

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